Technical Manual of Aquaponics Combined with Open Culture Adapting to Arid Regions

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Technical Manual of Aquaponics Combined with Open Culture Adapting to Arid Regions

Supervising Edition by
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Preface

The need for the ability to produce food in environments with limited resources such as water and soil are a challenge for any society that demands better living conditions in any part of the world.

Intensive food production systems that promote the efficient use of water resources are of vital importance to develop them in arid climate zones, and even more so, that they can be operated with the use of waters of moderate salinity, which are resources not used for food production today. For this reason, the Aquaponics project combined with open cultivation in arid areas, developed by the Government of Japan in conjunction with the Government of Mexico through the University of Tottori, the Tokyo University of Marine Science and Technology by the The Japanese Government and the Northwestern Biological Research Center, S.C. (CIBNOR, S.C.), the National Council of Science and Technology (CONACYT), and the Secretary of Agriculture and Rural Development (SADER) by the Mexican Government, were oriented to develop the Scientific and technical knowledge, as well as actions for the dissemination of technology to local cooperating producers, who are the direct beneficiaries of the scientific work carried out. With this, it is expected to contribute to the well-being of society that requires making adequate use of its soil and water resources, as well as the insertion of its productive activities in the markets to achieve sustainable aquaponics in arid environments.

Under this scenario, the results achieved in our studies allowed the use of waters with moderate salt content for the production of fish and vegetables, in addition to being able to give an end use to water in its application to irrigation in crops established in soil under the open culture.

The aquaponics system combined with open-field cultivation was verified and its operation was highly adequate for its implementation as a strategy in the sustainable production of food, as well as the possibility of commercial operation in these arid environments.

In this manual, a series of instructions are compiled as technical guides for the cultivation of fish and plants, as well as the operation of the energy supply and the observance of the health and safety of the crops, where the interested user can follow instructions for proper aquaponics system operation.

It is important to note that, based on this aquaponics technique to produce food intensively, the following was achieved: 1) The use of brackish water, 2) Improve the efficiency of water use, 3) Promote the use of brackish water in the production of food, 4) Harvest food of animal and plant origin in arid areas, and finally, 5) Prevention of salinization in the soil.

In addition, with the aquaponics system, it was possible to have zero carbon dioxide emissions to the atmosphere, with photovoltaic panels for energy supply as an alternative to establish these systems where there is no commercial electricity supply. It is important to highlight that the system needs to be microbiologically monitored to guarantee product safety and with it, the feasibility of proceeding with a certification of systems in organic food production.

The results achieved through the research period led us to 1.- establish fish farming, with high density per cubic meter of water, 2.- less time to reach commercial size in tilapia, 3.- ability to offer high quality tilapia to markets and the 4.- feasibility of raising snook fish. For the hydroponic cultivation case, we can say that it is the first case with the purpose of removing sodium salts in the hydroponic cultivation solution and with it, to reduce the environmental impact when the water is transferred for irrigation to the cultivation in open ground - field.

This particular management is of high importance in the purpose of salinity mitigation through the cultivation of plants with an affinity for sodium removal and of commercial interest for sale in markets. This particular case of salt removal from the hydroponic section is considered to be the first experiences carried out worldwide.

We are confident that aquaponics production techniques combined with open culture have the possibility of being implemented in the State of B.C.S. in a first phase through a series of verification tests in the town of Los Planes, B.C.S. where the model site is located. This action will undoubtedly be a positive result of the project. If this aquaponics is disclosed and developed in the State of B.C.S., it may contribute to the economic development of the region, as well as to the competitive training of producers with an emphasis on quality demands of crops by the markets. In addition, the developed aquaponics system will contribute not only to the economic aspect but also to the environmental aspect.

We hope that these results can be appropriated by the largest number of producers in arid zones to substantially improve the ability to produce food through the use of low-quality water that is not used in food production, and thereby providing a system of fish and vegetable production with the possibility of bringing food to the people who need it most.

Sincerely,

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1.Guideline of Aquaponics Combined with Open Culture Using Saline Water

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1. GENERAL OUTLINE

Salinity level of underground water often increases due to excessive irrigation and/or fertilization in arid regions. Supplying saline water to open field inhibits crops' growth and salinizes the soils. In our aquaponics system, at first salt-tolerant fish or shrimp is reared using saline underground water (Fig. 1), where materials from feeds and excretion are contained and they can be absorbed by crops as nutrients. Then crops are hydroponically cultivated using aquaculture wastewater. In hydroponics, crops which can grow absorbing salts are cultivated and decrease the level of salts and nutrients in the water. Lastly, crops are cultivated in the open culture field using desalted hydroponics wastewater. This aquaponics system enables to realize several good points; 1) use of saline water, 2) high water use efficiency, 3) fishery and agriculture production and 4) prevention from soil salinization. Additionally, required electric power is supplied by photovoltaics, enabling to eliminate the CO_2 emission and to operate in the area without electric transmission. Furthermore, microbiological monitoring is conducted, enabling to secure hygiene security.

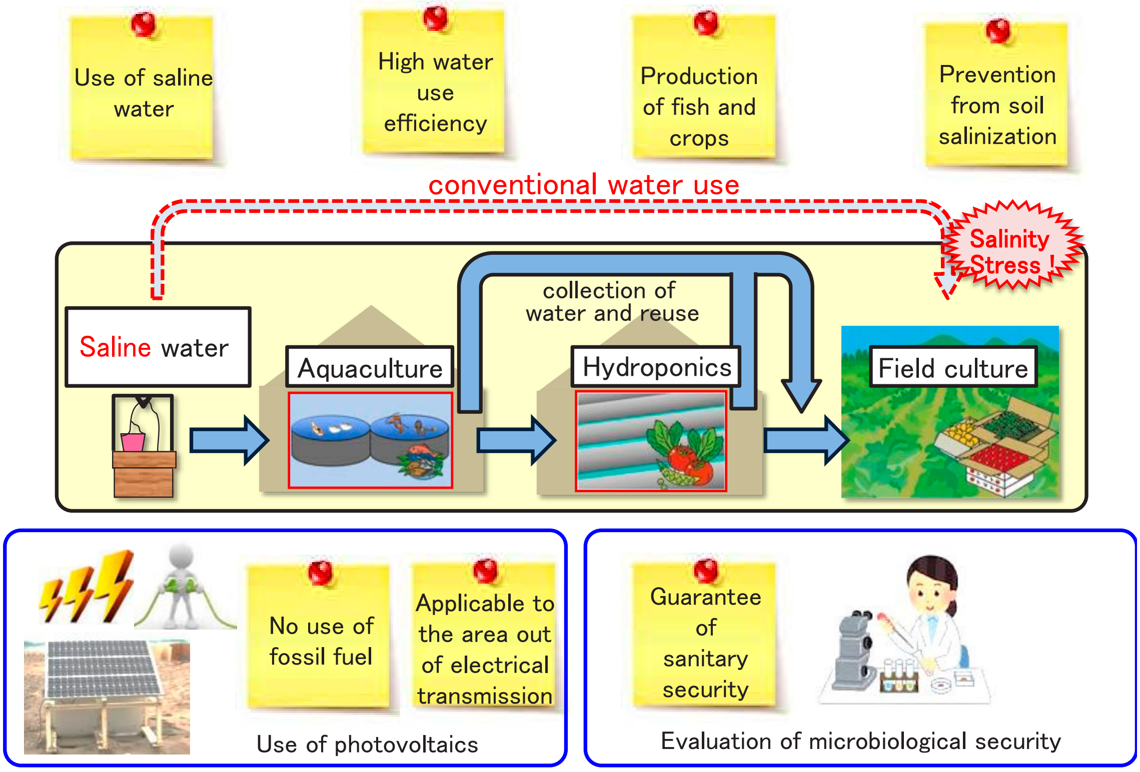

Fig. 1 Outline of aquaponics combined with open culture

2. OVERVIEW

Sketch of the aquaponics is shown (Fig. 2). Saline underground water is reserved in the reservoir tank. Saline underground water has been conventionally supplied to the open field, damaging crops.

In the aquaculture booth, fish and shrimp are reared. Nitrified water is created in the biofilter tank. The nitrified water is used in the rearing tanks and then sediments are removed in the sedimentation tank. The supernatant returns to the biofilter tank. Fish and shrimp are reared until they grow marketable size.

In the hydroponics booth, aquaculture wastewater is transferred from aquaculture booth to cultivating beds. Proper amount of the water in the beds is properly transferred to the reservoir tank for open culture, and the same amount is compensated with aquaculture wastewater.

In the open culture field, low EC water is prepared by diluting the water in the reservoir tank with pure water (the water collected from the air in the aquaculture and hydroponics booths using dehumidifier or the low EC underground water purchased), and then irrigated to the soil.

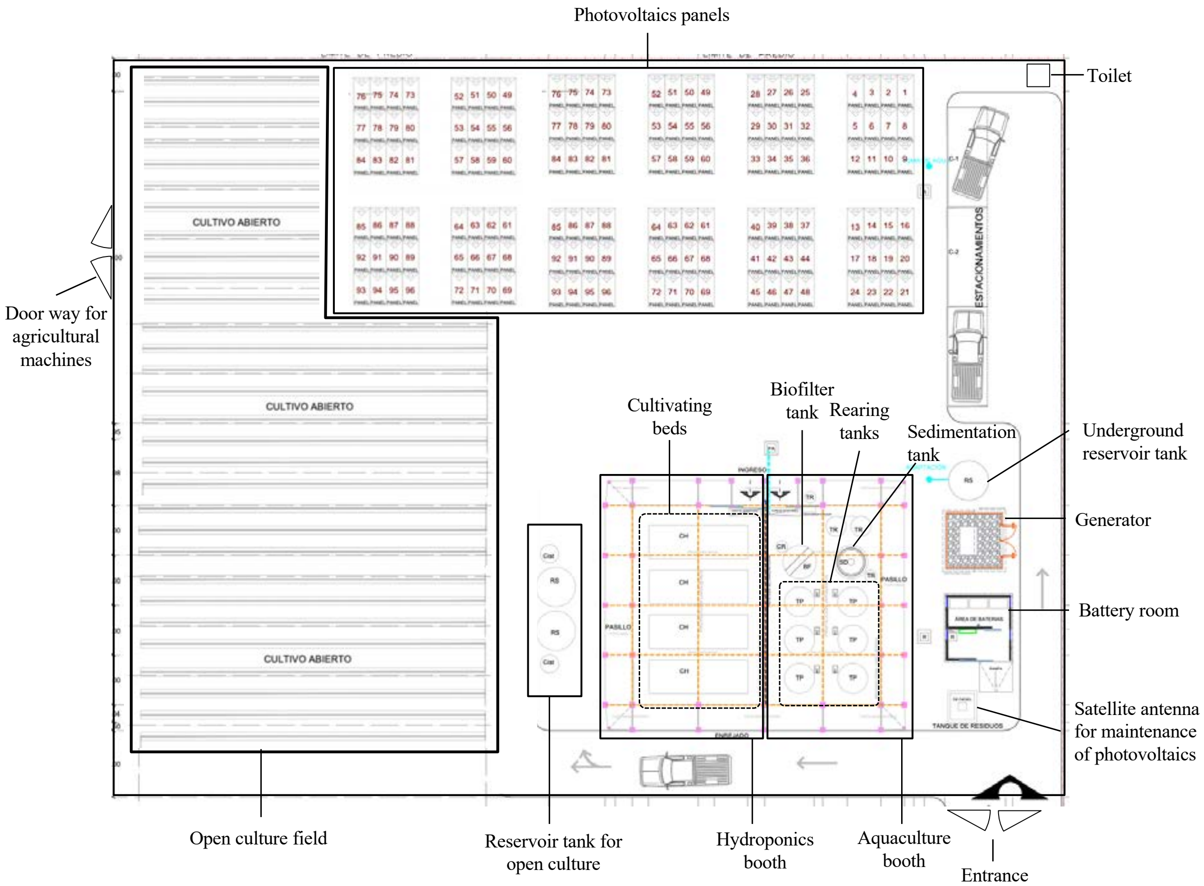

Fig. 2 Sketch of aquaculture combined with open culture

3. IMPACT

This aquaponics system is a new environment-friendly food production system adapting to arid regions. Noteworthy impacts are described as below based on the premise that the entire aquaponics system would be provided by public subsidies.

3-1 AQUACULTURE

3-1-1 High rearing density of tilapia

Recorded highest RAS (recirculating aquaculture system) rearing density of tilapia in the world is 5 - 10 % . The density in our project is 7.5 %, though it is less that 10 %.

3-1-2 High growth rate and feed efficiency of the tilapia reared with saline and hot water

Growth rate of tilapia reared with normal fresh water is about 1.4 %. In this project, the production was improved using growth promoting effect by saline and hot rearing water in addition to by using fast growing species, GIFT(genetically improved farmed tilapia).

3-1-3 World’s first! Success to rear white snook, a highly valuable saltwater fish in low saline RAS.

A challenging rearing of white snook in low saline RAS found good growth, although many trials of sea culture or rearing in high saline RAS of white snook are being conducted.

3-1-4 Supply of Japanese highly fresh and tasty fish

Adapting Japanese pre-shipment processing technology (fasting in a pure water and bleeding using ice temperature anesthesia) and keeping fresh technology enable to improve taste and sanitary security of tilapia. It was revealed that tasty essences became at maximum at 1- 2 days after shipping from the result of K-value, freshness indicator. In La Paz, the project site, a low quality tilapia (with smell and/or corruption) is traded with low price, therefore, pre-shipment processing and keeping fresh technology in this project would be assumingly acceptable in the tilapia market in La Paz.

3-2 HYDROPONICS

3-2-1 World’s first! Hydroponics to remove salts

There are a few trials to remove salts from salinized soils using plants which can grow absorbing salts (Phyto-remedation). In this project, we removed salts from hydroponics water.

3-2-2 High water use efficiency

Water use efficiencies defined as fresh weight of harvested products (g) per one little of water were; 11.8 – 15.4 (Swiss chard cultivated with tilapia rearing water in CIBNOR model system; 2016), 6.1 – 8.3 (Suaeda cultivated with artificial saline water in Tottori University, 2016), 2.1 (Purslane cultivated with tilapia rearing water in CIBNOR model system, 2017), 1.8 (Epazote cultivated with tilapia rearing water in Farmer's verification model system, 2019). These values were higher than those of crops cultivated with non-fertilized underground water.

3-3 OPEN CULTURE

3-3-1 Water use without waste water

In conventional aquaponics system, water was re-circulated between aquaculture and hydroponics and finally discarded when the water quality reached to useless level. In this aquaponics system, the useless water is diluted with the water collected from air in the system and then reused in open culture. Zero-emission of wastewater is realized.

3-3-2 Estimate of water use efficiency as an indicator of profitability (sales)

In this aquaponics system, same water is used not only in aquaculture and hydroponics but also in open culture. However, amount of water used in aquaculture doesn't clearly correlated with the fish yield, some amount of water not for consumption by crops but for system maintenance is required in hydroponics, and increasing of yield is not necessarily the proper indicator considering products quality though the amount of water consumption has good positive correlation with yield. In this aquaponics, therefore, it is difficult to evaluate whether actual and effective water use as entire aquaponics system is conducted or not, because the method and purpose of water use is varied among 3 productive systems. Then we estimated water use efficiency as an indicator of profitability (sales).

3-4 OPERATION BY PHOTOVOLTAICS

3-4-1 Saving electric charge

Power consumption to operate this aquaponics is 24,559 kWh / year, and averaged electric charge of ordinary homes in La Paz is 1.9 MXN / kWh. Annually 46,662 MXN of electric charge can be saved, because the photovoltaic system can supply all power to operate the entire aquaponics system.

3-4-2 Conservation of fossil fuel resources

Annual power consumption of this aquaponics can be converted to thermal energy of 88.4GJ / year (= 24,559 kWh / year X 3,600 kJ / kWh). In order to generate the annual power consumption by thermal power generation, thermal energy of 221.0 GJ / year (= 88.4GJ / year X 1 / 0.4) is required, because the thermal efficiency[*1)] is about 40 %. The amount of petroleum to generate the thermal energy of 221.0 GJ / year is 5.3 toe / year (= 221.0 GJ / year / 41.87 GJ / toe) because tons of oil equivalent[*2)] in 41.87 GJ / toe. This photovoltaics system, therefore, can conserve fossil fuel resource as petroleum.

[*1)] converting rate from thermal energy (calorific value) generated by fuel burning to electric energy (electric power generation)

[*2)] thermal energy generated by 1 ton of petroleum

3-4-3 CO_2 zero-emission

If power consumption of this aquaponics is supplied by thermal power generation, 14.4 tons of CO_2 (= 24.559 kWh / year X 0.5867 kg CO_2 / kWh[*3)]) would be estimated to emit. This photovoltaics system realizes CO_2 zero-emission and decreases 14.4 tons of CO_2 emission annually.

If the tender price of CO_2 (12.10 USD / CO_2 ton[*4)]) on California's emissions trading system in USA is used referring to the carbon emissions trading which is known as 'Cap and Trade', 174.35 USD (= 14.4 tons CO_2 / year X 12.10 USD/ CO_2 ton) could be saved.

[*3)] CO_2 emission coefficient

[*4)] https://www.env.go.jp/earth/ondanka/det/os-info/mats/jokyo.pdf

3-5 SECURITY OF HYGIENE SAFETY

3-5-1 Rapid and accurate monitoring of harmful microbes

In this aquaponics, new method of rapid and accurate detection of harmful microbes was optimized to prevent from outbreak of harmful microbes for fish, crop and human.

4. COST

4-1 CONSTRUCTION COSTS

A list of the machinery and construction facilities installed in Los Planes as this aquaponics system and their costs are shown as "Acquisition value" (Table 1.). The total cost required for the procurement of the system was 657.60 million pesos (40,200,000 yen), consisting of solar power generation systems 43%, buildings 32%, and equipment costs 7% for aquaculture, hydroponics, and open culture.

Tab. 1 Machinery and facilities used in field demonstration of aquaponics combined with open culture, Model site in Los Planes

Item		Acquisition value (peso)	Service life of component (year)	(A) Annual depreciation costs (peso)	(B) Annual repair costs (peso)	Reference ("Annual maintenance costs") (A)+(B)
For Aquaponics	Aquaculture component	179,294	10	17,929	8,965	26,894
	Hydroponics booth	129,316	10	12,932	6,466	19,397
	Open culture booth	173,321	10	17,332	8,666	25,998
	Solar insallation	2,800,249	10	280,025	140,012	420,037
	Net room facilites	2,132,241	10	213,224	106,612	319,836
	Other common items	39,116	10	3,912	1,956	5,867
Sharing with existing cultivation sector	Tractor	720,000	10	72,000	36,000	108,000
	Pick-up truck	400,000	5	40,000	20,000	60,000
	Total: peso	6,573,537	–	657,354	328,677	986,031
Reference	Total: US$	349,656	–	34,966	17,482	52,448
	Total: Japanese yen	40,197,179	–	4,019,718	2,009,859	6,029,577

Note 1) The service life of machinery and equipment is based on Mexican government standards.

Note 2) Depreciation is calculated using the straight-line method.

Note 3) Annual repair expenses were calculated by applying a value of 5% of the acquisition price with reference to the Japan Agricultural Research Association "New Edition Farming Handbook",Japan Agriculture and Forestry Statistics Association, 1985.

Note 4) The exchange rate of peso was 6.11516 yen / peso and 18.8 peso / US $.

4-2 MAINTENANCE COSTS

The annual maintenance costs of the aquaponics system combined with open culture are shown in the rightmost row of Table 1. Annual maintenance costs are shown as the sum of two items: annual depreciation costs (calculated by the straight-line method) and annual repair costs. The annual maintenance cost is 990,000 pesos (6.03 million yen) for the overall management, which comprises solar power generation systems 43%, buildings 32%, and equipment and materials costs 7% for aquaculture, hydroponics, and open culture. Which is equivalent to the composition ratio of construction costs.

5. ESTIMATE OF WATER USE EFFICIENCY AS AN INDICATOR OF PROFITABILITY (SALES)

Water use efficiency as an indicator of profitability (sales) was estimated (Tab.2). The water use efficiency is high, because same water is used throughout aquaculture, hydroponics and open culture in this aquaponics. In tab. 2, value of water use efficiency estimated are shown based on the data obtained in verification tests. The values should be increased from now on by efforts such as introducing more valuable products and/or developing new rearing and cultivating methods.

Tab.2 Water use efficiency as an indicator of profitability (sales) in aquaponics combined with open culture

Fish in aquaculture, crop in hydroponics and open culture	Duration	Yeild of aquaculture	Yield of hydroponics	Yield of open culture
	(month)	(kgFW/6 tanks)	(kgFW/4 tanks)	(kgFW/0.03 ha)
tilapia+Swiss chard+chili pepper (habanero)	5	422	427	196
tilapia+epazote+chili pepper (habanero)	5	422	168	196
tilapia+Swiss chard+chili pepper (morron)	5	422	427	323
tilapia+epazote+chili pepper (morron)	5	422	168	323
tilapia+Swiss chard+chili pepper(serrano)	5	422	427	639
tilapia+epazote+chili pepper (serrano)	5	422	168	639

Fish in aquaculture, crop in hydroponics and open culture	Total yield (A)	Water amount for aquaculture (B)	Water use efficiency (C); (C) = (A) ÷ (B)
	(kgFW/system)	L	FW kg/L
tilapia+Swiss chard+chili pepper (habanero)	1,045	76,685	0.0136
tilapia+epazote+chili pepper (habanero)	785	76,685	0.0102
tilapia+Swiss chard+chili pepper (morron)	1,173	76,685	0.0153
tilapia+epazote+chili pepper (morron)	913	76,685	0.0119
tilapia+Swiss chard+chili pepper(serrano)	1,488	76,685	0.0194
tilapia+epazote+chili pepper (serrano)	1,229	76,685	0.0160

Fish in aquaculture, crop in hydroponics and open culture	Sale			
	Aquaculture	Hydroponics	Open culture	Total (D)
	(Peso/6 tanks)	(Peso/4 tanks)	(Peso/0.03ha)	(Peso/system)
tilapia+Swiss chard+chili pepper (habanero)	21,864	10,314	18,347	50,525
tilapia+epazote+chili pepper (habanero)	21,864	72,144	18,347	112,356
tilapia+Swiss chard+chili pepper (morron)	21,864	10,314	13,704	45,882
tilapia+epazote+chili pepper (morron)	21,864	72,144	13,704	107,712
tilapia+Swiss chard+chili pepper(serrano)	21,864	10,314	15,903	48,081
tilapia+epazote+chili pepper (serrano)	21,864	72,144	15,903	109,911

Fish in aquaculture, crop in hydroponics and open culture	Water use efficiency as an indicator of profitability (sales) (E); (E) = (D) ÷ (B)
	(peso/L)
tilapia+Swiss chard+chili pepper (habanero)	0.659
tilapia+epazote+chili pepper (habanero)	1.465
tilapia+Swiss chard+chili pepper (morron)	0.598
tilapia+epazote+chili pepper (morron)	1.405
tilapia+Swiss chard+chili pepper(serrano)	0.627
tilapia+epazote+chili pepper (serrano)	1.433

Water use efficiency estimated by profitability (sales) of products is obtained in verification test in Los Planes (1 system). Data of tilapia are obtained from operation from December 2018 to November 2019. In aquaculture, the management is not always performed to obtain the maximum yield, considering that the aquaculture wastewater should be continuously supplied to hydroponics. Yield of hydroponics and open culture is referred from 2-2 (M. Yamada et al.) and 2-3-2 (Larrinaga et al.), respectively. In open field culture in the verification test, chili peppers were cultivated from October 2019 to February 2020, and the water use efficiency is estimated as the case of the operation from autumn to winter season.

6. REQUIREMENTS FOR EXTENSION OF AQUAPONICS COMBINED WITH OPEN CULTURE

Necessary requirements for extension of aquaponics combined with open culture

Through the above research activities aiming at social implementation, the following seven items were identified as necessary requirements for the introduction of the aquaponics combined with open culture to Southern Baja California.

1. Realization of high productivity by applying highly developed technologies
2. Promotion of development of production technologies with diversity
3. Key technical and management indicators for the aquaponics combined with open culture
4. Fostering managers who manage the aquaponics combined with open culture
5. Higher value-added aquaponics management by value chain
6. Establishment of subsidy and financing program to spread the aquaponics combined with open culture
7. Establishment of the extension system for technical and management guidance

The contents of each item are as follows:

6-1 REALIZATION OF HIGH PRODUCTIVITY BY APPLYING HIGHLY DEVELOPED TECHNOLOGIES

Aquaponics combined with open culture is a system that uses salt-containing water to produce fish and vegetables by combining production processes of aquaculture, hydroponics, and soil culture. It was developed as a high-tech system which accompanies great difficulties in controlling water and nutrient for obtaining products by connecting aquaculture tanks, hydroponics beds, irrigation facilities for soil cultivation, motor pumps for water supply and distribution, and solar power generators, etc. Sophisticated technology has been developed for each production process and systematized as an aquaponics combined with open culture.

In actual operation, these sophisticated production techniques must be applied to achieve high productivity for fish and vegetables.

To that end, it is important that managers and labor staffs should be familiar with the contents of production technology and use them effectively based on the characteristics of the production process. Depending on the stage of growth of fish and vegetables, and corresponding to seasonal characteristics of nature, the system must be operated efficiently to develop production activities.

The following items were focused to develop as the key technologies in the production process.

<Main technologies developed by the project>

- Aquaculture: Selection of suitable species for aquaculture, determination of optimum rearing environment
- Hydroponics: Selection of suitable species for cultivation, determination of optimum cultivation method
- Open culture: Selection of suitable species for cultivation, determination of optimum cultivation method
- Power supply: Development of power system design policy and maintenance method suitable for the aquaponics combined with open culture
- Safety assessment (Microbiological quality-control): Development of a rapid and accurate microbiological monitoring method of the aquaponics combined with open culture
- Combining technology between aquaculture and agriculture: Understanding the water balance in the aquaculture-agriculture combined system, development of evaluation method for water-use efficiency, and development of technologies for preventing salinization of open-cultured soil
- Social implementation: Reflection of developed technologies into verification tests, grasping the requirements for extension

6-2 PROMOTION OF DEVELOPMENT OF PRODUCTION TECHNOLOGIES WITH DIVERSITY

Production technology of aquaponics combined with open culture developed through project research has shown to have the potential to establish in Southern Baja California through verification tests at the model site, Los Planes.

There are many places in the state where the salinity of underground water is high and where transmission energy is difficult to use. The major achievement of this project is that it has demonstrated that aquaponics management can be established even in areas where these production environment conditions are poor. If the aquaponics combined with open culture spread and establish by management bodies in the state, it can be expected to contribute to the local economy through creation of new jobs and increased industrial output. In addition, it became clear that the developed aquaponics system can contribute not only to economic aspect but also to a multi-functional aspect such as local environmental conservation. Specifically, it was proved that the developed technologies contribute to the prevention of soil salinization and the suppression of CO_2 generation in dryland agriculture.

The challenge to make the above-mentioned advantages more effective is to develop the aquaponics combined with open culture with diversified production technologies which can be adapted to different environmental and geographical conditions by increasing the types of fish and vegetables to be produced. The following items are expected to be promising for the spread of future aquaponics in Southern Baja California, including the items under test in this project.

<Promising production items by the aquaponics combined with open culture>

- Aquaculture: tilapia, whiteleg shrimp, white snook
- Hydroponics: swiss chard, purslane, suaeda edulis, table beet
- Open culture: pepper (variety: habanero, jalapeño), rosemary, thyme, table beet, coriander, radish

6-3 KEY TECHNICAL AND MANAGEMENT INDICATORS FOR THE AQUAPONICS COMBINED WITH OPEN CULTURE

As part of the verification test, management analysis such as productivity analysis, profitability analysis, production cost analysis and break-even point analysis organized the standard technologies and management indicators for the aquaponics combined with open culture. For managers who will work on the aquaponics system, these standard indicators can be used as a reference for management.

6-4 FOSTERING MANAGERS WHO MANAGE THE AQUAPONICS COMBINED WITH OPEN CULTURE

Aquaponics combined with open culture presupposes investment in expensive plant and precise production technology. In order to succeed in the operation of aquaponics with such characteristics, managers must have excellent managerial abilities. In particular, in addition to high production technology capabilities, positive attitudes to tackle management innovation, funding capabilities, marketing capabilities, financial management capabilities, information response capabilities, etc. are required. Therefore, when to start aquaponics, the managers should have a reliable management ability.

Taking these characteristics into accounts, the target group for the aquaponics combined with open culture in Southern Baja California State, for the time being, is individual management bodies with the character of corporate management and organized farm management bodies such as Ejidos and voluntary groups. In order to spread and establish aquaponics management in the State, it is important to foster of managers with these conditions.

6-5 HIGHER VALUE-ADDED AQUAPONICS MANAGEMENT BY VALUE CHAIN

The management-economic objective of the aquaponics combined with open culture is to achieve high value-added management by combining aquaculture and agriculture (hydroponics, open-air cultivation) using salt-containing water and efficient use of management resources.

Generally, added value represents an index indicating the value created by management body through production activities. In order to retain more added value within the management body, it is important for managers to engage as much as possible proactively in a series of management activities such as procurement of production equipment and materials, employment of labors, production, sale of harvests, and provision of services using harvests.

This means the creation of a value chain that conforms to each management body. The value chain is explained as a concept that comprehensively captures corporate activities, breaks them down into strategic activities, increases productivity by enhancing mutual relationships, enhances cost reduction and product differentiation, and increases corporate competitiveness. In order to build and strengthen the value chain of management, it is important not to easily rely on others to procure producer goods or sell harvests, but to explore markets by the effort of managers. In addition, the capable management body is required to be innovative so as to challenge to produce processed agricultural products and to supply restaurants harvested products.

6-6 ESTABLISHMENT OF SUBSIDY AND FINANCING PROGRAM TO SPREAD THE AQUAPONICS COMBINED WITH OPEN CULTURE

In order to start the operation of the aquaponics combined with open culture, in addition to the facilities of fish firming and vegetable cultivation, water distribution equipment and solar power generation equipment that link production processes are necessary, so the initial investment amount is high. The amount of investment far exceeds the capacity of ordinary farmers and fishermen in Southern Baja California, so subsidies and financing schemes are essential for facility installation. It is necessary to launch a business effectively from a comprehensive policy perspective that combines industrial promotion within the state, dietary improvement of the residents and nature conservation.

In addition, looking at the present situation of aquaponics which was established previously in the State by government subsidy, there are cases where operation was suspended due to lack of working capital and technical capabilities shortly after the commencement of the facility. It is expected that the contents of assistance which will be provided by the authorities which promote aquaponics system should be considered after the initiation of operation of management bodies.

6-7 ESTABLISHMENT OF THE EXTENSION SYSTEM FOR TECHNICAL AND MANAGEMENT GUIDANCE

Production activities by aquaponics combined with open culture means that managers make a challenge of high-input and high-output management. Managers have to do a lot of preparatory work prior to the establishment the aquaponics system, such as procuring investment funds, learning production techniques, securing sales destinations, and reconciliation with residents in the area where the aquaponics is located. In order to stabilize management as soon as possible after the establishment of the aquaponics system, it is necessary to address expansion of production through technological improvements and new capital investment, development of sales channels for advantageous sales, and sound financial management. Unlike corporate management in the industrial sector, corporate scale of the primary industry sector is generally small. Therefore, in order for managers to respond appropriately to the establishment and subsequent operation of aquaponics system, it is essential to establish the extension system for technical and management guidance. Along with the promotion of aquaponics system, it is required to establish the extension system by Federal and State government.

7. COOPERATORS

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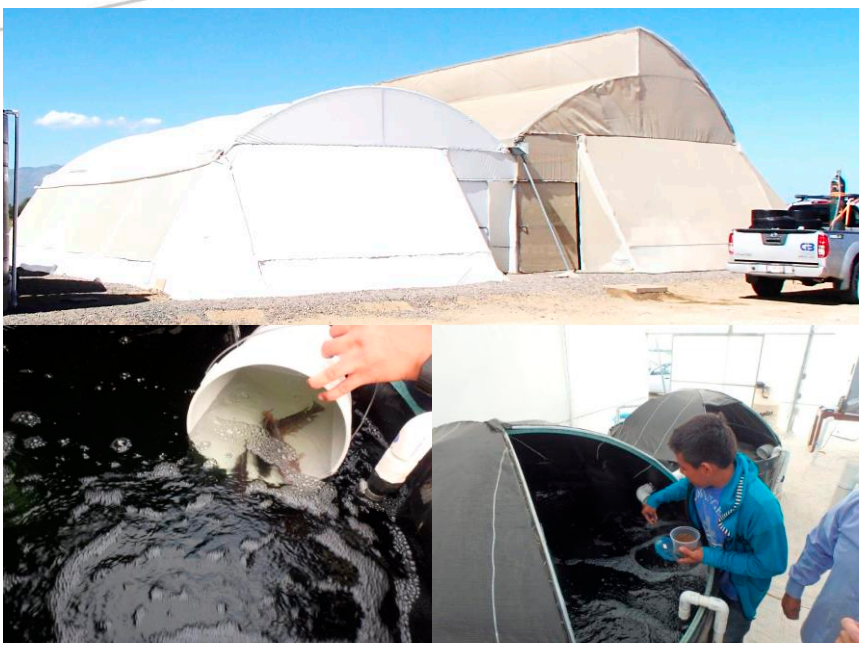
2. Technical Manual for Operation of Aquaponics Combined with Open Culture

2-1 Technical Manual for Tilapia Farming in the Recirculating Aquaculture System



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1. DAILY CONTROL ROUTINE

Before starting the routine, it is necessary to check the aeration and recirculation systems.

1-1 WATER RECIRCULATON

Check the recirculation and water leakage of each tank, In case the water does not recirculate through the tanks, check the pumps, amount of water and piping clogs in each tank.

1-2 AERATION

Check the aeration of all systems, in case of not observing aeration bubbles, check aeration diffusers, air piping and blower.

1-3 OBTAINING OF WATER PARAMETERS TWICE A DAY

(8:00 AM and 5:00 PM)

Handy meters are used to obtain data of the water temperature, DO, pH, salinity, and conductivity. Write down the values on the record sheet.

1-4 FEEDING

Weigh rations during the day, record the amount of food that is provided to fish.

5 times a day up to 60 g fish

8:00	**12:00**	**14:00**	**17:00**	**20:00**

3 times a day more than 60 g fish

8:00	**12:00**	**16:00**

1-5 CLEANING OF BIOFILTER

Remove the organic matter from the biofilter, with a damp magitel towel. Rinse it before changing biofilter. Clean the biofilter to fill the water, using the submersible pump of the reservoir tank.

1-6 CLEANING OF REARING TANK

Clean the inner of the tanks, this can be done with a brush or a magitel towel.

1-7 CLEANING OF SETTLING TANK

Clean the particulate fraction accumulated in the settling tank with a magitel towel, throw it away at the defined site of waste storage.

1-8 OBSERVATION OF SWIMMING BEHAIBOR OF RAIZED FISH

Extraordinary movements and their causes are pointed to the following. It is very important to understand precautionary signs and take the necessary measures before the fish die.

a) Phenomena: Fish swim close to the surface, gather at aeration and do not eat food well.
Causes: Lack of oxygen and / or nitrite toxic
Measures: Measure dissolved oxygen and check how aeration works.
In case of abnormal on aeration, adjust it.
In case of normal airation, there is a lot of possibility of nitrite toxicity. Inform experts.

b) Phenomena: Fish swim by closing their fins, rub against tubes and walls and do not eat food well.
Causes: Possibility of parasitosis
Measures: Inform experts.

c) Phenomena: Fish close their fins, fin points melt, hemorrhage is shown on the body part.
Causes: Possibility of bacterial infection
Measures: Inform to experts.

d) Phenomena: The color of fish is changed, irregular movement is shown, it crashes into walls and dies.
Causes: Possibility of ammonia toxicity
Measures: Change the water immediately and inform to experts.

This routine will be done daily throughout the growing period.

NOTE: The normal behavior of the fish can be observed through the tank window, and they usually swim in a group, they are very voracious so they rarely leave food. In case of a different behavior, check aeration and recirculation of rearing system. Check pH.

Log everything done.

2. HEALTH MEASURES IN THE AQUACULTURE FACILITY

The sanitary mats will be placed in the entrance of the aquaculture facility, they will be changed daily. It is important to do this when starting work, to maintain good control at the entrance. Before work, hands and rubber boots are sterilized with ethyl alcohol spray.

2-1 DISINFECTION OF THE TOOLS

Fish net and cleaning tools (brush, magitel towel) are prepared for each tank and they shoud not be shared between tanks.

2-2 WASHING THE TOOLS

**** The tools must be washed every time it is used. Dry under the sun light after that do not leave tools exposed to the sun for a long time**

a) Tools washing will be done every time it is used.
b) The nets and brushes are washed with soap, vinegar and let them dry.
c) Keep the tools clean and in good condition.

3. DAILY RECORD

The logbook is the most important tool to know the operation of the aquaculture facility and to make decisions in case of emergency. The logbook is filled daily, filled with a pen, it records all the rearing works that were done during the day. The parameters of rearing environment must be taken every day, twice a day at 8:00 am and 5:00 pm before feeding. It is important to keep track of the weather, fish movements and everything that is done on a daily basis.

Date – Name

Water parameters

Tank No.	Temperature (°C)	DO (mg/L)	pH	Conductibity (mS)	Salinity (ppt)
1					
2					
3					
4					

The parameters obtained from each tank at 8:00 am and 5:00 pm will be recorded in the logbook.

Write down the numerical values of water parameters of the tanks at 8:00 am and 5:00 pm

Feeds - rations

Feeding					
Tank No.	**8:00 am**	**11:00 am**	**2:00 pm**	**5:00 pm**	**8:00 pm**
1					
2					
3					
4					

Any observation, weather, activities in fish, behavior of the system and organisms will be recorded.

Fig.1 Exemplification of the data sheet. The data that have to be contained in a logbook are expresserd and it must be recorded everyday

4. PARAMETERS OF REARING SISTEM

It is important to keep the system so as the water environment to be maintained within these parameters of following Tab.1. If you notice any abnormality, Search the manual for the process to solve the problem. If you can not find the solution in this manual, ask experts it as soon as possible.

Tab.1 Optimum water parameters for tilapia culture, check that the tank parameters are within the optimum values presented in this table

Parameters	Units	Measuring equipment	Optimum ranges	Critical values Take corrective actions
DO	mg/L	YSI Potable	**> 4.5**	< 4.0 mg/L
Temperature	°C	YSI Potable	**28 - 32**	< 24 °C and > 34 °C
pH	N/A	Portable potentiometer	**6.5 - 9**	≤ 5
Ammonia	ppm	Test with Kit	**0.01 - 1**	≥ 2
Nitrite	ppm	Test with Kit	**< 0.1**	> 0.1
Conductivity	umhos	YSI Potable	**200-500**	>500

Any parameter within the critical values must be attended to as soon as possible, since it causes stress in culture which reduces the metabolism and growth rate, the fish can be affected disease from opportunistic pathogens, or suffer suffocation, intoxication or other symptoms that compromise on bioassay and do not allow to conclude it successfully. Periodic maintenance of equipment is needed, so ask for equipment adjustment once weekly to experts.

IF THE WATER PARAMETAR DO NOT BE OPTIMUM VALUE INDICATED IN TAB.1, TAKE A FOLLOWING MEASURES.

4-1 OXYGEN SUPLLY TO SYSTEM

In case of values less than 3 mg / L in dissolved oxygen, check the aeration outlet in the system, regulate the aeration valves and check blower. In case of total loss of oxygen, it will be necessary to introduce external oxygen (oxygen tank or implement aeration through a recirculation pump with waterfall cascade). Be alert to the behavior of organisms, if fish breathe on the surface concentrating in the aeration.

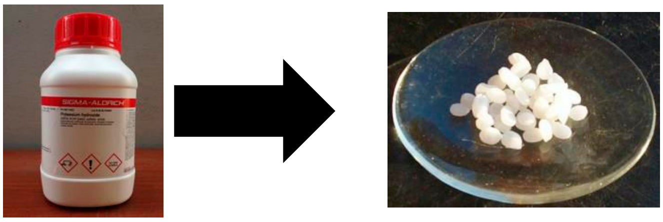
4-2 ADDING OF POTASSIUM HYDROXIDE (KOH)

Objective: Ammonium is converted to nitrate in the biofilter. At that time the pH is lowered, so you have to add KOH to recover pH as bellow.

Measurements: Measure 300ml of 1 mol KOH (Potassium Hydroxide) and pour it into the biofilter. Then repeat this work in each tank. After waiting 2 hours, measure pH and observe fish movements in each tank. Repeat this work until pH is recovered as above.

KOH is used to increase the alkalinity of the rearing water (raise the pH) and also potassium is added to the rearing water as nutrient for hydroponic plants in cases of using the rearing water for aquaponics.

The KOH is contained in a sigma bottle.



Potassium Hydroxide (KOH) (KOH)

Fig.2 Exemplification of potassium hydroxide, the brand may vary

<u>To prepare KOH solution</u>

Wear gloves (alkaline solution)

*In order to place the KOH, it is necessary to prepare 4 liters of the solution. In this case, they would weigh 225 g.

4-3 ACCUMULATION PREVENTION OF AMMONIUM, NITRITE AND NITRATE

AMMONIA

a) Remove sediments
b) Adjust aeration
c) Place substrate (contact surfaces) to retain suspended solids
d) Add nitrifying bacteria, probiotics and biofilters
e) Water replacement

NITRITE

a) Water replacement
b) Adjust the food amount

NITRATE

The concentration to which the nitrates will be taken at 150 mg N/ L, in case of detecting higher levels, water will be replaced to the hydroponic system.

5. FEEDING

Feeding (adequate size of food, measure the amount of food, method of feeding and condition of fish) is one of the most important work for fish rearing. The commercial food for tilapia is used for rearing of fish. The amount and particle size of this food will be changed according to the body weight and mouth size of fish.

Tab.2 shows the weight of the fish and the corresponding ration per day and per ration. The feeding will be given 3 times per day for fish (more than 60g). To choose the corresponding ration it is necessary to perform the biometrics and obtain the average body weight of the fish in each tank. The data of average size obtained will be found in the table, this will yield the total ration per day and in the column is the individual ration of food.

Tab.2 The optimum feed amount of tilapia calculated from the body weight and the equation of optimum feeding rate on the body weigh from 60g to 500g

BW (g)	P (%)	Number (fish/tank)	RDP (%/day)	Biomass (kg/tank)	Protein (g/tank/day)	FA (g/tank/day)	SFR (%/day)	FA/ 5times (g/tank/day)	FA (kg/tank/week)
60.0	120	180	17.43	10.8	188.3	427.9	4.0	85.6	2.99
70.0	120	180	16.72	12.6	210.7	478.9	3.8	95.8	3.35
80.0	120	180	16.11	14.4	232.0	527.3	3.7	105.5	3.69
90.0	120	180	15.57	16.2	252.3	573.4	3.5	114.7	4.01
100.0	120	180	15.09	18.0	271.6	617.3	3.4	123.5	4.32
110.0	120	180	14.65	19.8	290.1	659.4	3.3	131.9	4.62
120.0	120	180	14.26	21.6	307.9	699.8	3.2	140.0	4.90
130.0	120	180	13.89	23.4	325.0	738.6	3.2	147.7	5.17
140.0	120	180	13.55	25.2	341.4	776.0	3.1	155.2	5.43
150.0	120	180	13.23	27.0	357.3	812.0	3.0	162.4	5.68
160.0	120	180	12.94	28.8	372.6	846.8	2.9	169.4	5.93
170.0	120	180	12.66	30.6	387.4	880.4	2.9	176.1	6.16
180.0	120	180	12.40	32.4	401.7	912.9	2.8	182.6	6.39
190.0	120	180	12.15	34.2	415.5	944.4	2.8	188.9	6.61
200.0	120	180	11.91	36.0	428.9	974.8	2.7	195.0	6.82
210.0	120	180	11.69	37.8	441.9	1004.4	2.7	200.9	7.03
220.0	120	180	11.48	39.6	454.5	1033.0	2.6	206.6	7.23
230.0	120	180	11.27	41.4	466.8	1060.8	2.6	212.2	7.43
240.0	120	180	11.08	43.2	478.6	1087.8	2.5	217.6	7.61
250.0	120	180	10.89	45.0	490.2	1114.0	2.5	222.8	7.80
260.0	120	180	10.71	46.8	501.4	1139.5	2.4	227.9	7.98
270.0	120	180	10.54	48.6	512.2	1164.2	2.4	232.8	8.15
280.0	120	180	10.37	50.4	522.8	1188.2	2.4	237.6	8.32
290.0	120	180	10.21	52.2	533.1	1211.6	2.3	242.3	8.48
300.0	120	180	10.06	54.0	543.1	1234.3	2.3	246.9	8.64
310.0	120	180	9.91	55.8	552.8	1256.4	2.3	251.3	8.79
320.0	120	180	9.76	57.6	562.3	1277.9	2.2	255.6	8.95
330.0	120	180	9.62	59.4	571.5	1298.8	2.2	259.8	9.09
340.0	120	180	9.48	61.2	580.4	1319.1	2.2	263.8	9.23
350.0	120	180	9.35	63.0	589.1	1338.9	2.1	267.8	9.37
360.0	120	180	9.22	64.8	597.6	1358.1	2.1	271.6	9.51
370.0	120	180	9.10	66.6	605.8	1376.8	2.1	275.4	9.64
380.0	120	180	8.97	68.4	613.8	1395.1	2.0	279.0	9.77
390.0	120	180	8.86	70.2	621.6	1412.8	2.0	282.6	9.89
400.0	120	180	8.74	72.0	629.2	1430.0	2.0	286.0	10.01
410.0	120	180	8.63	73.8	636.6	1446.8	2.0	289.4	10.13
420.0	120	180	8.52	75.6	643.8	1463.1	1.9	292.6	10.24
430.0	120	180	8.41	77.4	650.8	1479.0	1.9	295.8	10.35
440.0	120	180	8.30	79.2	657.6	1494.4	1.9	298.9	10.46
450.0	120	180	8.20	81.0	664.2	1509.4	1.9	301.9	10.57
460.0	120	180	8.10	82.8	670.6	1524.0	1.8	304.8	10.67
470.0	120	180	8.00	84.6	676.8	1538.2	1.8	307.6	10.77
480.0	120	180	7.90	86.4	682.9	1552.0	1.8	310.4	10.86
490.0	120	180	7.81	88.2	688.8	1565.4	1.8	313.1	10.96
500.0	120	180	7.72	90.0	694.5	1578.4	1.8	315.7	11.05
510.0	120	180	7.63	91.8	700.1	1591.1	1.7	318.2	11.14
520.0	120	180	7.54	93.6	705.5	1603.3	1.7	320.7	11.22
530.0	120	180	7.45	95.4	710.7	1615.2	1.7	323.0	11.31
540.0	120	180	7.36	97.2	715.8	1626.8	1.7	325.4	11.39
550.0	120	180	7.28	99.0	720.7	1638.0	1.7	327.6	11.47

BW: Body weight, P: Percentage of standard feeding rate, RDP: Rate of daily protein intake, FA: Feed amount, SFR: Standard feeding rate.

Fig.3 Preparation of commercial food for tilapia cultured in RAS

6. BIOMETRY

Tab.3 Tools and materials required to measure body length and weight of cultured fish

Digital balance	Tares	Fish net
Ictiometer	Magitel towels	Mertiolate
Clove oil	Gloves	Log book

- Water quality control (by temperature, pH and KOH)

Do not feed to fish before biometrics.

Prepare all the tools and materials, preferably clean a large table for biometrics, clean the ichthyometer, digital balance and trays where fish will be weighed body weight and measured total lenght and/or bodylenght. It is important to wear gloves during biometrics. This procedure, it is recommended to do it carefully avoiding stress to excess fish.

Fig.4 Tools required to carry out the biometrics of fish

PROCEDURES

1) Tares are prepared with aeration.
2) Two large tares to receive the fish.
3) Prepare 30L of anesthesia (clove oil) water in a plastic container.
4) Prepare a plastic vessel with water on top of the balance.
5) Adjust the balance with 0 g measurement.
6) Put fish in the anesthesia water with a fish net and the fish take anesthesia.
7) Prepare the fish in the large tare and then measure fish weight one each.
8) Write down the data in the log.
9) Put the fish into the container with normal rearing water and fish recover.
10) After fish recovery, transport gently to rearing tank.
11) Repeat this procedure with the 15 fish.
12) Once the fish is recovered, return the fish to the corresponding tank.
13) Start the whole process with the next tank.

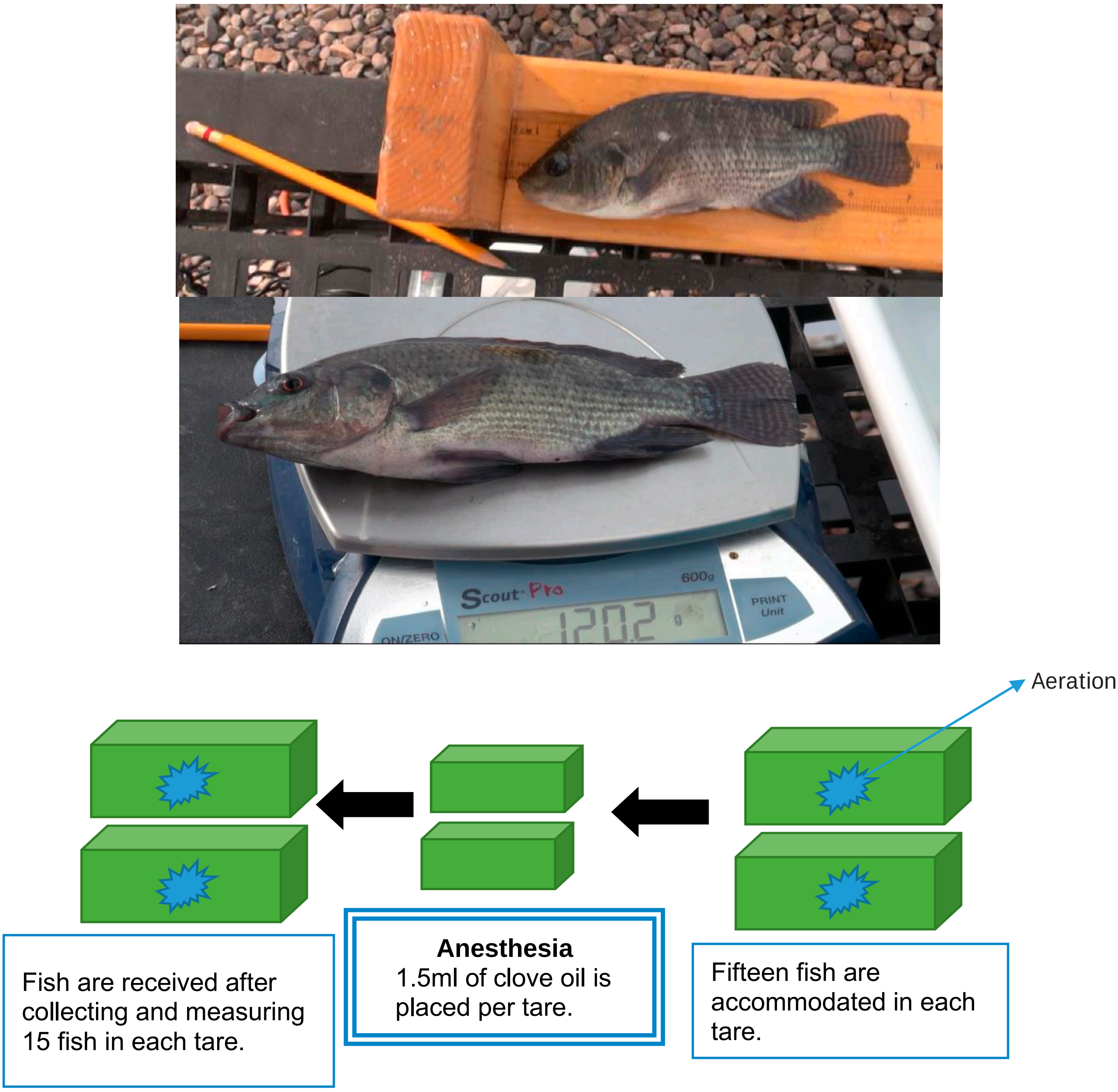


Fig.5 Diagram to exemplify the biometrics and the steps that are carried out, the drawing indicates the accommodation of the tares and the steps for the anesthesia and recovery of the organisms

7. REVIEW OF SYSTEM COMPONENTS

7-1 RECIRCULATION

The water recirculation of the system is given by a pump connected to the biofilter.

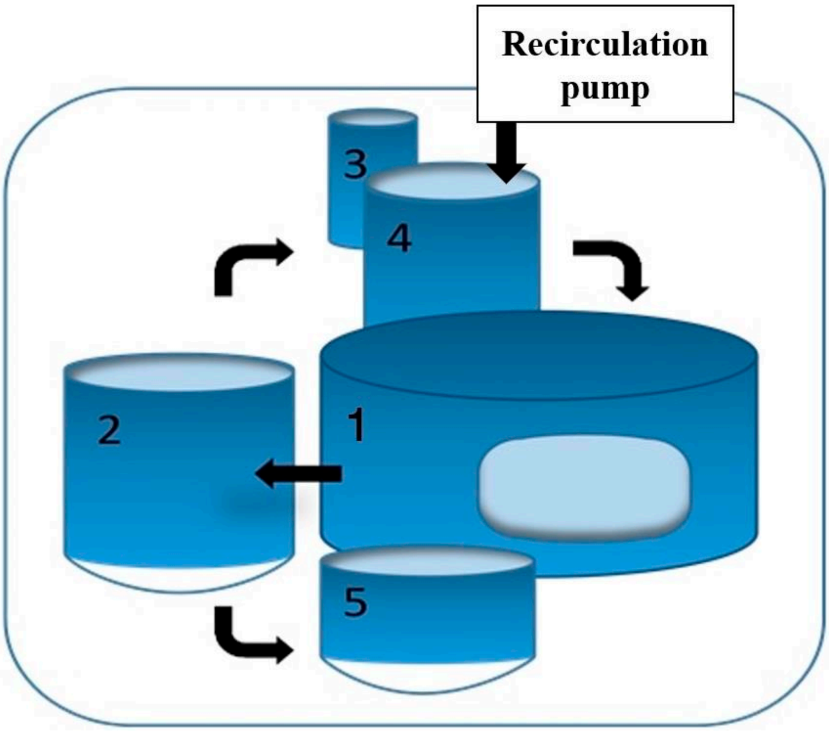


Fig.6 Flow diagram of recirculating aquaculture system for tilapia farming. 1: fish rearing tank, 2: settling tank, 3: foam fractionator, 4: biofilter, 5: mineralizer for sediment from RAS

If the recirculation pump fails, it can be replaced to another.

1) Check the pump connection (metal base with connectors).
2) Check the pump, whether it contains organic matter or any object stuck.

STEPS FOR REPLACEMENT OF PUMP

1) Before replacing, the water stopcock from the settling tank to the biofilter is closed.
2) The pump is removed, replaced by a new one, the water stopcock from the settler to the biofilter is opened.
3) The pump is turned on.
4) Water must pass through the flute inside the tank.

8. SYSTEM CLEANING

For optimal system operation, it is important to keep the system components clean. The cleaning includes the tanks and the tank wall, the settling tank, the biofilter. The cleaning of the tanks and the biofilter is recommended to be done once a week.

8-1 TANK CLEANING

The cleaning of the tanks should be done once a week. The edge of the tanks will be carved with a brush, removing the organic matter that is attached. The tank floor will be siphoned every three days, with a siphon of 3/4 compressed tip. The entire floor will be siphoned evenly in order to remove the organic matter that could be retained on the tank floor.

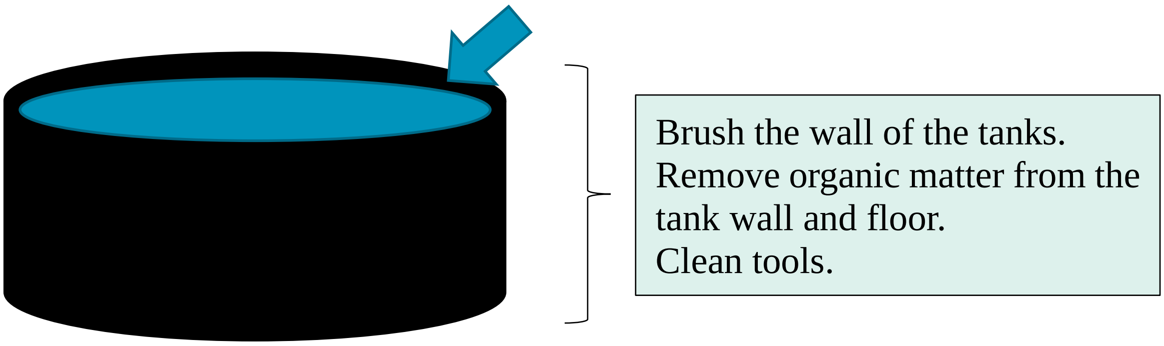


Fig.7 Exemplification of the cleaning of the tanks and the steps to be followed

8-2 CLEANING OF SEDIMENTERS AND REMOVING ORGANIC MATTER

Tab.4 Tools needed for organic matter removal, which has to be ready before removal

Hose	Brush
Cuvettes	Jug
Magitel towel	Gloves

*Once a week, the retained solids must be removed from the settling tank, it is important to remove all organic matter, and place it in the mineralizer or waste storage site.

8-3 STEPS FOR CLEANING OF THE SETTLING TANK

<u>Put on gloves</u>

1) The recirculation pump and the foam fractionator pump are turned off.
2) The water stopcock from the settling tank to the biofilter is closed.
3) The settling tank is carved, after that half an hour is expected for all organic matter to go to the tank bottom.
4) After half an hour, the valve for emptying the settling tank is opened.
5) Removal matter is placed in buckets, collect 5 buckets per tank. It is important to remove as much sludge.
6) The settling tank is empty at once and clean water is added and the walls of settling tank are brushed.
7) All tools are rinsed, and all the particulate fraction is removed.
8) Once cleaned, the stopcock from the settling tank to the biofilter is opened.
9) The recirculation pump is turned on.
10) The level of water lost is filled with clean water.
11) Check that the recirculation works correctly and normally.

It is important to avoid the accumulation of organic matter in the system, since the accumulation of organic matter can intervene and affect the water quality of rearing water.

9. WATER TRANSFER

9-1 WATER SUPPLY

Clean water is used. The biofilter water level must be observed. If the level is lowered, supply the water, immediately. Otherwise take the following measures:

9-2 HIGH LEVELS OF AMMONIUM, NITRITES OR NITRATES

High levels of ammonium are due to a problem in the nitrogen cycle, this can be caused by accumulation of organic matter, excess feeding and excess biomass. Therefore, if high levels of ammonium or nitrites are detected, it is important to change the water, clean the tanks, remove sediments and check aeration system.

9-3 DRAINAGE FROM TANK

For the accumulation of nitrates, in case of presenting an amount greater than 150mgN/L, the transfer of rearing water will be carried out to hydroponics system.

In case of transferring rearing water to the hydroponics system,

Tab.5 Tools needed for water transfer

Pump	Hose
Water tanks	

1) Close the water supply valve in the rearing tank.
2) Place a submersible pump in the tank and pass the water to the hydroponics system. The amount of water is 1.8 kL.
3) Then clean the tank of RAS and carry out treatment before selling of fish in the same tank.

10. EMERGENCY MEASURES FOR FAILURES IN THE SUPPLY OF ELECTRICAL ENERGY

It is important to have a fuel for the power generator, it must be always in good condition.

Note: Test it operation, capacity and use every three months so as several people can manage it.

It is important that the members of the farm trained on the use, operation of the power generator, so that anyone can start it up if required.

11. TREATMENT BEFORE SHIPPING

The harvest will be done monthly before the hydroponics system is started, all the production in a tank will be harvested, for which the following steps will be taken.

1) Set the harvest and shipping date.
2) After deciding the date, the period of fasting of the fish in the clean water begins, which will last for 5 days.
3) The water circulation is stopped and the water is changed to the clean one (approximately 95%). The fish are then raised without food and only with aeration and tank cleaning is continued.
4) During these 5 days only the system will be monitored, if the water parameters are taken twice a day, the cleaning routine will be continued.

11-1 CAPTURE, BLOOD DRAW AND PREPARATION OF THE FISH

1) Clean and disinfect table with chlorine, clean the entire area where the fish will be processed, have enough water, and ice, prepare the areas for the sacrifice of the fish and the blood removal.
2) Organisms will be captured, placed in 1 m^3 containers with ice mixed with water, to reach low temperatures.
3) It will wait until fish rigidity of hypothermia.
4) Once asleep the animal will be removed from the ice, the knife will be placed on the back of the gill or the artery between the heart and gills will be cut. Then the body temperature is recovered as the environmental.
5) After waking from hypothermia, he bleeds by moving his heart again. Once bled, it will be devicted and placed in coolers with enough ice, which will be sealed and placed in the truck for transport.
6) The coolers will be sealed with the fish and taken to their destination, the same day of harvest.
7) This procedure has to be followed with meticulousness, since this process is very important and necessary to maintain the high quality of the product. The entire tank will be harvested.
8) After the harvest is finished, it is important to disinfect the area, wash all the tools and conteiners used with soap and chlorine. Dry the entire working area.
9) Accumulated viscera will be discarded to waste storage site.

Fig.8 Photograhps about the processing of harvested fish

12. EMPTYING AND CREANING OF REARING SYSTEM AFTER HARVESTING

After the harvesting of the fish. The settling tank, biofilter and foam fractionators will be removed and washed, all removed organic matter will be placed in the mineralizer.

After the organic matter is removed, the tank will be emptied, the water will be taken to the hydroponics system.

The wall of the tank and the floor will be cleaned, all areas will be brushed with brush to remove all waste, After the tank is clean, 250 L of clean water and 250 ml of chlorine and / or lime will be placed, which will be mixed with the water in the tank, the lever will open to release the retained water and take away all the accumulated residuals.

After the tank is clean and empty, it will be allowed to dry for a week, before the new introducing of new jubnile fish. During this dry period, pipes, connections, drains and other system components will be checked for maintenance or if it is necessary to repair the affected parts.

13. NOTES

Once abnormality is detected, contact with experts immediately and consult the measures to be taken. In the case of fish farming, it is very important to take quick measures. If your action is delayed, you will lose a lot of money.

14. BIBLIOGRAFY

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16. PHOTOGRAPHS IN CHARGE OF

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17. ACKNOWRIGEMENT

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2-2 Technical Manual for Hydroponics Using Aquaculture Wastewater

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Table of Contents

This manual summarizes the techniques for hydroponics using wastewater from aquaculture (2-1) using saline underground water. Information such as numerical values and photographs are obtained from verification tests of hydroponics using wastewater from aquaculture performed using saline water conducted in the module on the site of the Northwestern Biological Research Center, S.C. (hereinafter referred to as CIBNOR), at San Juan de Los Planes (hereinafter referred to as Los Planes) (Refer to Appendix, p. 210 for their locations) and at the Field Science Center, Faculty of Agriculture, Tottori University. The contents described are: 1) chemical composition and safety of underground water and aquaculture wastewater, 2) acceptable salts concentration in the rooting solution for each crop, 3) procedure of receiving water from aquaculture and discharging water to open culture, 4) crop cultivation, harvesting and regeneration, 5) troubleshooting.

1. GROUNDWATER QUALITY IN SOUTHERN BAJA CALIFORNIA - LOS PLANES AND CIBNOR-

Electric conductivity (EC) is an index to know the amount of nutrients contained in a solution. The higher the EC value, the higher the concentration of nutrients.

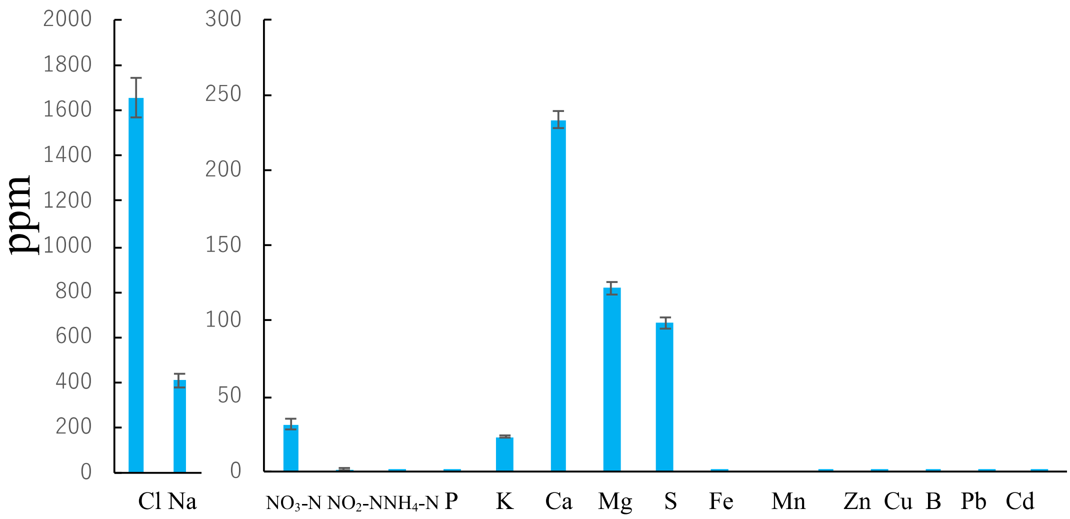


Fig.1 Mineral concentrations in groundwater of Los Planes (Nov. 2018 - Jul. 2019) Bars indicate S. E.

As shown in Fig.1, the groundwater of Los Planes contains an excessive amount of Cl and Na, so the value indicated by EC may be considered to indicate the total amount of Cl and Na. Compared to tap water, the EC of Los Planes is very high throughout the season (Fig.2 and Tab.1). For reference, the EC of tap water in La Paz city is around 1.0dS/m. In addition, nutrient concentrations in groundwater may not be constant because EC values vary greatly by season

(Tab.1). Annual average of harmful heavy metals such as Cd and Pb in the groundwater (Fig.1) and also in the aquaculture wastewater (Tab.6) were lower than the upper limit of WHO in groundwater.

The NO_3^--N concentration in aquaculture wastewater was extremely high, but the NO_3^- concentration in leaves of Swiss chard (Kaburagi et al. 2020) were lower than the upper limit (3500 ppm) regulated value for the spinach, which is in the same family (Amaranthaceae) as Swiss chard, reported by the UK as Food Standard Agency (Red Tractor Farm Assurance, 2016.)

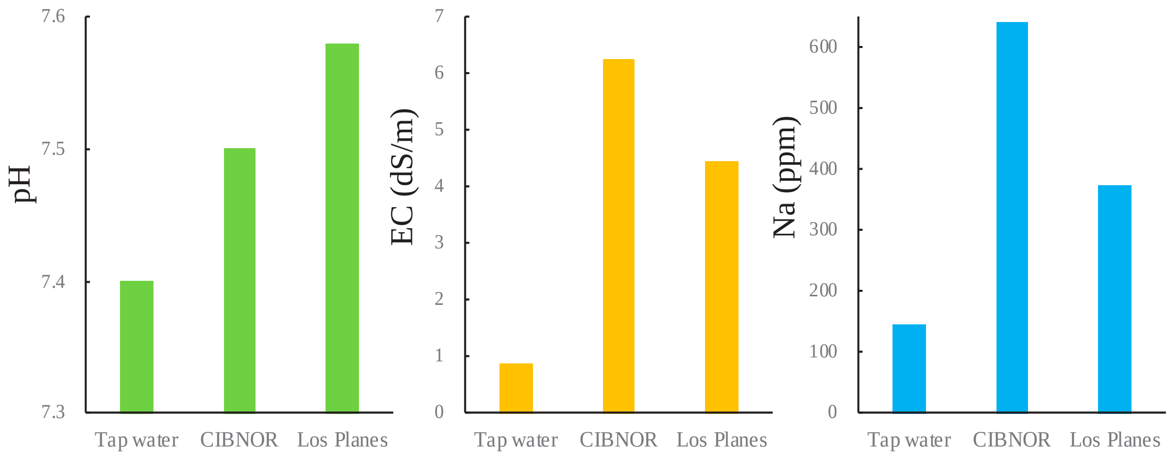


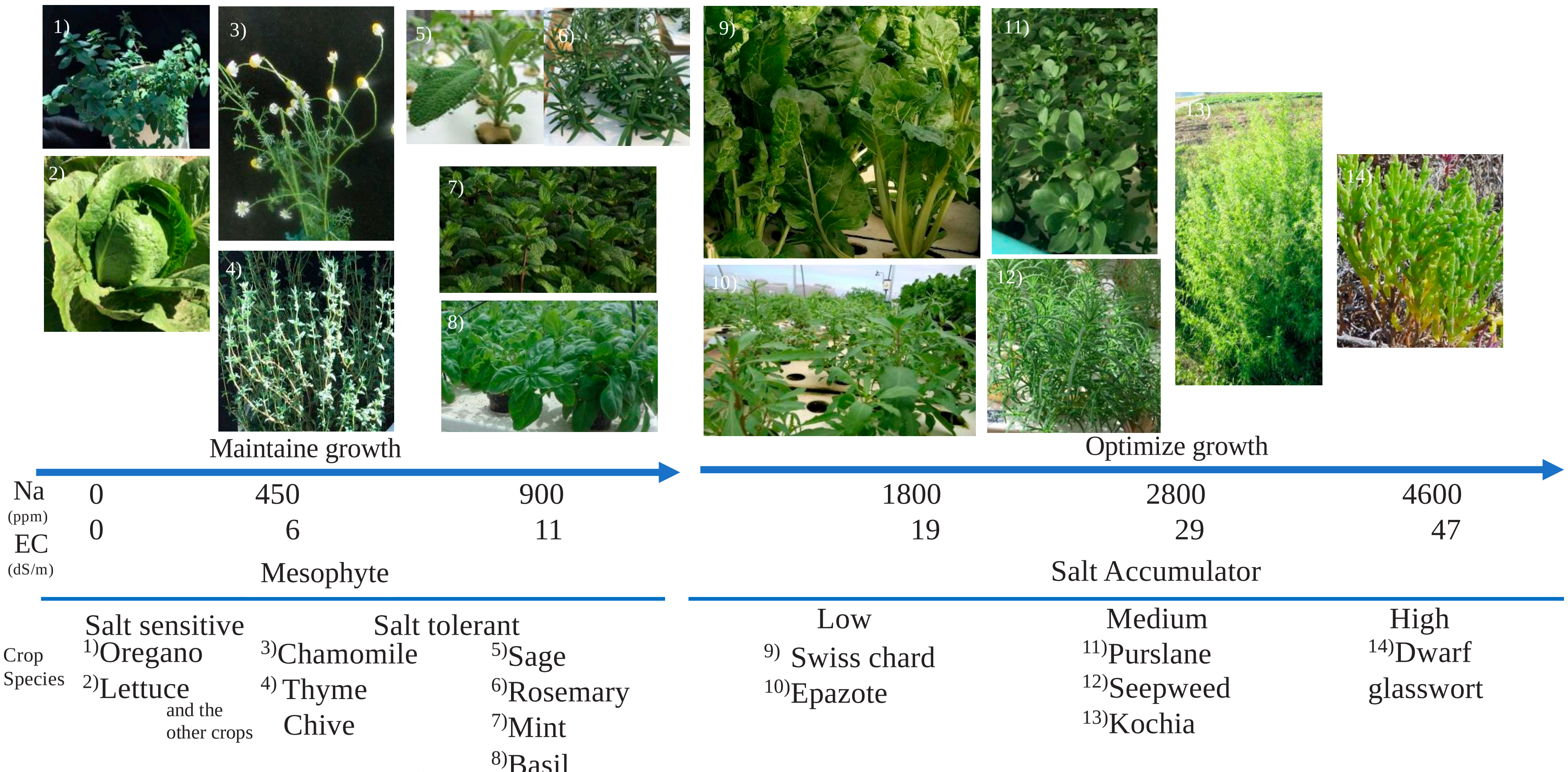
Fig.2 pH, EC, and Na concentration of the tap water and the ground water in CIBNOR and Los Planes
Values are averages from 2015 to 2019.

Tab.1 Seasonal changes in pH and electrical conductivity (EC) of groundwater at Los Planes

	2018		2019									
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
pH	7.63	6.21	6.47	7.85	7.31	6.82	6.42	7.00	7.41	7.36	7.28	7.62
EC (dS m^{-1})	4.73	7.00	5.69	4.80	4.47	4.53	4.30	4.34	4.40	4.41	4.35	4.22

2. SELECTION OF CROP SPECIES SUITABLE FOR SALINITY

In agricultural production using highly saline water, use of salt accumulation crops enables to remove salts. It is also possible to cultivate salt-tolerant mesophyte with relatively low salt concentration. The salt tolerance of mesophilic crops is described in Maas Category (1984) see 2-3-1. Fig.3 shows the salt tolerance of the herbs and the response of salt accumulation crops to Na. From the difference in response to salt, you are able to select the crop species according to a difference in Na concentration of groundwater.



This figure was made based on the results of thyme, oregano, sage and basil (Tanaka et al. 2018), chamomile and chive (Yokoyama, unpublished), rosemary (Mercado et al. 2019), swiss chard and epazote (M. Yamada et al. 2016), seepweed (Sakata, unpublished data), purslane and mint (Kaburagi, unpublished data), kochia (S. Yamada et al. 2016) and dwarf glasswort (Ohiri and Fujiyama, 2011). Values of Na and EC were based on actual measurements of hydroponics from above mentioned research.

Fig.3 Selection of suitable crop by the response to salt for the growth

3. SELECTION OF CROP SPECIES

For hydroponics, crop species with all three characteristics mentioned below were selected: 1) crop species with high ability to absorb salt; 2) grow well in groundwater with high salt concentration such as Los Planes; and 3) crop species with good market value. In the process of hydroponic cultivation, these selected crop species remove salt from the water. This process provides lower salt water for open-field cultivation and, as a result, prevents from salt accumulation in the soil (Tab.2 and Photo.1).

Swiss chard (*Beta vulgaris* L. var. cicla), Spanish name; acelga) is famous as global vegetables. Purslane (*Portulaca oleracea* L., Spanish name; verdolaga) is a kind of weed in Japan but can be seen in the market in Mexico and other countries as vegetable. Seepweed or romerit (*Suaeda edulis* Flores Olv. & Noguez, Spanish name; suaeda) is used as food and feed because its seeds contain high level of oils and minerals. Epazote (*Chenopodium ambrosioides* L., English name; Mexican tea) is a medicinal plant.

The cultivation calendar which indicates the appropriate season for seeding, transplanting and harvest in B.C.S., Mexico is shown in Tab.3. Production is very high in Swiss chard and purslane, and water use efficiency is highest in Swiss chad and lower in epazote (Tab.2). Sodium absorption is highest in seepweed. Cultivating these salts-accumulating plants enables to use a low saline water in the open-field, leading to reduce salts accumulation in the soil.

Photo.1 Swiss chard, purslane, seepweed, and epazote (from left)

Tab.2 Comparison of the cultivation period, production rate, water use efficiency, capacity of salt absorption, market price of the selected plant species

	Cultivation period	Production	Water use efficiency	Sodium absorption	Market price in Mexico (6.12 yen = 1 peso)	
	(Month)	(FW t/ha)	(FW kg/Water L)	(g/kg)	(Yen/kg)	(Peso/kg)
Swiss chard	78	38～46	0.1237～0.1640	28～80	147	24
Seepweed	25	7.3～19	0.0608～0.0829	30～140	Self-consumption	Self-consumption
Purslane	36	36.2	0.0230	46～57	147	24
Epazote	72	16.7	0.0065	18～62	2631	430

Regarding production and water use efficiency, results for Swiss chard and purslane were cultivated at CIBNOR in 2016 and 2017 using tilapia aquaculture wastewater (Kaburagi, unpublished data). Regarding production and water use efficiency, results for epazote were cultivated at Los Planes in 2019 using tilapia aquaculture wastewater (M. Yamada, unpublished data). As for the sodium absorption, the values of Swiss chard and epazote were the results when cultivated under sodium condition (460 to 4600ppm) from M. Yamada et. al., 2016, results of purslane is when cultivated at 1150ppm sodium condition (Koma, unpublished data). All parameter results of seepweed is when cultivated at 1150ppm sodium condition (Sakata unpublished data). And data of market price in Mexico was noted at chapter 4 in this manual (Kobayashi et. al. 2020).

Tab.3 Appropriate season for seeding, transplanting and harvest is shown as circle

		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Swiss chard	Seeding	○	○	○	○	○	○	×	×	○	○	○	○
	Transplant	○	○	○	○	○	○	×	×	○	○	○	○
	Harvest	○	○	○	○	○	○	×	×	○	○	○	○
Seepweed	Seeding	○	○	○	○	○	○	○	○	○	×	×	○
	Transplant	○	○	○	○	○	○	○	○	○	×	×	○
	Harvest	○	○	○	○	○	○	○	○	○	×	×	○
Purslane	Seeding	○	○	○	○	○	○	○	○	○	○	○	○
	Transplant	○	○	○	○	○	○	○	○	○	○	○	○
	Harvest	○	○	○	○	○	○	○	○	○	○	○	○
Epazote	Seeding	○	○	○	○	○	○	○	○	○	○	○	○
	Transplant	○	○	○	○	○	○	○	○	○	○	○	○
	Harvest	○	○	○	○	○	○	○	○	○	○	○	○

4. SEEDS

Prepare fresh seeds. Then check the germination rate. Among the varieties of swiss chard, the Na loving characteristics is stronger in the order of fordhook giant > ruby red > calico (Kaburagi, unpublished) (Photo.2). The characteristics is to grow absorbing salts and has optimum Na concentration in the medium for growth (M. Yamada et al., 2016). Seeds of epazote, purslane and seepweed are very small (Photo.3).

Photo.2 Seed bags of different swiss chard varieties
Fordhook giant, ruby red and calico (from left).

Photo.3
Seeds of swiss chard (left), purslane (center) and epazote (right)

5. CULTURE SOIL

Use culture soil for seedling. Prepare fresh (new, if using commercial soil) soil. It is desirable to fertilizer-mixed soil that supports the early growth stage of plants, such as prepared culture soil (Photo.4). Fill the cell trays with the culture soil, then level the ground and irrigate well.

Photo.4 Prepare of culture soil. SOGEMIX(left), VERMILITA + nutrients (middle), 1:1 Mixture of SOGEMIX and VERMILITA (right).

6. SEEDING

For swiss chard seeding, use sticks or fingers to make a hole twice as deep as the seed, and sow the seed one by one. Then, cover holes with the prepared culture soil, press it by hand to make it firmly adhere to the soil, and irrigate plenty of water. Because swiss chard is photophilic crop, no covering is required. For purslane and seepweed seeding, due to the very small size of the seeds, sprinkle the seeds and cover culture soil very thinly, lightly compressed and carefully water it. It is good to cover the surface of culture soil with newspaper etc, to keep right temperature and moisture for germination.

7. NURSERY

Seedlings beds should be cared for 10 - 14 days for Swiss chard, and 7 - 10 days for seepweed, purslane and epazote until the true leaf emerges. Irrigate liquid fertilizer such as Hyponex as needed (Photo.5). Water lightly to prevent from leaf damage when applying liquid fertilizer. In order to prevent from bird damage, it is desirable to cover the nursery room with net. In Japan, seedlings are carefully cultivated, as the word “Once the seedlings are nursed well, then it means that half the harvest was done successfully" (Photo.6).

Photo.5
Liquid fertilizer which should be diluted to the optimum concentration for crops


Photo.6 Germinated swiss chard. High germination rate (left), low germination rate (right).

Tab.4 shows the period for seedling raising in the cell tray, the period until seedlings become suitable for transplanting and possible harvesting times. Optimum time for transplanting is when the first true leaves emerge for Swiss chard, when the plant height becomes 5 cm for Suaeda, when the plant height becomes 7 cm for purslane and when the third true leaves expands for epazote (photos in the left). Plant size shown in the right in photo. 7 is maximum for transplanting.

Tab.4 Period for preparation of seedlings, from transplanting to first harvest and harvest times

	Nursery of seedlings in cell tray	Period from transplanting to first harvest	Harvest times
Swiss chard	4 weeks	6～8 weeks	8 times
Seepweed	6 weeks	8weeks	5 times
Purslane	3 weeks	6～8 weeks	8 times
Epazote	8 weeks	4～6 weeks	5 times

8. PREPARATION FOR THE TRANSPLANT TO HYDROPONIC TANK

8-1 TRANSFERRING OF AQUACULTURE WASTEWATER

Aquaculture wastewater with NO_3^--N of 56 to 150 ppm is transferred to the hydroponic beds (Photo.8). Wastewater in the aquaculture tanks are transferred to the hydroponic beds by opening the valve. If the water temperature is low in winter, transfer wastewater and leave it for one day before the transplant.

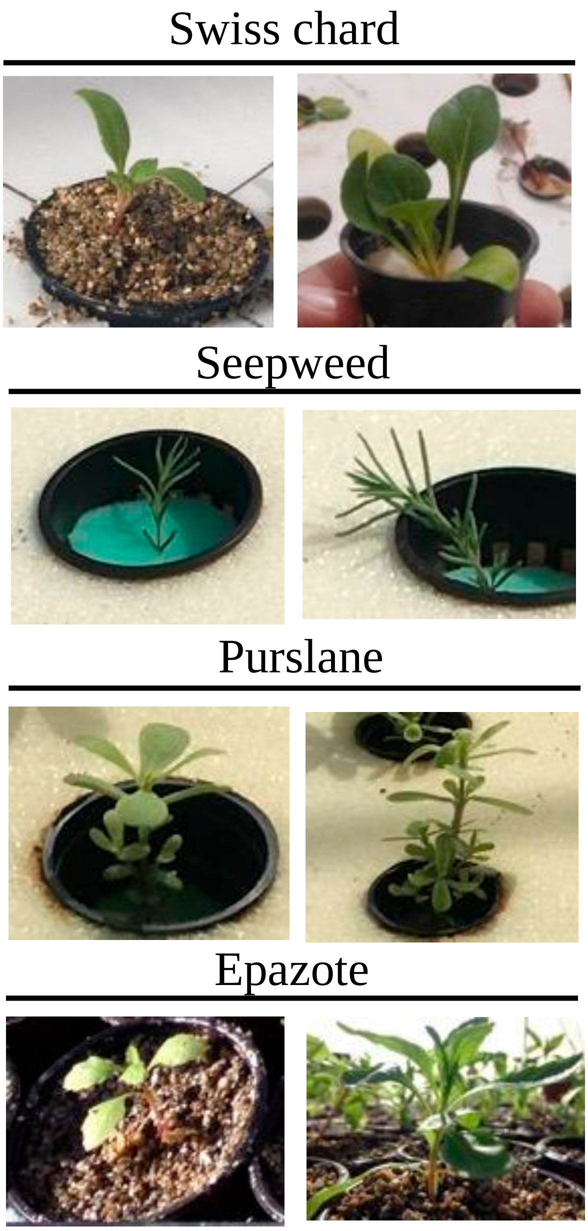


Photo.7
Seedlings size for transplanting The size in the left and right side is suitable and maximum size for transplanting, respectively

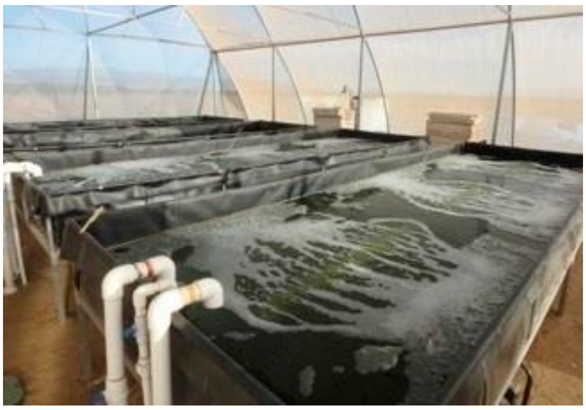


Photo.8
Supply of wastewater to hydroponic beds

8-2 PREPARATION OF FLOATING BED

The margin between floating beds should be as narrow as possible to suppress evaporation. Materials of floating bed should be adjusted according to the bed size to minimize the margin. Consider the hole size so as to hold cultivating cups (Photo.9 left). Distance between plants needs 20 cm for Swiss chard and 15 - 20 cm for purslane, epazote and Suaeda. As planting density, 16 plants / m^2 for Swiss chard, 22 plants / m^2 for epazote and 36 plants / m^2 for purslane and Suaeda are recommended (Photo.8 Right). Holes which are not used considering planting density should be plugged with materials such as sponge to minimize evapotranspiration (Photo.9 right).

Photo.9 Floating bed

Drill holes in the floating bed (left). Transplant considering planting density (right).

8-3 TRANSPLANT USING CULTURE SOIL

Beforehand, set a water-absorbing paper in a perforated plastic cup (Photo.10) as a support. Roots are too short to directly absorb water. To maintain the moisture of the culture soil, it is important to use the water-absorbing paper. Then a perforated plastic cup is filled with culture soil that has been well absorbed water in advance. Carefully remove the seedlings from the cell tray using a wooden spatula or so on, so as not to damage the roots (Photo.11-1). The medium in which the seedlings were nursed is also put into the cup with culture soil and allowed to adhere to the soil well (Photo.11-2 to 11-4). Cups with seedlings are set on a floating bed (Photo.11-5), which will float above the wastewater. Set perforated plastic cups into the hole in the floating bed. During this process, take very carefully not to damage the root. Damaged roots can cause poor plant growth. Finally, check the aeration, such as the amount of air and the position of aeration tubes, etc.

Photo.10 Perforated plastic cup with water-absorbing paper.

Photo.11
Transplant seedlings into plastic cups (using culture soil)

8-4 TRANSPLANT USING SPONGE

Beforehand, cut the sponge for the transplant (Photo.12). Cut with the size about 3.5 x 3.5 x 2.5 (cm) (not necessarily exact). Make a cut in the center. Carefully take out the seedlings from the cell tray so as not to damage the roots （Photo.13-1). The root is sandwiched between the cut of the sponge so that the root comes out under the sponge and the leaves come out on the sponge (it is ok if the roots may have attached to the medium) (Photo.13-2). Put the sponge with plant into the plastic cup, then pull the root out of the cup carefully (Photo. 13-1 to 5) Put the sandwiched sponge into the plastic cup, and insert the plastic cup into the hole of the floating bed (Photo.9). During this process, take very carefully not to damage the root. Damaged roots can cause poor plant growth. When taking a long time for the work before insert to floating bed, put seedlings on the water in a backet temporary. Finally, check the aeration, such as the amount of air and the position of aeration tubes, etc.

Photo.12
Sponge with a cut in the center

Advantages and disadvantages of different transplanting methods (culture soil or sponge) are summarized in Tab.5. Choose one of these methods.

Tab.5 Advantages and disadvantages of different transplanting methods between culture soil and sponge

	Advantages	Disadvantages
Culture soil	*Less risks to damage roots when transplant *There are nutrients in culture soil *Grow fast at the early growth stage *Moistured	*Cost more than sponge *Moist excessively especially in summer *Pests infestation and diseases are likely to occur *More work for cleaning up *A lot of wastes *Soil settles on the hydroponics bed *Plastc cup may need to be washed
Sponge	*Cheap *Clean *Occurrence of insects and diseases can be suppressed *Easier and faster to transplant *Not excessively moistured *Easy to clean up *Plastic cups do not need to be washed	*High risls to damage roots when transplanting *There are no nutrients on sponge *Grow slow at the early growth stage

You can also consider rock wool.

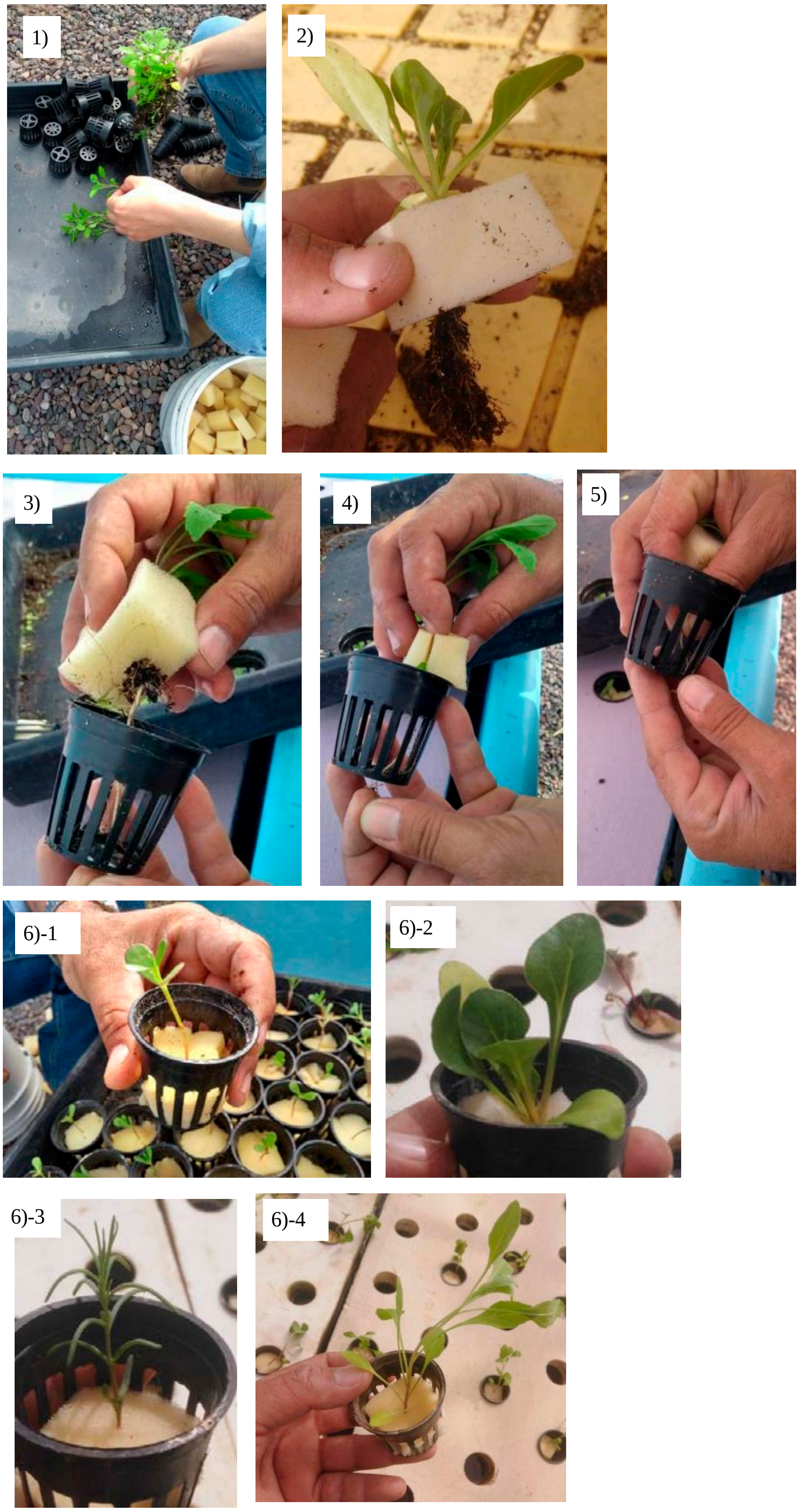


Photo.13 Transplanting seedlings into plastic cups (using sponge)
6)-1 Purslane. 6)-2 Swiss chard. 6)-3 Seepweed. 6)-4. Epazote.

9. WASTEWATER EXCHANGE

9-1 HYDROPONIC WASTEWATER TRANSFER TO OPEN-FIELD CULTIVATION

For the wastewater exchange process, firstly, the water in the hydroponic beds is transferred to an open-field irrigation tank. The amount of water to be transferred from each cultivation bed is preferably 1/3 to 1/4 of the total amount of the bed.

9-2 PREPARATION OF HYDROPONIC WASTEWATER FOR OPEN-FIELD IRRIGATION

Through the work of 9-1, the wastewater from hydroponic beds are stored in the open-field irrigation tank periodically. In the process of hydroponics, water in the hydroponic bed is lost due to the evapotranspiration. In addition, depending on the type of nutrients contained in the hydroponic effluent, its concentration is also increased by evapotranspiration. Then, these lost water by evapotranspiration is collected as fresh water by a dehumidifier. This collected fresh water is mixed with the hydroponic wastewater to lower the concentrated nutrients in wastewater. Then, this water with lower nutrient concentration is used for the open-field cultivation. When the amount of water collected by dehumidifiers is insufficient, fresh water (EC 0dS/m) purchased can be also used. Important note for the mixing ratio of wastewater and fresh water is to adjust this mixed wastewater to a value lower than the EC of groundwater. For example, to supply water with an EC of 4dS/m or less to the open-field when the initial EC value of the hydroponic wastewater is 8dS/m, the mixture ratio of the hydroponic wastewater and the water collected by the humidifires should be about 1:1 (Photo.14).

9-3 AQUACULTURE WASTEWATER TRANSFER TO HYDROPONIC BEDS

In Los Planes module, when the EC of aquaculture wastewater reaches 5 to 6dS/m, the wastewater is exchanged ＜1＞ Transfer hydroponic wastewater to an open-field irrigation tank, then ＜2＞ Supply aquaculture wastewater to hydroponic beds). This work should be done considering the amount of irrigation water required by open-field culture. This wastewater exchange process is important to supply nutrients necessary for growing crops (Tab.6).

Photo.14
Adjusting the EC in irrigation tank for water supply to open-field cultivation

Tab.6 Example of components and concentrations in the aquaculture waste water and the hydroponics medium

	EC (dS/m)	pH
Aquacurture waste water at Los Planes		
Maximum	6.77	6.91
Minimum	4.74	4.97
Average	5.47	5.70

	Na (ppm)	Cl (ppm)	NO_3^--N (ppm)	NO_2^--N (ppm)	NH_4^+-N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Aquacurture waste water at Los Planes									
Maximum	625	3280	288	3.59	32.9	23.7	89.9	471	223
Minimum	306	1581	60	0.06	0.2	0.3	13.1	220	125
Average	406	1887	115	1.37	10.5	10.4	47.3	302	152
Tottori university medium for NO_3 loving crops									
			56.0			12.4	78.2	40.1	48.6
CIBNOR medium for basil									
			36.3		13.4	12.4	78.2	40.1	48.6

	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	B (ppm)
Aquacurture waste water at Los Planes					
Maximum	0.095	0.384	0.951	0.099	1.427
Minimum	0.005	0.028	0.104	0.003	0.453
Average	0.051	0.201	0.395	0.034	0.748
Tottori university medium for NO_3 loving crops					
	2.000	0.500	0.100	0.010	0.814
CIBNOR medium for basil					
	2.000	0.500	0.100	0.010	0.814

Aquaculture wastewater contains essential elements for crop plant such as NO_3^--N, P and K in addition to Na and Cl originated from underground water (Tab.6). The wastewater contains too much NO_3^--N, Ca and B and too less P, Fe, Mn, Zn and Cu (especially Fe). There is a correlation between these elements and EC. Therefore daily EC measurement enables us to estimate what element is excessive or insufficient (Fig.4-1 and Fig.4-2). Then we can add some elements depending on crop plant species. Potassium deficient epazote was shown (Photo.15). Chlorosis, a symptom of K deficiency was exhibited in younger leaves of the plant cultivated with insufficient K in the nutrient solution. Leaves is dark green under sufficient K condition (Photo.21). Attention should be especially paid to antagonistic inhibition of K absorption by Na, because aquaculture wastewater contains much amount of Na originated from underground water.

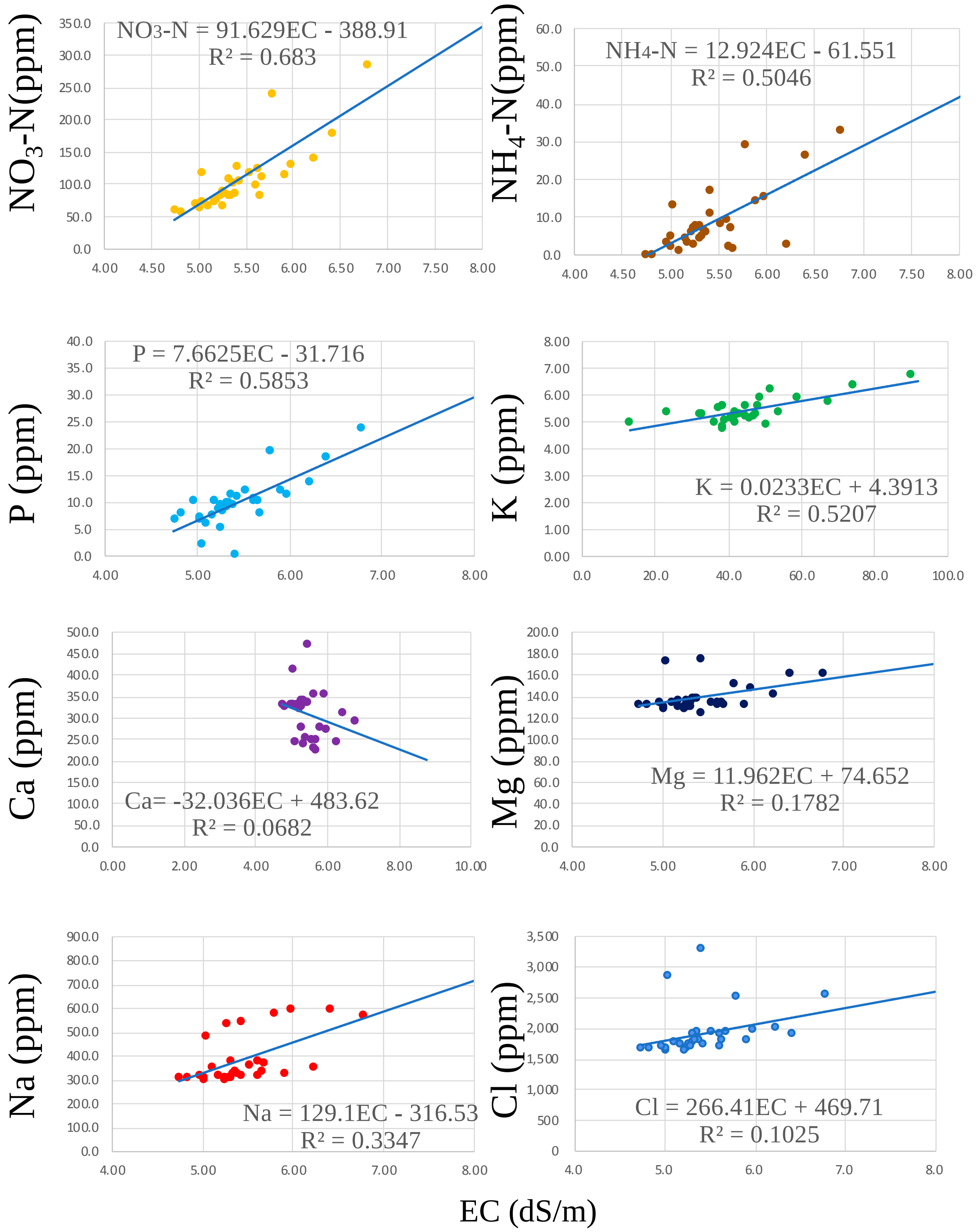


Fig.4-1 Relationship between electrical conductivity (EC) and macro nutrients concentration in aquaculture wastewater

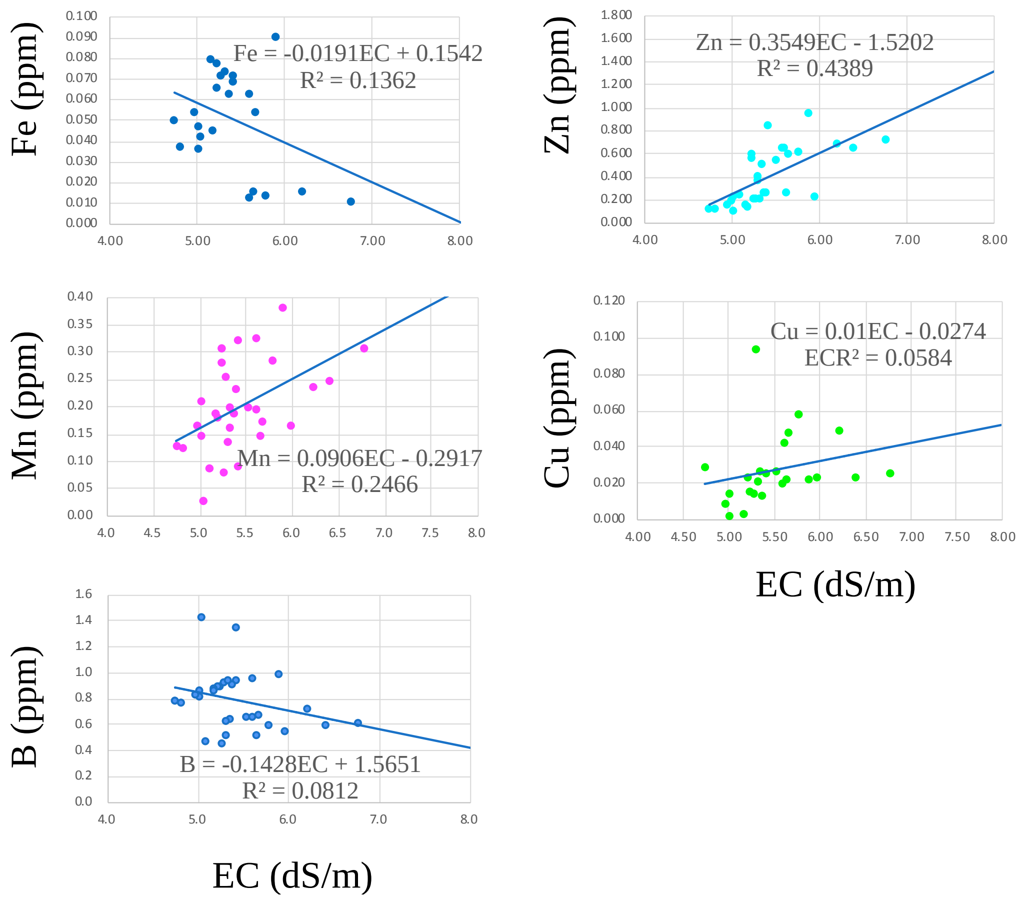


Fig.4-2 Relationship between electrical conductivity (EC) and micro nutrients concentration in aquaculture wastewater

Photo.15 Epazote top leaf exhibiting K deficiency (left; early stage, right; ternaminal stage)

10. DAILY WORK

10-1 CHECK THE AERATION

It is necessary to observe daily whether the air is supplied from the aeration tubes properly. Check every day to make sure you hear the sound of compressor. If you don't hear any sound, then check the compressor. You can say that an aeration is in good condition if the fine air comes out (Photo.16, left). When the equipment is newly installed, check whether this fine air is coming out. However, when cultivation starts and as plants grow, sometimes aeration may be too effective as the water level becomes shallow by evapotranspiration. Therefore, frequent adjustment of the aeration is required. If large water bubbles come out during the operation (Photo.16, right), it is necessary to check if the tubes are not clogged or deteriorated. Desirable dissolved oxygen amount (DO) is 6 mg/L or more for the best aeration condition. However, even when the DO value is desirable, if the floating bed is blowing white foam (Photo.17, left), the airflow is too strong, so the adjustment is required. Important note that this foam contains oil derived from the fish feed and plants will die if it adheres to the leaves (Photo.17, right).

Photo.16
Good aeration (left), and bad aeration (right)

Photo.17 Bubbles are coming out due to the excessive aeration (left). Oil slick on the lower leaves due to the foam (right)

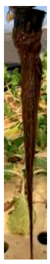


Photo.18 Healthy swiss chard root (left), poor swiss chard root (right)

When the DO is 6 mg/L or less, you need to check the root condition. When the roots are in good condition, its colors are white (Photo.18, left). When the aeration is poor, or the temperature is high, or the nutrient concentration is too high, then the roots colors may turn brown (Photo. 18, right).

When the compressor stops, the damages to the crops are very little if left without aeration only for a day or two, so repair the compressor within one or two days. Well-growing Swiss chard, purslane, seepweed, and epazote are shown in Photo.19, 20, 21 and 22.

Photo.19 Well-growing Swiss chard

Photo.20
Well-growing purslane

Photo.21 Well-growing seepweed

Photo.22 Well-growing epazote

10-2 CHECKS FOR THE PEST PREVENTION

Check the pest damages. There are many types of insect pests such as scale insects and caterpillar larvae. In the aquaculture combined with open culture, insects and/or disease occurred in open culture may affect the crops in hydroponics. Refer to 2-3-2 about insects' kind, appearances and countermeasures. Larval coccid (Photo.23-a), aphids(Photo.23-b), parmel spodoptera litura (Photo.23-c), parmel diamondback moth (Photo.23-d), and greenhouse whiteflies also found.

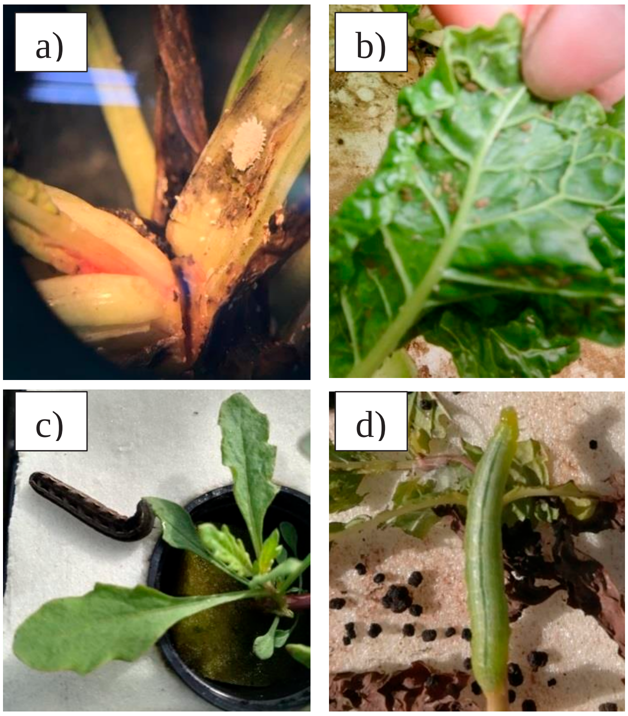


Photo.23
a) Larval coccid on the stem base of Swiss chard, b) Aphid sucking phloem sap in the reverse of Swiss chard leaves. c) Parmel spodoptera litura eating epazote. d) Parmel diamondback moth eating up leaves and scattering excrement.

10-2-1 Pre-pest management

Before transplant, immerse seedlings in a filled solution such as garlic extract. Try to use organic as possible. Since it is important to control the pest insects before they occur, prevent them from invading as much as possible by opening and closing the greenhouse doors carefully and putting nets on the door, for instance.

10-2-2 Post-pest management

Use sticky yellow insect-catching paper (Photo.24). The application of pesticides not only harms the health of farmers, but also is bad for the consumers. Also, it is necessary to pay attention to the type and the number of insects that occur depending on the seasons. At the beginning of infestation with the pests, you are able to exterminate manually by squashing by hand. If outbreak of pests were happened, then use organic pesticides (such as concentrated garlic solution). Replace crops with new seedlings if outbreak is uncontrollable.

Basically, it is the same as the countermeasures for normal open-field cultivation. Removed crop plants should not be set free in the module but to be burned down or discarded far away.

Photo. 24 Greenhouse whiteflies on yellow insect catcher
Whiteflies need to be prevented from the early stages of their growth.

11. HARVEST

11-1 SWISS CHARD

When the leaf blade becomes about 40cm, leave 2 to 3 new leaves, and cut off 2-3 remaining outer leaves from the base of the petiole with a clean blade. The cut leaves are put in a plastic bag, labeled, and shipped on that day or next day (Photo.25 and 26). At this time, especially at first harvesting poorly growing leaves are similarly cut off with a blade and discarded so the new leaves can absorb more nutrients. After the harvest, while continuing to exchange the aquaculture wastewater, repeat the harvest and cultivation approximately 8 times. Harvest outer leaves while leaving new leaves each time.

Photo.25 Swiss chard harvest

Photo.26 One bundle of swiss chard

11-2 PURSLANE

When plants grew to the market size, leave 2 to 3 young shoots and harvest the remaining shoots (Photo.27). Repeat the harvest and cultivation approximately 5 times.

Photo.27
One bundle of purslane

11-3 SEEPWEED

Harvest in the same manner as purslane. Repeat the harvest and cultivation approximately 8 times.

11-4 EPAZOTE

Harvest in the same manner as purslane. Repeat the harvest and cultivation approximately 5 times.

12. REGENERATION AFTER THE FIRST HARVEST

After harvesting, they will be re-produced (Photo.28), so return to Chapter 9, 10 and 11, and repeat the cultivation while replacing the aquaculture wastewater.

Photo.28 Regenerating Swiss chard (left) and epazote (right)

13. CLEANING

After the cultivation is completed, hydroponic wastewater is transferred into a tank for open-field cultivation by opening a valve. It is not necessary to completely empty the cultivation bed when continuing new hydroponic cultivation. For such case, cleaning is not required (Tab.7). Necessity of discarding plants and plant holders and cleaning beds are described in Tab. 5. Waste plants and culture soils can be used as a material of compost, if they were not infected by pests and/or disease during cultivation.

Tab.7 How to clean depending on the transplanting method

Transplant method	Waste	Cleaning methods and the need for cleaning
Soil	Plant wastes	Compost
	Culture soil	Compost
	Absorbent paper	Discard
	Plastic cup	Wash if needed
Sponge	Plant wastes	Compost
	Sponge	Discard
	Plastic cup	No need to wash

14. WHAT TO DO IF CROPS DO NOT GROW WELL

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Thank you so much. ARIGATOU GOZAIMASHITA.

2-3 Technical Manual for Open Culture Using Aquaponics Wastewater

2-3-1 Technical Manual for Water and Soil Management of Open Culture

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Table of Contents

This manual is written for management of crop cultivation in open fields of the Aquaponics Combined with Open Culture (ACOC) system. It consists of three parts, that is, planning, practice and maintenance. In particular, the planning part is described in detail comparing other parts, because farmers is custom to cultivation management.

1. PLANNING

1-1 PREPARATION

It is important to know a daily maximum evapotranspiration (ET_{max}) and available water of objective farm lands for planning a rational irrigation scheme. Farmers or Planners need to collect concerning meteorological and soil data.

1-1-1 Daily maximum evapotranspiration

There are two methods for estimation of ET_{max}. One is the pan evaporation method and the other is the reference evapotranspiration method. The former is better for farmers than the later, because it doesn't need any complex calculation. The later needs to several calculation procedures to obtain the reference evapotranspiration. However, it is not so difficult for farmers to use this method, because the free computer software for the calculation is released to the worldwide by the Food and Agriculture Organization of the United Nations (FAO). The basic procedure is simply explained in this manual.

(1) Pan evaporation method

In pan evaporation method, potential evapotranspiration (ET_{PAN}, mm/d) is estimated as pan evaporation, E_o (mm/d), multiplied by the evapotranspiration ratio (K_p). Although K_p is depend on season and crops, generally becomes from 0.8 to 1.2.

$$ET_{PAN} = K_p E_o \tag{1}$$

A standard apparatus of pan evaporation is a Class-A-Pan evaporimeter shown in Photo.1. It is a large pan with 120 cm diameter and 10 cm depth. They are used in many meteorological observatories which observe evaporation. Generally speaking, people can use the data for free or relative inexpensively because the official organizations like the meteorological observatory open the data to worldwide. Users can measure the pan evaporation by themselves using a small pan (20 cm diameter and 10 cm depth) in the case of no meteorological observatories near objective farmlands (Photo.2). Although the accuracy of observation of E_o using small pans is poorer than Class-A-Pan evaporimeters, it is advantage to enable to grasp local evaporation.

Photo.1 Class-A-Pan evaporimeter

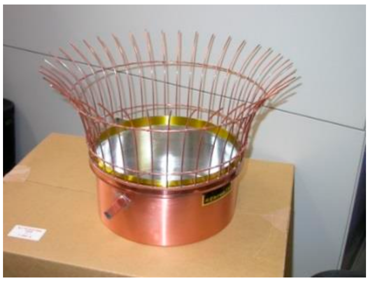

Photo.2 Small pan evaporimeter

The procedure of observation of E_o using a small pan.

[Step 1] Set a small pan horizontally and pour water to a depth of 20 mm.

[Step 2] Measure the depth, h (mm), after 24 hours.

[Step 3] E_o (mm) is calculated by Eq.(2).

$$E_o = 20 - h \qquad (2)$$

[Step 4] Return the water depth to 20 mm.

[Ex. 1] Estimation of potential evapotranspiration by pan evaporation method

Month	Days	Evaporation (mm)		ET_{PAN} Case of $K_p = 0.8$
		Monthly total	Daily total	
Jan.	31	100.7	3.2	2.6
Feb.	28	121.7	4.3	3.5
Mar.	31	166.5	5.4	4.3
Apr.	30	198	6.6	5.3
May	31	224.7	7.2	5.8
Jun.	30	238.1	7.9	6.3
Jul.	31	248.3	8.0	6.4
Aug.	31	215.8	7.0	5.6
Sep.	30	186.3	6.2	5.0
Oct.	31	167.3	5.4	4.3
Nov.	30	121.1	4.0	3.2
Dec.	31	96	3.1	2.5
Total	365	2084.5	5.7	4.6

Evaporation is observed in La Paz city in Baja California

Water depth of initial condition should be kept in constant. Water body in the pan stores radiation energy and the energy is used to evaporate the water in the pan. Therefore, when initial condition of water depth in the pan is changed, evaporation also changes. Measurement time should be also constant in the same reason.

When it rains, E_o is corrected by Eq.(3).

$$E_o = 20 - h + R \qquad (3)$$

where, R: precipitation (mm).

(2) Reference evapotranspiration method

There are many methods for estimation of reference evapotranspiration (ET_o). The Penman-Monteith method (PM_{FAO}), the Priestrly-Taylor method (PT) and the Hargreaves Method (HM) are representative methods among them. Users select them according to the type of data available. PM_{FAO} is the most popular one, because the FAO provides a free software to estimate ET_o by this method, Cropwat8.0, on the website (http://www.fao.org/land-water/databases-and-software/cropwat/en/).

1) Penman-Monteith method

It is a standard method which FAO recommends to use for estimation of evapotranspiration and much available reference data is prepared. Sunshine duration, n (h), daily maximum air temperature, T_{max} (^{0}C), daily minimum air temperature, T_{min} (^{0}C), daily mean wind velocity, U (m/s), and daily mean relative humidity, Rh (%) are at least required to estimate ET_o.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (4)$$

where, ET_o: standard evapotranspiration (mm/d), R_n: net radiation (MJ/m^2), G: soil heat flux (MJ/m^2), T: daily mean air temperature(^{0}C),u_2: daily mean wind velocity at a 2-m height (m/s), e_s, e_a: saturation vapor pressure and actual vapor pressure at T ^{0}C, Δ: slope of the saturation vapor pressure curve at T ^{0}C (kPa/^{0}C) and γ: psychrometric constant (kPa/^{0}C).

The procedure of calculation of ET_o is as follows;

[Step 1] Daily mean air temperature

T is calculated by Eq.(5) using daily maximum and minimum air temperatures.

$$T = \frac{T_{max} + T_{min}}{2} \qquad (5)$$

[Step 2] Saturation and actual vapor pressures

When the daily mean air temperature is T ^{0}C, saturation and actual vapor pressures are determined by Eqs.(6) and (7).

$$e_s = 0.611 exp\left(\frac{17.27T}{T + 237.3}\right) \tag{6}$$

$$e_a = \frac{Rh}{100} e_s \tag{7}$$

[Step 3] Net radiation

The net radiation (R_n) is determined by the global solar radiation (R_s), alvedo of the soil or canopy surface (α), and effective radiation emitted from the soil or canopy surface (R_L).

$$R_n = (1 - \alpha)R_s - R_L \tag{8}$$

R_s and R_L are estimated by Eqs.(9) and (10).

$$R_s = \left(0.25 + 0.5\frac{n}{N}\right) R_a \tag{9}$$

$$R_L = \sigma(T + 273.2)^4\left(0.34 - 0.044\sqrt{e_a}\right)\left(0.1 + 0.9\frac{n}{N}\right) \tag{10}$$

where N: daylight hours (h), R_a: extraterrestrial radiation (MJ/m^2) and σ: Stefan-Boltzmann constant (4.19×10^{-9} MJ/m^2 K^4). R_a is determined the location of sun and earth. The solar declination δ (rad), inverse relative distance Earth-Sun d_r, the latitude of the objective farmland ϕ (rad), and sunset hour angle ω_0 (rad) are given by Eqs.(11), (12) and (13)

$$\delta = 0.409 \cos\left(\frac{2\pi}{365}J - 1.39\right) \tag{11}$$

$$\omega_0 = \cos^{-1}(-\tan\emptyset \tan\delta) \tag{12}$$

$$d_r = 1.0 + 0.033 \cos\left(\frac{2\pi}{365}J\right) \tag{13}$$

where J: number of the day in the year between 1 (1 January) and 365 or 361 (December 31).

R_a is given by Eq.(14) using these values.

$$R_a = \frac{1.37 \times 10^{-3}}{{d_r}^2} \times \frac{86400}{\pi} \times (\omega_0 \sin\emptyset \sin\delta + \sin\omega_0 \cos\emptyset \cos\delta) \tag{14}$$

N is given by Eq.(15).

$$N = \frac{2\omega_0}{15} \tag{15}$$

The ET_o can be estimated by substituting the data of n, T_{max}, T_{min}, U, and Rh (%), and values estimated by Eqs.(5) – (15) into Eq.(4). When the time unit is day, G can be assumed 0 (MJ/m^2).

2) Priestrly-Taylor method

PT can be expressed as a simpler formulation than PM_{FAO}. However, the accuracy of estimation is good under the arid climate.

$$ET_{PT} = A\frac{\Delta}{\Delta + \gamma}\frac{R_n}{l} \quad (16)$$

where ET_{PT}: reference evapotranspiration of PT (mm/d), A: experimental constant (ordinarily, 1.26), l: latent heat of vaporization of water (2.439 MJ kg^{-1}).

3) Hargreaves method

When there is limitation of meteorological data obtained, HM is the effective to estimate reference evapotranspiration.

$$ET_H = 0.0023(T + 17.8)(T_{max} - T_{min})^{0.5}\frac{R_a}{l} \quad (17)$$

where ET_H: reference evapotranspiration of HM.

Crop evapotranspiration, ET_c, are calculated ET_{max} which multiplied by crop coefficient, K_c.

$$ET_c = K_c ET_{max} \quad (18)$$

K_c is not a simple constant value because it depends on the crop growth stage and wind speed. However, we can adopt maximum number for irrigation plan. Table 1 shows examples of the maximum crop coefficients. They are mainly quoted from the literature (Allen et al., 1998). When you need more information, please refer to the literature.

Tab.1 Examples of crop coefficients

Crop	K_{cMax}	Crop	K_{cMax}
Celery	1.0	Table beet	1.05
Lettuce	1.0	Sweet potato	1.10
Radish	0.90	Cowpeas	1.05
Sweet pepper	1.05	Avocado	0.85
Tomato	1.15	Chili pepper*	1.15

* refer to Shukla et al. (2016)

1-1-2 Available water

A soil moisture retention curve (SMRC) is essential to design the irrigation plan as soil information of objective farm. Comparing meteorological data, there is few data of SMRC opened to outside. Therefore, it is very difficult to obtain the data. Users usually request the measurement to the nearest research institute. The measurement of SMRC takes much time. Therefore, users should request the institute to measure only several water contents which needed to design irrigation plan. The constants are the field capacity and the wilting point. The field capacity means volumetric water content of soil corresponding to pF 1.5 to 2.0. It is defined as the soil moisture condition when gravitational drainage of root zone is over. The wilting point means volumetric water content of soil corresponding to pF 4.0 to 4.2. It is defined as the soil moisture condition when crop is wilt. When soil become dry over the wilting point, crops will die.

Crop available total amount of soil water is defined by using these water contents. It is named available water (*AW*) and is the basic value for determining the amount of irrigation water.

$$AW = \theta_{fc} - \theta_{wp} \qquad (19)$$

where θ_{fc}: field capacity, θ_{wp}: wilting point.

Readily available water (*RAW*) is adopted for water management of root zone without water stress instead of *AW*.

$$RAW = \theta_{fc} - \theta_{st} \qquad (20)$$

where θ_{st}: water content when water stress occurs in a crop. θ_{st} corresponds to pF 3 and we call it "water stress point" in this manual.

[Example 2] Calculation of available water

Conditions: Soil texture = sandy loam

Field capacity θ_{fc} = 0.210 corresponding to pF2.0
Wilting point θ_{wp} = 0.0594 corresponding to pF4.2
Water stress point θ_{st} = 0.100 corresponding to pF3.0
(Refer to Fig.1)

Available water *AW*=0.210 - 0.0594 = 0.1506
Readily available water *RAW*=0.210 - 0.100 = 0.110

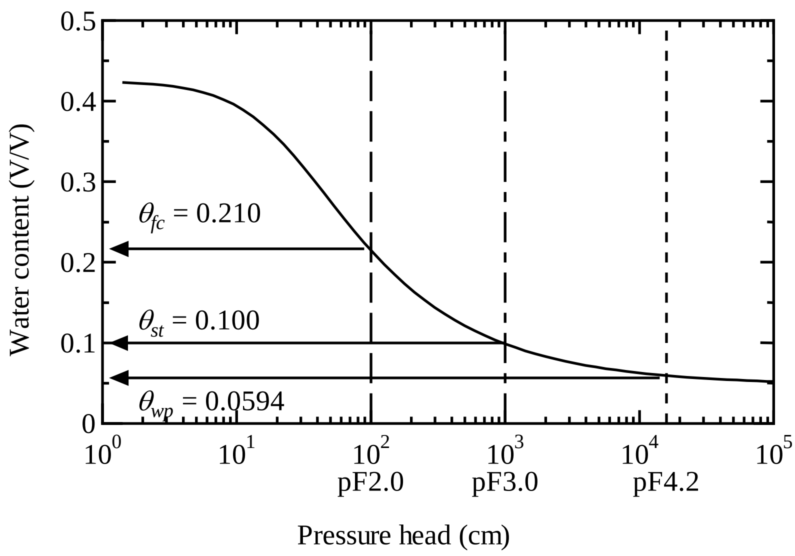

Fig.1 Soil water retention curve and soil water contents (field capacity and wilting point)

1-1-3 Soil investigation

(1) Soil salinity

Users must pay their attention to occur the salt accumulation for open cultivation under the arid climate. Soil salinity measurement should be conducted before and after cultivation.

1) Sampling

The location of sampling points of each field is shown in Fig.2. The amounts of soil sampling at a point is about 100 g. Each sample should be kept in a closed bag. Soil Sampling is conducted in 2 depths in the root zone at each point. It is desirable to collect in all irrigation plots, but if labor is difficult, a representative irrigation plot in the objective farm may be selected and surveyed.

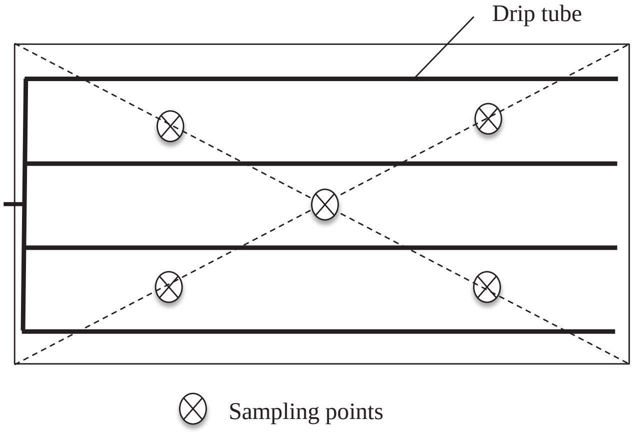

Fig.2 Soil sampling points in each irrigation plot

2) Soil drying

Sampled soil is well dried in an airy room. Air-dried soil is crashed and passed through a 2-mm sieve. The air-dried soil collected at 5 points in Fig.2 are well mixed and analyzed as representative soil sample of the plot.

3) Measurement of soil salinity

Various salts are dissolved in soil water. There is a linier relationship between the total dissolved solid concentration (TDS) and the electric conductivity of soil water (EC). Therefore, soil salinity is usually assessed using the EC measured by an electric conductivity meter (Photo.3).

Photo.3 Electric conductivity meter

When we measure soil water EC, we make soil paste or suspended water adding water into air-dried soil. According to the amount of added water, there are some measurement methods, that is, saturated extraction method, 1:2 extraction method, 1:2.5 extraction method and 1:5 extraction method. The 1:2 extraction method is explained in this manual.

In the 1:2 extraction method, the amount of added distilled water is two times of the weight of soil.

[Measurement procedure for soil water EC]

[Step 1] Observe the water content (kg/kg) of soil sample

i) Measure the weight of small amount of soil (around 5 g); M_1 (g)

ii) Dry it in the oven with 105 ℃ for 24 hours.

iii) Cool it to room temperature and measure the weight; M_2 (g)

iv) The water content, ω (kg/kg) is given by Eq.(21)

$$\omega = \frac{M_1 - M_2}{M_1} \qquad (21)$$

[Step 2] Collect the around 100 g of the target air-dried soil sample

[Step 3] Measure the weight; M_3 (g)

[Step 4] Determine the amount of added water

Very small amount of water is remained in air-dried soil. Considering the remained water, the amount of added water (Mw) is determined by Eq.(22).

$$M_W = a\frac{1}{1+\omega}M_3 \qquad (22)$$

where a = 2 in the 1:2 extraction method.

[Step 5] Make suspended water

Pour the distilled water into air-dried soil and mix it well.

[Step 6] Measure EC

Insert the probe of the EC meter into the suspended water and measure the EC (Photo.4). Stir the suspended water with the probe slowly and don't stop it during measurement. An ordinary sensor simultaneously measures water temperature, too. Record the EC and temperature of the water.

Photo.4 Measurement of EC of soil suspended water

4) Determination of cultivated crop

User can select crops which cultivated in the open field of the ACOC system. However, they need to consider the relationships between soil EC and salt tolerance of crops. They can refer the Maas's figure (Fig. 3). The x-axis of this figure is EC of soil water in saturated extraction method (EC_e). Therefore, the results obtained by the 1:2 extraction method can't be directly applied into this figure. Although it is lack of accurate, it may be possible to consider whether the target crop can be cultivated using the Maas's diagram, assuming that two times of the measurement result of the 1: 2 extraction method is the first approximation of EC in the saturated extraction method.

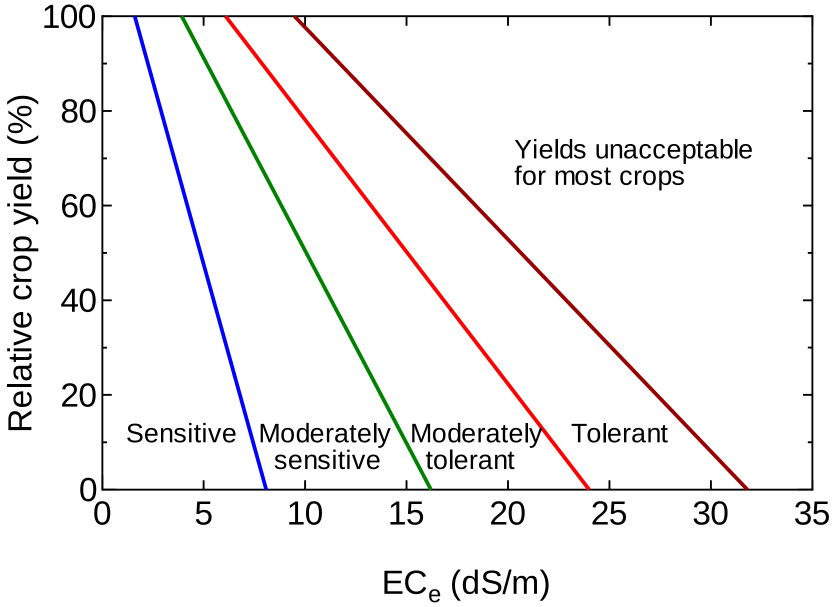

Fig.3 Relationships between salt tolerance of crops and EC of soil water (EC_e) (Maas 1984)

FAO summarized the category of main crops in the Maas's diagram (Ayers and Westcot,1985). It is quoted in Table 2.

Tab. 2 Relative salt tolerance of agricultural crops (Ayers and Westcot,1985)

TOLERANT	
Fibre, Seed and Sugar Crops	
Barley	*Hordeum vulgare*
Cotton	*Gossypium hirsutum*
Jojoba	*Simmondsia chinensis*
Sugarbeet	*Beta vulgaris*
Grasses and Forage Crops	
Alkali grass	*Puccinellia airoides*
Alkali sacaton	*Sporobolus airoides*
Bermuda grass	*Cynodon dactylon*
Kallar grass	*Diplachne fusca*
Saltgrass, desert	*Distichlis stricta*
Wheatgrass, fairway crested	*Agropyron cristatum*
Wheatgrass, tall	*Agropyron elongatum*
Wildrye, Altai	*Elymus angustus*
Wildrye, Russian	*Elymus junceus*
Vegetable Crops	
Asparagus	*Asparagus officinalis*
Fruit and Nut Crops	
Date palm	*Phoenix dactylifera*
MODERATELY TOLERANT	
Fibre, Seed and Sugar Crops	
Cowpea	*Vigna unguiculata*
Oats	*Avena sativa*
Rye	*Secale cereale*
Safflower	*Carthamus tinctorius*
Sorghum	*Sorghum bicolor*
Soybean	*Glycine max*
Triticale	*X Triticosecale*
Wheat	*Triticum aestivum*
Wheat, Durum	*Triticum turgidum*
Grasses and Forage Crops	
Barley (forage)	*Hordeum vulgare*
Brome, mountain	*Bromus marginatus*
Canary grass, reed	*Phalaris, arundinacea*
Clover, Hubam	*Melilotus alba*
Clover, sweet	*Melilotus*
Fescue, meadow	*Festuca pratensis*
Fescue, tall	*Festuca elatior*
Harding grass	*Phalaris tuberosa*
Panic grass, blue	*Panicum antidotale*
Rape	*Brassica napus*
Rescue grass	*Bromus unioloides*
Rhodes grass	*Chloris gayana*
MODERATELY TOLERANT (cont.)	
Grasses and Forage Crops	
Ryegrass, Italian	*Lolium italicum multiflorum*
Ryegrass, perennial	*Lolium perenne*
Sudan grass	*Sorghum sudanense*
Trefoil, narrowleaf birdsfoot	*Lotus corniculatus tenuifolium*
Trefoil, broadleaf	*L. corniculatus arvenis*
Wheat (forage)	*Triticum aestivum*
Wheatgrass, standard crested	*Agropyron sibiricum*
Wheatgrass, intermediate	*Agropyron intermedium*
Wheatgrass, slender	*Agropyron trachycaulum*
Wheatgrass, western	*Agropyron smithii*
Wildrye, beardless	*Elymus triticoides*
Wildrye, Canadian	*Elymus canadensis*
Vegetable Crops	
Artichoke	*Helianthus tuberosus*
Beet, red	*Beta vulgaris*
Squash, zucchini	*Cucurbita pepo melopepo*
Fruit and Nut Crops	
Fig	*Ficus carica*
Jujube	*Ziziphys jujuba*
Olive	*Olea europoea*
Papaya	*Carica papaya*
Pineapple	*Ananas comosus*
Pomegranate	*Punica granatum*
MODERATELY SENSITIVE	
Fibre, Seed and Sugar Crops	
Broadbean	*Vicia faba*
Castorbean	*Ricinus communis*
Maize	*Zea mays*
Flax	*Linum usitatissimum*
Millet, foxtail	*Setaria italica*
Groundnut/peanut	*Arachis hypogaea*
Rice, paddy	*Oryza sativa*
Sugarcane	*Saccarum officinarum*
Sunflower	*Helianthus annuus*
	palustris
Grasses and Forage Crops	
Alfalfa	*Medicago sativa*
Bentgrass	*Agrostisstoloniferapalustris*
Bluestem, Angleton	*Dichanthium aristatum*
Brome, smooth	*Bromus inermis*
Buffelgrass	*Cenchrus ciliaris*
Burnet	*Poterium sanguisorba*
Clover, alsike	*Trifolium hydridum*

MODERATELY SENSITIVE (cont)

Grasses and Forage Crops

Clover, Berseem	*Trifolium alexandrinum*
Clover, ladino	*Trifolium repens*
Clover, red	*Trifolium pratense*
Clover, strawberry	*Trifolium fragiferum*
Clover, white Dutch	*Trifolium repens*
Corn (forage) (maize)	*Zea mays*
Cowpea (forage)	*Vigna unguiculata*
Dallis grass	*Paspalum dilatatum*
Foxtail, meadow	*Alopecurus pratensis*
Grama, vlue	*Bouteloua gracilis*
Lovegrass	*Eragrostis sp.*
Milkvetch, Cicer	*Astragalus cicer*
Oatgrass, tall	*Arrhenatherum, Danthonia*
Oats (forage)	*Avena sativa*
Orchard grass	*Dactylis glomerata*
Rye (forage)	*Secale cereale*
Sesbania	*Sesbania exaltata*
Siratro	*Macroptilium atropurpureum*
Sphaerophysa	*Spoerophysa salsula*
Timothy	*Phleum pratense*
Vetch, common	*Vicia angustifolia*

Vegetable Crops

Broccoli	*Brassica oleracea botrytis*
Brussel sprouts	*B. oleracea gemmifera*
Cabbage	*B. oleracea capitata*
Cauliflower	*B. oleracea botrytis*
Celery	*Apium graveolens*
Corn, sweet	*Zea mays*
Cucumber	*Cucumis sativus*
Eggplant	*Solanum melongena esculentum*
Kale	*Brassica oleracea acephala*
Kohlrabi	*B. oleracea gongylode*
Lettuce	*Latuca sativa*
Muskmelon	*Cucumis melon*
Pepper	*Capsicum annum*
Potato	*Solanum tuberosum*
Pumpkin	*Cucurbita peop pepo*
Radish	*Raphanus sativus*
Spinach	*Spinacia oleracea*
Squash, scallop	*C. pepo melopepo*
Sweet potato	*Ipomoea batatas*
Tomato	*Lycopersicon lycopersicum*
Turnip	*Brassica rapa*
Watermelon	*Citrullus lanatus*

MODERATELY SENSITIVE (cont.)

Fruit and Nut Crops

Grape	*Vitis sp.*

SENSITIVE

Fibre, Seed and Sugar Crops

Bean	*Phaseolus vulgaris*
Guayule	*Parthenium argentatum*
Sesame	*Sesamum indicum*

Vegetable Crops

Bean	*Phaseolus vulgaris*
Carrot	*Daucus carota*
Okra	*Abelmoschus esculentus*
Onion	*Allium cepa*
Parsnip	*Pastinaca sativa*

Fruit and Nut Crops

Almond	*Prunus dulcis*
Apple	*Malus sylvestris*
Apricot	*Prunus armeniaca*
Avocado	*Persea americana*
Blackberry	*Rubus sp.*
Boysenberry	*Rubus ursinus*
Cherimoya	*Annona cherimola*
Cherry, sweet	*Prunus avium*
Cherry, sand	*Prunus besseyi*
Currant	*Ribes sp.*
Gooseberry	*Ribes sp.*
Grapefruit	*Citrus paradisi*
Lemon	*Citrus limon*
Lime	*Citrus aurantifolia*
Loquat	*Eriobotrya japonica*
Mango	*Mangifera indica*
Orange	*Citrus sinensis*
Passion fruit	*Passiflora edulis*
Peach	*Prunus persica*
Pear	*Pyrus communis*
Persimmon	*Diospyros virginiana*
Plum: Prune	*Prunus domestica*
Pummelo	*Citrus maxima*
Raspberry	*Rubus idaeus*
Rose apple	*Syzgium jambos*
Sapote, white	*Casimiroa edulis*
Strawberry	*Fragaria sp.*
Tangerine	*Citrus reticulata*

(2) Soil pH

Soil pH is the very important factor for crop cultivation as same as soil EC. When the soil pH of the designed farm land is out of adequate value, we need to improve the soil pH using $CaSO_4$ or $Ca(OH)_2$.

The measurement of soil pH is almost same of soil EC except using a pH meter (Photo.5). After measuring soil EC, same suspended water can be used for measurement of the soil pH.

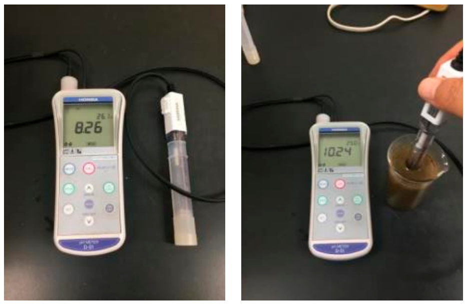

Photo.5
pH meter and measurement of soil pH

1-2 DESIGN OF IRRIGATION PLAN

1-2-1 Determination of daily maximum consumptive use

Consumptive use (*CU*) means the amount of depletion of soil water in a root zone and is defendedbyEq.(23).

$$CU = ET - C_w \qquad (23)$$

where C_w: capillary raised water from soil layer lower than a root zone. Although the C_w should be considered in an irrigation plan under the monsoon climate, it can be assumed C_w=0 under the arid climate. Therefore, it can be consider C*U*=*ET*. Therefore, daily maximum consumptive use, CU_{max}, are given by Eq.(24).

$$CU_{max} = ET_c \qquad (24)$$

1-2-2 Determination of the amount of each irrigation

There are two methods for determination of the amount of each irrigation. One is assumed that soil water of a root zone is uniformly consumed through the whole zone, another is assumed that *CU* is different in each soil layers in the root zone. The difference of *CU* in each soil layer is called soil moisture extraction pattern (SMEP). The former is explained in this manual.

If irrigation is conducted when soil water of the root zone reach the wilting point, the amount of each irrigation (*i*) is determined by Eq.(25)

$$i = AW \times D = (\theta_{fc} - \theta_{wp})D \qquad (25)$$

where *D*: the thickness of the root zone (mm).

If water management of root zone is conducted within no water stress condition, irrigation is performed at the timing which the water content of root zone reaches the water stress point. In this case, the amount of each irrigation (i_s) is given by Eq.(26).

$$i_s = RAW \times D = (\theta_{fc} - \theta_{st})D \qquad (26)$$

[Example 3] Under the condition of the example 2, the thickness of the root zone is 200mm. i=0.1506×200=30.12 (mm), i_s=0.110×200=22.0 (mm)

1-2-3 Determination of irrigation interval

Irrigation intervals (n_i and n_s) are determined by following equations.

$$n_i = \frac{i}{CU} \tag{27}$$

$$n_s = \frac{i_s}{CU} \tag{28}$$

[Example 4] ET_c=6.4 (mm) from example 1, and CU_{max}=6.4 (mm) from example 3

$$n_i = \frac{30.1}{6.4} = 4.7$$

$$n_s = \frac{22}{6.4} = 3.4$$

The irrigation interval is 4 days in the case that the all of available water is consumed during the interval and it is 3 days in the case that the root zone is controlled without water stress.

1-2-4 Determination of irrigable area

In the ordinary field irrigation planning, required amount of water are acquired and irrigation facilities are designed, according to the field area which we will irrigate. However, we need to take the reverse procedure for ACOC system, because the amount of water resource is limit in this system. Moreover, it is need to consider that there is a time interval when the effluent from the hydroponic zone is supplied into the irrigation tank for open fields.

When you conduct the field water management without water stress for crops, available irrigation area A_{irr} (m^2) is given by the following equation, the amount of each irrigation

$$A_{irr} = \frac{V}{i_s \times \frac{m}{n_s} \times 10^{-3}} \tag{29}$$

where V (m^3): amount of irrigation water which enable to be supplied from the hydroponics zone, m (d): time interval when the water is supplied into the tank, i_s (mm): the amount of each irrigation when water stress in crop doesn't occur.

[Example 5] When the irrigation water of 5 m^3 is prepared in every week under the condition of i_s of 22.0 (mm) and n_s of 3 (d), A_{irr} is determined as follows;

$$A_{irr} = \frac{V}{i_s \times \frac{m}{n_s} \times 10^{-3}} = \frac{5}{22 \times \frac{7}{3} \times 10^{-3}} = 97.4 \quad (m^2).$$

1-2-5 Design of irrigation facilities

(1) Number of drip tubes

A drip tube has small holes called emitters through which water drops fall. A drip tube forms circular or banded wet areas according to an irrigation rate and a distance between emitters. Point source type of drip tubes form circular wet zones. Line source type form banded wet zones. The circular wet area changes to the banded one, when the irrigation time is enough long and the irrigation rate is sufficient large. Therefore, here we explain line source type of drip irrigation.

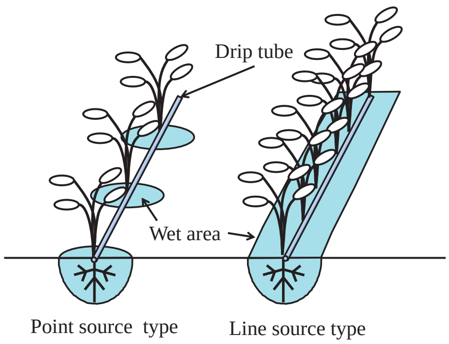

Fig.4
Types of wet area formed by a drip tube
(Inosako, 2014)

The number of drip tubes, m_D, which can be installed into the field of size of the long of L_f and the wide of W_f is determined by Eq.(30).

$$m_D = \frac{L}{L_f} = \frac{A_{irr}}{L_{wet} \times L_f} \tag{30}$$

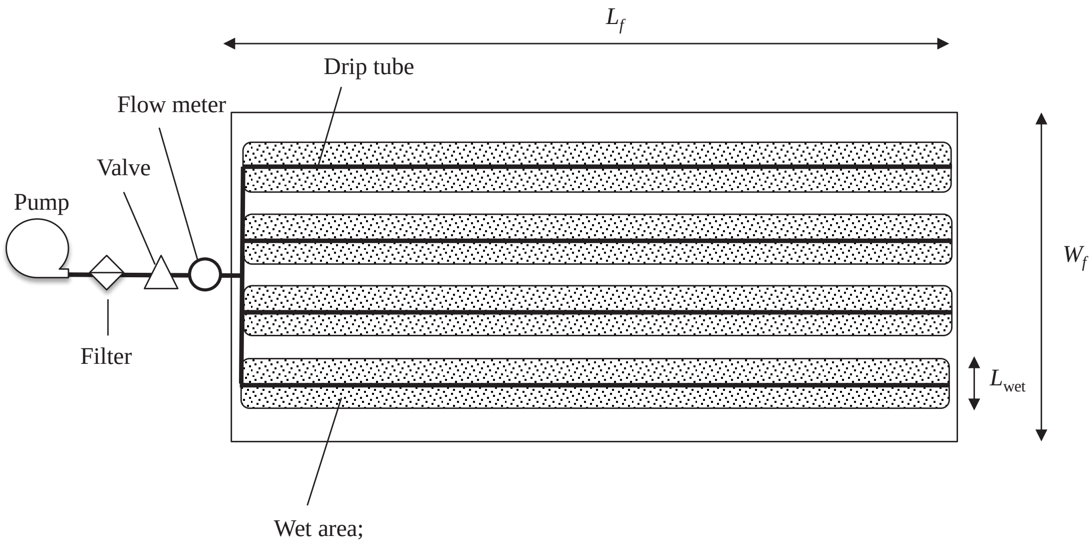

Fig.5 Example of location of irrigation facilities

where L_{wet} (m): the wide of wet area formed by a drip tube, L (m):the total length of drip tubes, defined by $L=A_{irr}/L_{wet}$. Fig.5 shows an example for location of drip irrigation facilities. However. we need to consider various farm works, for example, seeding or planting, pesticide spraying, harvesting and so on, when we actually determine the distance of drip tubes and the number of tubes.

[Example 6] When L_{wet} is 0.4 m and L_f is 25 m under the condition of the example 5,

$$m_D = \frac{A_{irr}}{L_{wet} \times L_f} = \frac{97.4}{0.4 \times 25} = 9.74$$

That is, 9 drip tubes can be settled in this irrigation field.

(2) Irrigation facilities

Fig.5 shows an example of the location of irrigation facilities of the open field in the ACOC system. As irrigation water is conveyed in drip tube from a storage tank to an open field by a pump, it is essential to set a filter for protection of tube clogging. A valve is installed at the downstream side of filter and it is closed to stop irrigation if necessary. If you use an electromagnetic valve, you can control automatically the irrigation system. If the pressure of pump you can use is too large, a pressure regulator should be installed in the irrigation line. The flow meter is essential to control the amount of irrigation water and keep the soil water condition adequately.

2. PRACTICE - GUIDELINE OF OPEN CULTIVATION

Basic procedure for open cultivation is as follows;

[Step 1] Tilling soil and make ridges

[Step 2] Locating of irrigation systems

Set irrigation systems into the field following the irrigation plan.

[Step 3] Conducting a test run of the irrigation system and determination of irrigation time

Check for the leak of irrigation line and the clogging of emitters in test run, and determine the adequate irrigation time to supply the designed amount of water to the field.

[Step 4] Seeding or planting

[Step 5] Management of irrigation

Above mentioned, the irrigation intervals of some days are set in irrigation plan. You can increase irrigation days instead of decreasing the amount of each irrigation water and the irrigation interval. It called a high-frequent irrigation with small amounts of water. In a drip irrigation, increase of the amount of each irrigation sometimes cause the excess wet condition in soil under emitters. As result, it may increase irrigation water percolating into lower than the root zone. The high-frequency irrigation with small amounts of water can avoid this situation. Therefore, it is adequate for a saving-water irrigation.

A manager of the field must record the following information; i) the irrigation date, ii) the start time of irrigation, iii) the stop time of irrigation, iv) the flow meter value at the start time, v) the flow meter value at the end time. Moreover, calculate the duration and amounts of each irrigation on data sheet (refer to Table 3). It is an effective countermeasure for protection of miss-reading of flow meter values to take picture of flow meters.

[Step 6] Harvesting

The date and yield must be recorded by a manager.

Tab.3 Example of a record sheet for irrigation

Date	Irrigation time		Duration of Irr. (min)	Flow meter (m^3)		Amount of Irr. (m^3)
	Start	End		Start	End	
2019/9/10	10:00	11:00	60	32.0427	32.1000	0.0573

3. MAINTENANCE

3-1 SALINITY CONTROL

3-1-1 Salinity monitoring after each cultivation

Salt accumulation should alway be paid attention in open cultivation in arid/semi-arid regions. Photo.6 is a picture taken soil surface near an emitter of drip tube in open field in the Takramakan desert. A circular salt crust clearly appears on the soil surface. It is corresponded to a trace of wet area generated by drip irrigation. Although salt accumulation such as Photo.6 does not appear for irrigation period, salts are often concentrated on the soil surface at the edge of the wet area.

Photo.6
Salt accumulation near a emitter of a drip tube in the Takramakan desert
(Saito T., 2006. March 5th)
(Inosako, 2014)

Rich fertilizer contents and various salts are dissolved in the irrigation water prepared in the ACOC system. Therefore the measurement of soil salinity is expected after harvesting. Soil sampling in that case does not need to be performed on the entire field as shown in Fig.2. As shown in Fig.6, soil sampling is carried out 4 points. Salinity measurements are followed the procedure explained in Sec.1-1-3.

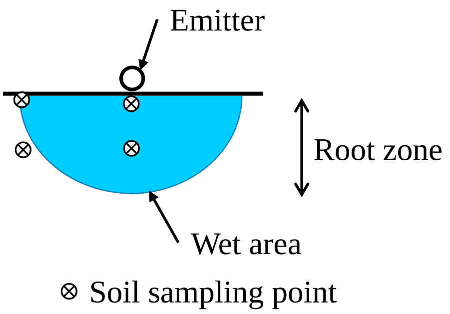

Fig.6
Soil sampling point after a crop cultivation period

3-1-2 Removal of salts

Threshold of soil EC in a root zone should be determine to control soil salinity condition. If measurement of soil EC after cultivation is over the threshold, field managers should remove salts from a root zone. Relative crop yield which corresponded to the salt tolerance of crops in Fig.3 can be adopted as one of thresholds. For example, when soil EC reaches the EC_e of the relative yield of 90%, field managers takes a countermeasure for removal salts from their fields. Their examples are shown in the website of FAO, http://www.fao.org/3/T0234E/T0234E03.htm or the literature (Ayers and Westcot,1985).

Leaching is the most popular method for removal of salt from farm lands. Amounts of water for leaching can be estimated by Eq.(31) using “Leaching Requirement, *LR*”.

$$I_t = CU_t + W_L = \frac{CU_t}{1 - LR} \tag{31}$$

where CU_t is total consumptive water use for a cultivation period.

LR is defined using EC of irrigation water, EC_{iw}, and EC of drainage water, EC_{de}.

$$LR = \frac{EC_{iw}}{EC_{de}} \tag{32}$$

Rhoades (1974) proposed a simple estimation method of LR using average EC_e of a root zone at the tolerable degree of yield depletion of 10%.

$$LR = \frac{\sigma_w}{5\sigma_{e90} - \sigma_w} \tag{33}$$

where σ_{e90} (dS/m): EC_e at relative yield of 90%, σ_w (dS/m): EC of irrigation water.

[Example 7] Estimation of the amount of irrigation water considering amount of leaching water

Conditions: Crop is Cowpea, EC of irrigation water is 4dS/m,

Relative yield of 90% of Cowpea is 5.7 dS/m after FAO website.

LR can be calculated by Eq.(33).

$$LR = \frac{4}{5 \times 5.7 - 4} = 0.163$$

When CU_t is assumed 600 mm,

$$I_t = \frac{600}{1 - 0.163} = 716.8 \quad \text{(mm)}.$$

When A_{irr} is assumed 97.4m^2 such as the example 5,

$$I_t = 97.4 \times 0.7168 = 69.8 \quad (\text{m}^3).$$

This A_{irr} can be determined under the condition that the amounts of irrigation water is prepared 5 m^3 per week. The total amount of supplied irrigation water for 90 days is 5×90/7=64.3 (m^3). There is a lack of 5.5 m^3 for total amounts of irrigation required. It is necessary to secure the shortage separately for sustainable agriculture in ACOC system.

3-2 GROUND WATER MANAGEMENT

When the ground water level less than 2 m in arid region, soil water moves from the ground water surface to the root zone by capillary raise. The capillary raise has positive effects on water-saving irrigation. On the other hand, when the salt concentration of ground water is high, the risk of salt accumulation increases, because many salts conveyed from ground water to root zone with soil water.

Installation of an underdrainage system is an effective approach to decrease groundwater level in farmland. However, the existence of deep drainage channels are absolutely needed that an underdrainage system shows the effect.

In flat fields where underdrainage systems cannot be installed, it is useful to suppress capillary rise by laying a layer with coarse materials below the root zone. The phenomenon which the coarse layer prohibits soil water movement is named as a capillary barrier and this method is called the capillary barrier method.

[Example 8] In the field where sandy loam soil layer of a 50-cm thick laid on a light clay soil layer, cultivation experiments were conducted in the CB zone with a gravel layer of a 10-cm thick and the control zone without a gravel layer (Fig.7). Although ground water level were usually more than a 1-m deep from soil surface, it reached a 50-cm deep from soil surface in the shallowest case.

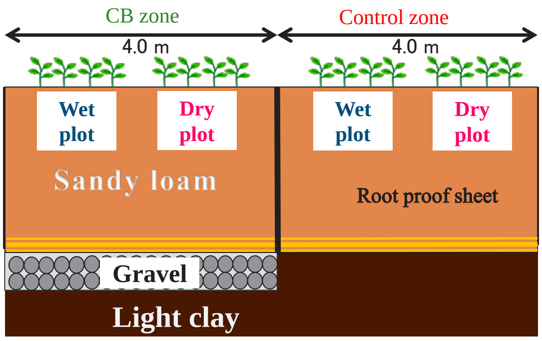

Fig.7 Soil profile of capillary zone and control.

Crop was capsicum and has the root zone of a 20-cm deep. Two irrigation treatments were installed into each zone. Available water of 30 % was irrigated to the wet plot when the crops consumed the same amounts of soil water. When the soil water condition at a 15-cm deep reached pF3.0, the available water of 30% were irrigated in the dry plot.

Total amounts of irrigation waters are the wet plot in the CB zone was 82mm, the dry plot in the CB zone was 24mm, the wet plot in the control zone was 51mm, and the dry plot in the control zone was 4.4mm, respectively. The difference of the total amounts of irrigation means the difference of the amounts of capillary rise from lower soil layer. Fig.8 shows the water balance in the sandy loam layer of each plot. Percolating loss of water was large in the wet plot in the CB zone. It means this treatment was an excess irrigation. Comparing both dry plots of the CB zone and the control zone, the amounts of capillary rise of the control zone are much larger than the CB zone. It is cleared that the effect of barrier of the gravel layer is very great to protect capillary rise. It is indicated that the capillary barrier method is effective for suppressing the soil water movement from groundwater.

It depend on the EC of groundwater whether this method is adopted or not. When the EC is low, this method should not be installed into the field because capillary rise from groundwater has effect on water-saving irrigation. On the other hand, in the case of groundwater of high EC, the method can be an option to block salt accumulation by the capillary rise. However, shown in Fig.8, when the groundwater level reaches the upper of the coarse layer, this method lose the barrier effect. Therefore, the installation depth needs to be determined carefully considering the past groundwater level fluctuations.

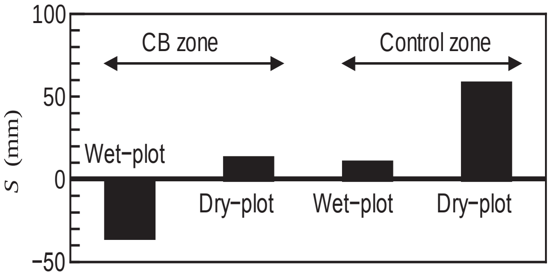

Fig.8 Water balance of sandy loam layers

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2-3-2 Technical Manual for Chili Pepper Production

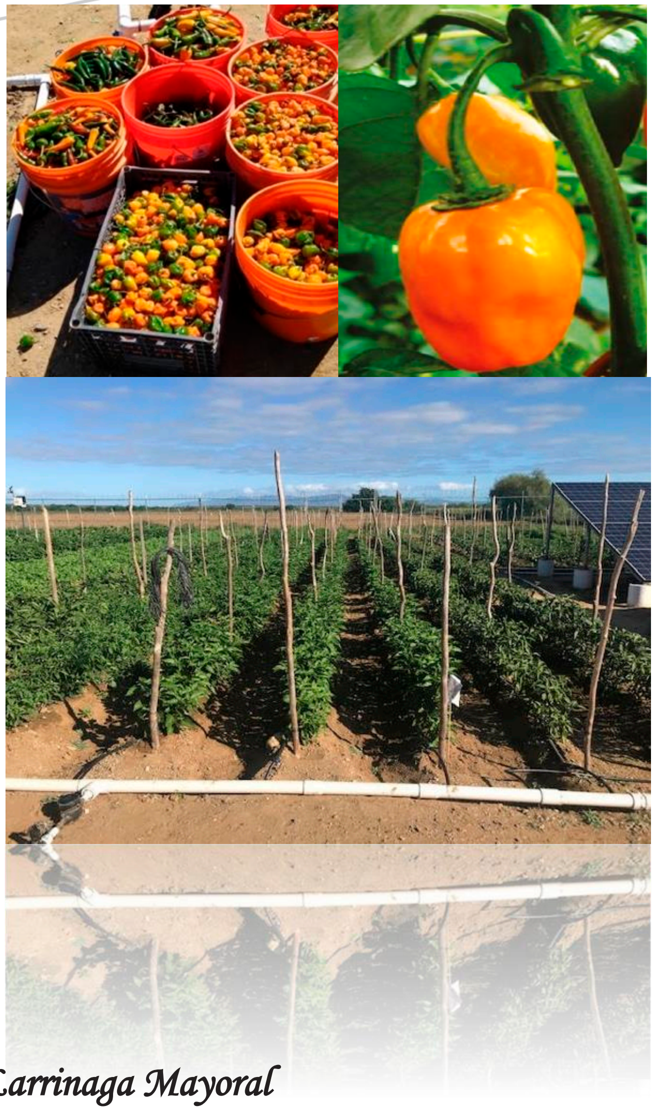

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Table of Contents

1. FOREWORD

In the State of Baja California Sur, agriculture for several years is a traditionalist activity despite presenting a series of problems, mainly related to the availability and quality of water for irrigation. A constant depletion of the aquifer, saline intrusion and high costs of extraction and production, causing severe effects on crop development, mainly due to the scarcity of the hydrological resources and the increase in the salinity of irrigation water and soil, that have impoverished agro-ecosystems.

For the State of Baja California Sur (B.C.S.), agriculture is an important economic activity. However, constant depletion of aquifers, saline intrusion, and the high cost of water extraction have severely hit the local agricultural economy.

Among the vegetables grown in B.C.S., chili pepper is a common crop, with around 2000 hectares dedicated to cultivate each year. However, chili pepper cultivation using water-saving measures requires a large amount of labor, technification, and crop knowledge. In addition, chili pepper requires large amounts of water at certain stages of development, which is difficult to achieve in arid areas. One way to conserve hydrological resources is the use of advanced water-saving measures such as pressurized drip irrigation.

Vegetable crops require significant amounts of water due to their natural constitution. The cultivation of any plant in arid areas is not only affected by the rainy season and the dry season, but the success of the crops will depend on the water supply in the critical stages of crop development.

Among horticultural crops, chili is the most important. Mexico is the country with the greater genetic variety of Capsicum, which is produced in the 32 states of the Republic. The main producing states are: Chihuahua, Sinaloa, Guanajuato, Zacatecas and Sonora. The most cultivated varieties are jalapeño, serrano, poblano, morron and habanero. Chili pepper is planted in around 150,000 hectares in the country and produced with more than two million tons of dried and green chile annually. This means a commercial value of approximately 13,224 million pesos. Mexico ranks as the main exporter chili green internationally and occupies the second largest producer in the world. The country is divided into six producing zones of chili green, which are different in the type of planted pepper. 1. In the Gulf area (Veracruz and Tamaulipas) jalapeños and serranos are produced mainly. 2. In the south (Yucatan and Tabasco) there are jalapeños, coastal and habanero; 3. In the Bajío area (Guanajuato, Jalisco and Michoacán), poblanos (anchos), mulatto and pasilla; 4. In the central Mexico (Puebla and Hidalgo) they specialize in poblanos, miahuatecos and carricillos; 5. In the north (Chihuahua and Zacatecas) they produce jalapeños, sunflower and widths; 6. In the North Pacific area (Baja California, Sinaloa and Sonora) they have bell, anaheim, jalapeños and caribes.

Main chili peppers grown in Mexico.

Poblanos. It is used as an ingredient at making mole and dyes; it is green chili and is the base of the typical and famous Mexican dish of “chiles en nogada”. Producing areas: Guanajuato, San Luis Potosí, Durango, Aguascalientes, Zacatecas, Sinaloa, Nayarit, Jalisco and Puebla.

Chili de arbol. In fresh matter and dried matter, it is given the same name and it is one of the types of chili that are used either for fresh or dried. It is very spicy and the most widely used variety for making sauces. Producing states: Jalisco, Nayarit, Aguascalientes, Zacatecas, Chihuahua and Guanajuato.

Chili Chilaca. It is called chilaca at the green matter and pasilla at the dried matter. I know it is another of the most used chili species in Mexico. Although it is also consumed fresh, it prefers you in a dry state. It has moderate itching and it is one of the basic ingredients of moles and marinades, and also it is made with countless sauces. Production areas: Aguascalientes, Jalisco, Guanajuato, Querétaro, Zacatecas, San Luis Potosí, Michoacán, Nayarit and Oaxaca.

Chili Mirasol. When it dries, it changes the name to guajillo. It is a chili that is used mainly in the dry state to make moles, marinades and sauces. It is little spicy. Producers: Aguascalientes, Zacatecas, San Luis Potosí and Durango.

Chili Güero. In fresh it is known as güero or Hungarian Caribbean, dried as chilhuacle. It is one of the chilis less spicy than normally consumed in Mexico. Generally, it is used integer; for example, you fill with a dogfish or used for Veracruz style fish.

Baja California Sur is the State with extensive areas that offer a potential of resources for the agricultural exploitation with technology oriented to the control of irrigation water. The use of pressurized irrigation system is the most appropriate for agriculture in arid areas.

B.C.S. has many valleys and plains that are well adapted to farming using advanced water saving measures. Adequate agricultural areas, such as the Vizcaíno valley in the north of B.C.S., the Santo Domingo valley located in the center of B.C.S., and the valleys of La Paz, Los Planes, Todos Santos and Carrizal, located in the south of B.C.S., all are characterized by their geographical isolation and low relative humidity, which are useful for the production of high quality crops.

2. INTRODUCTION

Chili pepper is native to the temperate regions of the Americas and was introduced into Europe in 1514 by Spanish and Portuguese navigators. There is currently a lot of confusion among scientists regarding the classification of chili pepper plants, among the species and C. capsicum, C. ftutnces, C. pubenses, C. chinenses and, at present, there is only a very broad classification. Therefore, to classify it in a simple way, there are spicy chilies, those spicy chilies such as those with spikey shape and with a strong and spicy flavor. Botanists group within the same species, *Capsicum annuum* L., because all chili pepper cultivars are perfectly interfertile.

Chili pepper is a very profitable crop, with the product being used fresh, dried, or canned. Average yields range from 25 to 40 t/ha, but with adequate field management, yields can be achieved up to 50 t/ha. Chili pepper grows well in arid climates under drip irrigation management, because the saving water is a main objective for the vegetal production in arid areas, and it can grow in soils with an electrical conductivity of four microsiemens/cm (dS/m) at maximum.

In the past two decades, the efficiency of chili pepper production in B.C.S. has markedly improved: from an average of 16.6 t/ha in 2000-2010 to 25.5 t/ha in 2010-2018 according to Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA). Currently, cropping in B.C.S. is changing toward a greater focus on horticultural crops such as chili pepper, tomato, and asparagus, as well as aromatic herbs, for export to the USA. With this change in the "crop pattern", agriculture in the B.C.S. desert will need to adjust the policy of water use in the field, defining the volumes of water authorized for agricultural activity. With this change in the “patron” of cropping, agriculture in B.C.S. will need to use strict rules for the water irrigation.

In this manual we describe the cultivation of chili pepper, mainly the common cultivars Serrano, Habanero, and Jalapeño, in arid areas by using effluent water from an aquaponics system (mentioned in an aquaculture and hydroponic section of main document) located in Los Planes, B.C.S.. Such effluent is loaded with plant nutrients. This technology is applicable for use by small to medium-scale producers that supply local markets, and can be a useful means of increasing self-sufficiency in remote areas by acting as a source of both fish and vegetables. The information presented here will be useful for growers in other areas with adaptations to the local situation.

3. LAND SELECTION

Chili pepper can be grown in a wide range of soils, ranging from sandy, sandy-silty, or silty to soils rich in humus. However, it needs good drainage because its roots are sensitive to low oxygen, and excessive amounts of nitrogen should be avoided because it can reduce yield. Therefore, when selecting land, it is necessary to conduct a soil analysis to determine the nitrogen, phosphorus, potassium and other minerals to know the concentration and can adjust the recommended levels for the crop and pH in the soil. The most appropriate pH is 6.3-6.8, at which nutrient availability is greatest.

4. SOIL IMPROVEMENT

Organic matter improves the physical structure and chemical composition of soil, prevents from compaction, facilitates cultivation by improving soil structure and improving soil fertility mainly. Materials of plant or animal origin, such as manure or plant residues, decomposed by the action of microorganisms, can be incorporated into soil to enhance physical conditions and nutrient availability, and improve moisture retention capacity.

4-1 COMPOST APPLICATION

Compost made from animal or plant materials is a useful source of nutrients and organic matter. In the study area, the organic matter content level is almost zero in the desert soil, ranging from 0.1 to 0.4% of organic matter. To improve the fertility condition in the soil, it is recommended to apply 10-20 t of compost per hectare per year before planting and incorporate it in the upper 15 cm of the soil layer. To significantly increase crop yield, large quantities more than 20 ton/ha of compost are necessary. However, smaller amounts still improve soil structure and help plant growth.

5. LAND PREPARATION

Preparation of land for chili pepper cultivation typically involves plowing, harrowing to break up large soil clods and incorporate plant residues, and leveling to improve surface irrigation. Land preparation begins after the last harvest or during fallow. The goal is to provide seedlings with the most favorable conditions for development. The operations needed differ according to the type of soil, the available machinery, and the history of the field with the previous harvest completed. The tasks essential for good soil preparation are described below.

5-1 SUBSOILER

Over-irrigation, the accumulation of salts from over-fertilization, and the use of heavy machinery can cause the subsoil to become compacted over time, which reduces the arable layer, makes it difficult to aerate the soil, and decreases water penetration, resulting in poor root development. Therefore, for medium to heavy soils it is advisable to perform subsoiler every 3 or 4 years. The subsoiler reaches down below the ploughing depth to break up a compacted layer that is beyond the reach of normal tillage equipment. The operation serves to form cracks that will improve infiltration rates and root penetration. The working depth of the subsoiler should be decided according to the compaction that has been identified and the soil moisture content at this depth. In sandier soils, this practice is usually not as important.

5-2 PLOWING

Plowing is conducted to turn over the arable layer, which improves the soil structure, promotes moisture retention, increases aeration, and allows for weathering of the soil. The plowing should be done at a depth that allows complete turning of the earth, usually 25-30 cm, with a disc type of plow; however, it is recommended that the depth be varied each year to avoid the formation of compact layers. It is important to make the plow when there is low residual moisture in the soil so as not to compact and destroy the soil structure.

5-3 TRACKING

Once the soil is plowed, tracks perpendicular to the direction in which the soil was plowed are traced at a depth of 10-20 cm to break up any large clods that remain. This results in a soft “bed” of soil that facilitates seed germination and seedling emergence. If the ground is still not soft, a second harrowing step can be performed perpendicular to the first. In soils where the clods after the plowing are small and easily broken apart, tracking is unnecessary.

5-4 LEVELING

The leveling or flattening of the plane of the soil surface is of great importance to achieve a good watering of the surface and avoid waterlogging, thus promoting plant development. This practice is recommended for soils whose slopes are greater than 0.1% (10 cm/100 m) and can be achieved using the tractor with a rail, plank to form a uniform surface.

On soils with a sandy texture and a slope of less than 0.1%, it is recommended to use a board or thick board with the harrow to improve the seedbed. If drip irrigation is used, it is not necessary to level, so you can cultivate land with higher slopes.

5-5 FURROWING

The spacing between furrows depends mainly on the cultivar, the soil texture, and the available machinery. For chili pepper, a distance of 0.90 m between furrows is recommended for a single row of plants per ridge, or 1.20 m for double rows. The maximum length of each furrow should be 100 m; shorter furrows of 50 m can increase irrigation efficiency, especially in light or sandy soils.

6. PREPARATION OF CHILI SEEDLING

6-1 CULTIVARS

Chili plants can be divided into those producing sweet peppers and those producing spicy peppers. Within this simple classification, there are a large number of types and cultivars with various colors, shapes, and numbers of lobes of their fruit, and variations in their foliage and plant height. The chili pepper fruit is yellow or green during development and gradually turns red, violet, or brown at maturity.

Most chili pepper cultivars produce fruits have similar dimensions (3 cm × 4 cm in Habanero, 3 cm × 5 cm in Jalapeño, and 3 cm × 7 cm in Serrano). For the obtention of seed, some farmers select the best fruits of vigorous plants and save the seeds from to sow during the next season and in some cases can achieve acceptable yields. However, this practice is not advisable, taking into account the total investment in the crop in addition to the possibility of not complying with the quality that the market demands for the crops.

6-2 SOWING

The majority of farmers use seedling transplantation, although direct sowing is sometimes possible, depending on the cost of seed.

Sowing into disinfected soil is recommended. Moist soil is placed in the cells of a germination tray to a depth of 0.5 cm, then one seeds is added to each cell as showed in photograph one and immediately covered with soil.

Photo.1 Sowing chili pepper seed in a germination tray

6-3 NURSERY

Chili pepper seeds should be germinated in 200-cell germination trays using peat-moss substrate. The seeds are placed 2 per cell Photo. 1). After 8 days, seedlings are thinned to one per cell. The plants under net house conditions, are stored for 30-40 days at 20-30 °C.

In a greenhouse, seeds can be germinated from September to October or and similar conditions in other location according to the Table 1 that shows the optimal, minimum, and maximum temperatures needed for the germination of chili pepper seed and the growth of seedlings. Under the optimal temperature range, it takes 6 to 8 weeks to produce plants that are large enough for transplantation.

Tab.1 Optimal, minimum, and maximum temperatures for the germination of chili pepper seed and growth of seedlings

	Germination temperature (ºC)	Day growth temperature (ºC)	Night growth temperature (ºC)	Time to transplantation (Weeks)
Optimal temperature	27	20	18	
Maximum temperature	35	27	20	6 to 8
Minimum temperature	18	18	13	

Seeds can be sown for early harvest, but the protection of a greenhouse or micro tunnel is needed (Photo. 2). It is important to note that the size of the cells of the germination tray will directly influence the yield and quality of the crop, so appropriate tray selection is important, therefore, the choice of germination trays recommended for this purpose will be those containing 200 cavities per tray. Once the seeds have been deposited in the cavities of the germination trays and covered with the substrate, they must be irrigated with fine jets of water and subsequently stacked and wrapped in black plastic to favor the necessary heat that causes uniform germination of the seeds. This activity will last between 7 to 10 days and it should be observed daily from 5 days to proceed immediately after the emergence of the seedlings to place the trays one by one in the necessary spaces inside the house for the growth and development of seedlings before transplant. At this time of growth and development, the seedlings will be irrigated daily to maintain adequate humidity in the trays, likewise, apply basic phytosanitary management against pests and diseases with conventional pesticides approved in the work region.

Photo.2 Management of germination trays during germination

During transplantation, the roots of the chili pepper plants can be damaged, especially by cold soils (temperature below 12 °C), which will slow the growth of the plant. Therefore, to help prevent root damage and promote the fast development of new roots, it is recommended to treat the seedlings with a high-phosphorus fertilizer before transplantation (e.g., 1L of 10-43-0 (N-P-K) in 150L of water or 1L of 6-24-6 in 100L of water). The fertilizer solution should be mixed well to ensure uniform coverage of the crop (Photo. 3).

Photo.3 Immersion of trays with seedlings in nutritive solution

6-4 TRANSPLANTATION

At 30-40 days after sowing, the seedlings are ready to be transplanted into the field.

There are several advantages of working with planters, apart from accelerating plant growth according to next points:

- Seeds saving compared to direct seed in the field in the planting operation.
- Significant water saving for 45 days (approximate time of plants in germination trays) by the transplanting operation in the field versus seedlings sown directly to the ground in arid areas.
- Under the development of seedlings in the greenhouse in the 45 days prior to transplantation, there are more seedlings in less space, which facilitates the control of fertilization, irrigation, pests and diseases.
- It affords greater protection against an unfavorable environment in relation to sudden changes in temperature, winds, and environmental relative humidity in the seedling stage mainly in the seedling state.
- The healthiest and most vigorous plants can be selected at the time of transplantation.

Chili pepper seedlings should be transplanted at a distance of 40 cm between plants, with two rows of plants per irrigation hose line and 80 cm between rows (Photo. 4). Using this arrangement, a population density of 44,000 plants/ha is achieved.

Photo.4 Planting chili pepper seedlings in an arid field

It is important to note that before transplantation, pre-transplant irrigation with a depth of at least 10 mm should be applied to minimize the stress of transplantation and to obtain the highest percentage of viable plants in the field (Photo. 4). This action is essential for the development of chili crops in the following stages of growth or vegetative development as shown in Photo.5

Photo.5
Growth after 30 days of manual transplantation

7. AGRICULTURAL TASKS

After transplantation, the focus shifts to keeping the crop free of weeds and ensuring that the soil is aerated. The goal is to promote maximum development of the crop and the cultivation of vigorous plants.

7-1 DIRECT SOWING IN THE FIELD, THINNING OR STRIPPING

This practice is still common by farmers with low technical knowledge in chili cultivation. They opt for direct sowing to the field and after germination and seedling emergence (80 days), they proceed to the choice of vigorous seedlings, removing the weak ones to achieve better plantings. However, when comparing the tray transplant method, this practice of direct sowing is no longer beneficial, generally it is less and less used in chili cultivation due to the increasing technification of the producers.

7-2 HILLING

Hilling is the practice of bringing soil to the base of the plant, which can be done by hand or with a cultivator, dependent on the developmental stage of the plant. As the height of the plant increases, it becomes increasingly necessary to use manual hilling because cultivators cannot get close enough to the plants without damaging them.

7-3 WEED CONTROL

Owing to the high planting density of chili pepper, weed development presents a series of problems that increase the cost of cultivation. Periodic weeding is used to avoid competition (Photo. 6). Two weedings with machinery at 20 days after transplantation are recommended to strengthen the base of the plant, avoid a bedridden plant, and avoid stunting.

Weeding allows aeration of the surface root zone of the crop where plastic sheeting has not been used, and is essential to prevent the proliferation of weeds, so that the number of weedings will be 4, the first two being the most important, eliminating or indirectly controlling pests prevalent then weeds will still develop that will need to be manually removed. It is important to avoid damaging the plants during weeding. It is recommended that once the weeds are picked, they be removed and either buried or burned to remove a potential source of contamination by pests or diseases.

Photo.6 Manual weeding for weed and pest control

7-4 IRRIGATION

Irrigation scheduling is one of the most important tasks for ensuring maximum yield per unit of planted area. Compared with conventional methods, drip irrigation uses a higher frequency of application, with the primary objective being to moisten the roots with repeated small applications of water. Irrespective of the irrigation approach, however, the fundamental goal is to fill the root zone to close to field capacity.

For drip irrigation of chili pepper, the irrigation system is installed with the hose placed in the center of the bed and emitters placed at 20cm intervals (Photo.7). Irrigation is based on a 3.0-mm depth daily (approx. 1 hr. of irrigation daily or 2.5 hrs. every third day), with adjustments depending on the weather to avoid wasting water. Irrigation control should take into account evaporation parameters reported by local weather stations, and humidity sensors and tensiometers should be placed around the crop (more details on how irrigation data is calculated based on evaporation records is mentioned in the Irrigation section of the main document).

Photo. 7 Chili pepper plantation with a drip irrigation system

Before transplanting, the field should be irrigated with between 8 to 10 mm. A soluble fertilizer injector should be equipped to apply fertilizers to the crops. When transplanting, the root system is located at a shallow depth (10 cm at deepest) and the roots is usually damaged decreasing water and nutrients absorption ability. Therefore, the necessary and sufficient amount of water and nutrients should be applied to ensure planting in the field.

When the amount of water in the soil is low, yields and production quality are decreased. However, excess moisture delays maturation in fruit, reduces solids content in fruit, and can sometimes affect the intensity of the color of fruit too. For chili pepper, the appropriate soil moisture is 80% - 85% of field capacity. This value varies depending on the environmental factors, therefore the amount of water supplied should be adjusted considering these factors.

7-5 FERTILIZATION

Fertilizers are applied to the crop through the drip irrigation system in weekly doses of 20-10-20 (N-P-K kg/ha), changing the dose according to the development of the crop. The composition of the fertilizer needed should be determined by sampling the crop on the leaves, soil and water in a one-time per month, and to know the concentration of macronutrients in the tissues according with the (Tab.2).

Tab.2 Recommended macronutrient levels in the tissues of chili pepper plants to ensure high yields under arid conditions

Nitrogen	3.5-4.0%	dry weight
Phosphorus	0.3-0.6%	dry weight
Potassium	4.5-5.0%	dry weight
Calcium	2.5-3.5%	dry weight
Magnesium	0.8-1.0%	dry weight

The most appropriate fertilizers for arid soils are ammonium nitrate, calcium nitrate, monoammonium phosphate, and phosphoric acid during the time from crop to harvest. . These fertilizers prevent soil alkalization because they produce an acidic solution that helps stabilize the soil pH, keeping it close to the optimal (i.e., 6.3-6.8) for maximum nutrient uptake.

It is also important to take into account the solubility of fertilizers, because compounds with low solubility can block the irrigation nozzles. It is important to note that high yields necessitate the use of high amounts of fertilizers, with potassium being the macronutrient that has the greatest effect on crop yield.

The NPK ratio of the fertilizer depends on the phase of crop development. In the vegetative growth phase (first 15 days after transplanting), a ratio of 1-1-1 is used. In the pre-flowering phase, a ratio of 2-1-2 is used. Once the plant is in bloom, a ratio of 2-1-3 is used. For Serrano, Habanero, and other spicy chili pepper cultivars, the ratio is then kept at 2-1-3, because the demand of fertilizer is lower in this type of chili pepper than other with a large fruit.

A soluble fertilizer injector is attached to the irrigation system for fertilization of the crop. The fertilizer should be prepared in advance by mixing in a water tank. It is then applied weekly (Photo. 8). Fertilization is based on 300 kg/ha N, 150 kg/ha of P, and 400 kg/ha of K, plus 120 kg/ha of Ca.

Photo.8
Fertilization of pepper plantation on field using a drip irrigation system

Fertilizer tank is connected to irrigation lines for the applying nutrient to crop.

8. MAIN PESTS AND DISEASES OF CHILI PEPPER

8-1 PESTS

8-1-1 Introduction

At present, the pests that most affect commercial chili pepper crops are similar in almost every country and are mainly arthropods, especially insects and arachnids. Insects in the subclass Pterygota and the orders Hemiptera, Thysanoptera, Lepidoptera, Coleoptera, Diptera, and Orthoptera are common pests.

In B.C.S., the most common pests of chili pepper are whitefly (*Trialeurodes* spp.) and the pepper weevil (*Anthonomus eugenii* Cano), which can cause large losses if they are not promptly dealt with. During planting, care should be taken to keep the crop's phytosanitation as high as possible.

8-1-2 Mites

The mites that damage chili pepper belong to the Tetranychidae and Tarsonemidae families. The economic importance of these pests has increased in recent years, most likely as a consequence of crop intensification, increased nitrogen fertilization and, above all, the indiscriminate use of phytosanitary products. Of the tetranychids that affect chili crops, *Tetranychus urticae* causes the greatest damage.

8-1-3 Red spider mite, two-spotted spider mite, yellow spider mite (*Tetranychus urticae* Koch)

The red spider mite is a cosmopolitan species. It is very polyphagous, being able to feed on more than 150 cultivated species.

(1) Morphology and identification

Adult red spider mites can have variable coloration depending on age, type of food, and climate. Young adults are greenish-yellow, with two large, dark spots more or less located on the lateral areas of the back and two red spots corresponding to the eyes (Photo.9). As they age, they become reddish, which is more intense in females. The adult female has an oval shape and reaches a length of 0.5-0.6 mm, being larger than males. The body of the males is fusiform, with very long legs, which allows for faster movement. The larvae are rounded, with three pairs of legs. The nymphs are similar to adults, already having four pairs of legs, and are yellow, against which the dark spots on the eyes stand out. The males, yellow on hatching, have a smooth chorion and are whitish, amber, or orange.

Photo.9 Red spider mite on an open-field chili pepper plant

(2) Damage

When feeding, red spider mites pierce the leaf epidermis and suck out the cellular contents. Affected tissue turns yellow and then brown (Photo. 10).

Photo.10 Red spider mite damage on an open-field chili pepper plant

(4) Control

The most appropriate control strategy depends on the time at which the crop is carried out and on the type or modality of it. In outdoor crops, preventives (natural barriers of plant traps, insect traps, etc.), and chemicals pesticides are the most commonly used methods. In greenhouse crops, biological control methods can also be used. Given the high multiplicative potential of the red spider mite, it is essential to control the pest from its first appearance. Many acaricides, however, have seen their effectiveness reduced by the emergence of resistance. Therefore, for best results, acaricides with different modes of action should be alternated.

8-1-4 Green peach aphid (*Myzus persicae* Sulzer)

Green peach aphid is a cosmopolitan species. In temperate or cold regions, it inhabits herbaceous or woody hosts. In warm regions, it inhabits only herbaceous hosts. It is an emigrant species and facultative.

(1) Morphology and identification

Wingless adults have an oval shape and can be distinguished from winged females because they lack a marked separation between the thorax and abdomen and are longer (1.4-2.5 mm). Adults are green or yellow with dark longitudinal spots, although the emigrant forms can show red or pink. It has highly developed, rough-textured antennae over leaving the body (Photo.11). The larvae are similar in their four stages of development to female pawns, turning from yellow to green as they develop. The winter egg is oval and black.

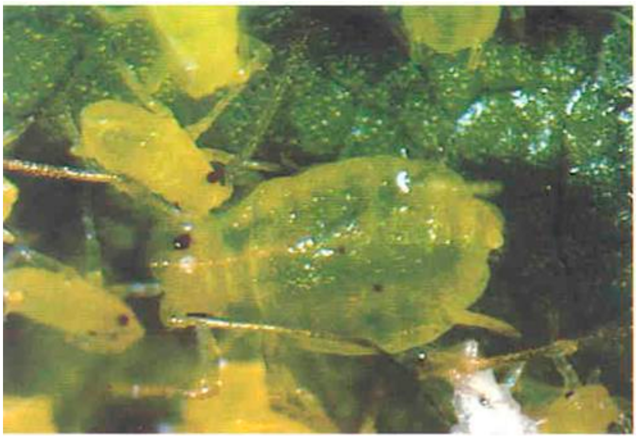

Photo.11 Green peach aphid on a chili pepper leaf

(2) Damage

Damage can be direct or indirect. Direct damage is caused by feeding on plant sap. When the sap is under sufficiently high pressure, the adults and larvae extract it passively and in large quantities to compensate for its low amino acid content. Aphids prefer to feed on the organs of young, tender, and developing plants. If the aphid colony is large enough, the plant weakens, with reduced growth and yellowing. A characteristic feature of an aphid infestation is the curling of the leaves towards the underside, where the aphids are usually located, in addition to the development of twisted buds and other deformations (Photo. 12).

Photo.12
Green peach aphids on a chili pepper leaf

(3) Control

1) Preventive methods

Prevention consists of the elimination of weeds near the crop, especially before transplantation, because they can harbor pockets of aphids and act as virus reservoirs. The placement of mesh barriers in greenhouses or seedbeds to prevent the entry of winged females is usually a fairly effective method to prevent early infection. Covering the ground between the rows of the crop with reflective materials, which repel aphids, is another. To identify when aphids are active, colored sticky traps can be used.

2) Biological methods

Aphids have a large number of natural enemies, including predators, parasites, and pathogens, that can be used to control their populations. The most important predators are chrysopids, coccinellids, syrphids, and cecidomyiids. Of these, chrysopids are the most important. They have long, narrow abdomens, membranous wings, and large eyes, and are green or brown. They lay small groups of white pedunculate eggs attached to the plant. The most important species are *Chrysopa formosa*, *Chrysoperla carnea*, and *Chrysopa septempunctata*. Some of them have been tested in greenhouse crops.

Photo.13 Biological control of green peach aphid using *Chrysopa* larvae during the cultivation of chili pepper

3) Chemical methods

For effective chemical control, the species of aphid must be identified as soon as possible. The development stage of the crop and the promptness of treatment once the aphids appear (in the primary development stage they are more susceptible to control by pesticides) are fundamental factors that affect the choice of active chemical.

Insecticides should coat the underside of the leaves in adequate quantity. Insecticides should be chosen with caution because specific or cross-resistance to some families of insecticides has been reported. Effective active substances include, malathion, methomyl, and pirimicarb. In the case of integrated greenhouse control, active materials that are compatible with auxiliary insects should be used, such as pyrethroids and methomyl.

8-1-5 Whitefly (Trialeurodes vaporariorum and Bemisia tabaci)

Whiteflies are hemipteran insects of the Aleyrodidae family. They are small, white bugs that in the adult state appear dusty. Two species, *Trialeurodes vaporariorum* (greenhouse whitefly) and *Bemisia tabaci* (silverleaf whitefly), are major pests in chili pepper crops.

(1) Morphology and identification

Adults are 1.5-2.0 mm long, the male being slightly smaller than the female. They have two pairs of rounded wings that when folded back form a triangular shape. Immediately after emergence they have a yellowish body and translucent wings, but over time they cover themselves with a whitish wax that is secreted from glands on the abdomen. The eggs measure approximately 0.2 mm, are yellowish-white, and are covered with a waxy dust. The female deposits the eggs vertically, fixing them via a very short pedicel to the underside of a leaf. Because this operation is performed by turning while the mouthparts are inserted into the plant, the eggs are laid in a semicircle. The larvae excrete a sticky substance called honeydew, which promotes the growth of sooty molds. There are four larval stages. The first instar is covered in short silk and is mobile. Once it finds an area on a leaf with sufficient nutrients, it attaches to the leaf via its mouth and molts. The second and third instar is immobile and very similar in appearance to the first instar but is more elongated and flattened. The fourth instar, which is also immobile, is elliptical, longer than it is wide, and bright yellow. It is surrounded by perimeter silks, with the peculiarity that six pairs of major silks are located on the back. The nymph has a capsule-like shape and develops after the fourth instar, inside its cover.

(2) Biology

In temperate areas, generations follow each other throughout the year. In the greenhouse, these pests multiply easily, with the different stages of development overlapping. In the open air, if the temperatures are low, they overwinter in the egg stage. The incubation period of the eggs is usually 12-15 days at 20-25 °C, but it varies with humidity and temperature. The development time of the larvae varies according to the climatic conditions, but is usually 15-45 days.

When the larva ends its development it becomes a nymph or pupa, a state that usually lasts about 10 days. Once adults emerge they need only 1 to 3 days to mate and lay eggs. Although reproduction is normally sexual, the females can also multiply by facultative parthenogenesis (unfertilized eggs produce males and fertilized ones females).

The fertility of females depends largely on the plant species on which it is feeding. Normally, 80-140 eggs are laid at a time, although on tomato it can be as many as 440, so the damage is often greater in this crop than in chili pepper.

8-1-6 Silverleaf whitefly (*Bemisia tabaci* Gennadius)

The silverleaf whitefly is a cosmopolitan species, although it is native to East Asia. For some years, it has been displacing *T. vaporariorum* in many areas in damage caused, not only because it is a vector for several major plant diseases but also because a more virulent biotype originating in South America has emerged. It can feed on more than 200 genera in at least 63 families.

(1) Morphology and identification

Adults are significantly smaller than those of *T. vaporariorum*, measuring approximately 1 mm. At rest, the wings fold back, but instead of being triangular as in *T. vaporariorum*, they form a more rectangular shape, as the wings come closer together.

The body is yellow and covered with a waxy secretion that also covers the wings, legs, and antennae. This secretion is produced by glands on the abdomen. The eyes are red and the antennae have seven knuckles (Photo.14).

Photo.14 Silverleaf whitefly

The mobile first instar is elliptical and flattened and fixes itself to a leaf to molt. The second and third instars differ in being immobile, yellower, and larger. The fourth instar also is immobile and does not present with the silks that the larva of *T. vaporariorum* has. The nymph is formed inside the larval cover of the fourth instar, distinguishing itself by its more intense yellow color and because the adult's eyes can be seen as small reddish spots. As in *T. vaporariorum*, the adult emerges via a T-shaped cut in the cuticle. The eggs are oval, somewhat asymmetrical, 0.2-0.3 mm long, and whitish, becoming brown as hatching approaches. They are laid in an upright position, attached to the leaves by a small pedicel, as in *T. vaporariorum*.

(2) Biology

In the warmest tropical and subtropical regions, the generations follow each other throughout the year. In temperate regions, *B. tabaci* usually overwinters as the nymph, which is more resistant to cold, and the first adults appear in early spring.

The first adult populations consist essentially of females, and only in autumn do the numbers of adults of both sexes become equal. Temperatures in the range of 16-34 °C are the most favorable for *B. tabaci* development. Limiting temperatures are below 9 °C and above 40 °C respectively. Temperature, relative humidity, and food quality strongly influence the duration of the life cycle of this pest.

In tomato, larval development takes 12-18 days at 30 °C and 60% relative humidity. One life cycle takes 22-51 days, with an average of 34 days. Under these conditions, the life span of an adult male is 3-13 days and that of an adult female is 8-43 days.

(3) Damage

Damage is caused as a direct result of feeding by adults and larvae. The feeding process consists of inserting the stylet into the phloem cells to absorb sap, which causes a general weakening of the plant. When the population is large, plant wilting and leaf death can occur. The adults usually colonize the tender leaves of the shoots, while the larvae prefer the low or mid-level leaves, and distribution tends to be irregular; *T. vaporariorum* colonizes more homogeneously.

Indirect damage is caused by the secretion of honeydew from larvae and adults. This substance promotes the growth of the sooty mold *Cladosporium sphaerosporum*. The layer of mold not only reduces photosynthesis and respiration, but also necessitates the washing of affected fruits before they are sent to market. Another indirect effect of *B. tabaci* infestation is its role as disease vector, most importantly of *Chilli leaf curl virus*. Of the different biotypes of *B. tabaci,* biotype B is considered a less effective virus vector than biotype A. However, its greater capacity for reproduction and its greater secretion of honeydew mean it produces more direct damage at equal population levels than *T. vaporariorum*.

Although adult whiteflies can make active flights of several meters, they spread mainly by contact with contaminated plant material and by wind. In greenhouses, infestations usually begin in specific areas that have come into contact with a contaminated plant or are in line with the prevailing wind. In the field, especially in summer, the adults are spread by the wind, so distributions are more homogeneous.

(4) Control methods

1) Preventive methods

Weeds are potential pest and virus reservoirs, and so all weeds should be eliminated from within the crop and from the surrounding area, both before transplantation and during cultivation. Residues from previous crops should also be removed. An important precaution is to make sure that the seedlings do not come to the field already contaminated. In crops grown in a greenhouse, appropriate treatments at the end of the growing season should used to prevent the pest from persisting inside the structure. Covering windows, doors, and any ventilation openings will reduce early immigration, which is the most common route of infestation.

2) Chemical methods

Although the control whiteflies by pesticides is not easy, it is currently the only method effective in outdoor crops. The use of pesticides to control whiteflies has several problems. First, it is difficult to ensure that the pesticides reach the whiteflies, which collect mainly on the underside of the leaves. Second, the honeydew and wax particles act as natural barriers, so surfactants must be added to the pesticides. Third, biotype B has a high level of resistance to carbamates and organophosphorus pesticides. Therefore, to avoid the development of further resistance, active materials with different forms of action and formulations should be alternated. Even so, current treatments are not very effective when whitefly populations are very large, because all stages of the insect are present on the plant. It is therefore recommended to start treatment when the first whiteflies are observed and repeat it as many times as is necessary within permitted limits according at the rules in local areas of plantation.

The most commonly used products for the control of whiteflies include imidacloprid and some of the so-called growth regulators such as teflubenzuron and buprofecin, which are not harmful to natural predators. Most of the pyrethroids, including alphacypermethrin, cypermethrin, bifenthrin, cufultrin, deltamethrin, and fluvalinate, are effective. It is recommended to alternate these products with others such as methomyl and endosulfan fo a more effectively control.

8-1-7 Epper weevil (*Anthonomus eugenii* Cano)

This small beetle belongs to the Curculionidae family, in the Anthonominae subfamily. Although it comes from Mexico, it is distributed throughout much of the Americas. In North America, it is found throughout the chili pepper-producing areas of California, New Mexico, Texas, and Florida, where it is able to survive the mild winters. It is similar in appearance to the cotton weevil, although smaller.

(1) Morphology and identification

Adults are 3-4 mm long. The body is black and covered with faint gray hairs. Like all curculionids, it has a beak-shaped head, at the end of which are the mouthparts. The beak is cylindrical and the antennae insert into it. The larvae are white with a dark-brown head. The eggs are spherical, somewhat flattened, and cream colored. Females deposit their eggs inside flower buds and developing fruit.

(2) Biology

In tropical regions, generations follow each other throughout the year. In temperate climates there may be 5-8 generations a year, and adults overwinter in grass. The incubation period of the eggs is variable, ranging from 4 to 8 days at 20-24 °C, and larval development lasts 20-25 days. The complete adult-to-egg cycle is usually complete in 7 weeks.

(3) Damage

Adult beetles feed on the leaves and flowers, although they also drill into the fruits. Neonate larvae develop inside the freshly set fruits, later feeding on the seeds and developing tissues, causing the abortion of many fruits. The larvae become nymphs inside the fruit. Once the adults emerge they fly away, easily dispersing throughout the crop.

Photo.15 Damage by pepper weevil during the flowering stage

The first symptoms of an attack are small holes in fruits that have fallen to the ground, as would be observed during a slug or caterpillar attack. Likewise, the leaves appear with small holes, 2-4 mm in diameter, that are more or less circular in shape but different from the holes produced by caterpillars (more big) when feeding. Scars on the fruits caused by oviposition are good indicators of an infestation.

(4) Control methods

A good preventive method is to eliminate weeds. Chemical control is effective. Pyrethroids, especially permethrin, have shown good results. Other recommended active substances are acefate, alphacypermethrin, bifenthrin, cypermethrin, diazinon, and fenitrothion.

8-1-8 American serpentine leafminer (*Liriomyza trifolii* Burgess)

The Agromyzidae family, within the order Diptera, has several species whose larvae live in and feed on leaf tissues creating characteristic tunnels or “mines”, hence the common name leafminer. The American serpentine leafminer native to Central America, is a cosmopolitan species that attacks more than 400 species. Although the chili pepper is considered not very sensitive to leaf miners, this pest can still cause considerable economic damage to crops.

(1) Morphology and identification

Adults are small, 1.3-2.3 mm in length. The thorax is black on the dorsal part and the rest is yellow. The antennae are yellow with a widened base, and the legs are yellow with black spots. The male differs from the female in having shorter wings and a lower, rounded abdomen with transverse bands on the dorsal part. The female is characterized by a yellow spot on her abdomen. The wings are transparent, slightly longer than the abdomen, and have a thickened transverse rib (Photo. 17).

The eggs are oval, white, 0.5 mm in diameter. They are deposited in the mesophyll of leaves, parallel to the surface. The eggs deposited by the insect are laid individually and are visible by observing the leaf against the light. The larvae go through three developmental stages that are largely indistinguishable, during which time the instars are whitish-yellow and lack differentiated legs, although 8-10 rings in the body can be seen. The final instar measures 2.0-2.5 mm in length. The pupae are barrel-shaped with strongly chitinized walls, 1.6-1.9 mm in length, yellow to light brown.

Photo.16
Adult female American serpentine leafminer depositing an egg on a leaf (http://www.hortoinfo.es/index.php/plagas/575-minador-bryoniae-16-11)

(2) Biology

In warm tropical or subtropical areas, generations follow each other throughout the year, with overlapping developmental stages. In temperate or cold climates, they usually spend the winter as pupae, emerging in spring. At 25 °C, the egg incubation period lasts 2-3 days. On hatching, the larva begins to feed on the leaf parenchyma, in which it excavates a sinuous tunnel by using its hook-shaped jaws. The size of the tunnel grows as the larva matures. At the end of its development, the larva makes a hole in the epidermis of the leaf to go outside and transform into a pupa, remaining on the same leaf or falling to the ground (Photo. 17).

Photo.17 American serpentine leafminer pupae on a chili pepper leaf

Adults emerge after 9-10 days at a temperature of 25 °C. At 24 h after emergence, they reach sexual maturity, starting setting of eggs at two days. The females live 3 weeks, whereas the males live only 2 days. The duration of the total life cycle depends on the temperature and the host plant, but it is around 17 days at 25 °C, 25 days at 20 °C, and 44 days at 15 °C. The temperature range for its development is 9-37 °C.

(3) Damage

Damage can be caused by female adults and larvae. Female adults damage leaves during oviposition and feeding, promoting rot. By far the greatest damage occurs when the larvae feed, because the tunnels within the leaves necrotize and lose their photosynthetic capacity, which is observed as a color change from green to brown (Photo. 19). In chili pepper crops, the most damaging attacks economically are those in seedlings or in new transplants, because if the larval load is high enough the affected plants can die. This insect is most active in the warm seasons and early fall. In winter they practically disappear, even from greenhouses.

(4) Control methods

Before transplantation, the phytosanitary state of the plants in the seedbed should be verified, and all weeds should be removed from the planting beds to prevent them from acting as a pest reservoir. It is advisable to use mesh in greenhouses in all access (entrances and exits, trap doors) and ventilation sites. In outdoor crops, the main method of control is the use of chemicals. Although some populations have developed resistance to insecticides such as pyrethroids (Peña, 1996), some products are still effective (e.g., dimethoate, omethoate, and diazinon). These insecticides should be applied as soon as the first mines in the leaves are observed. The treatments should be applied in the early hours of the morning, with the goal of wetting all of the leaves, especially new leaves, where the adults are located, although the effectiveness of these products against adults is low. In our experience with chili pepper crops, the main pests have been the American serpentine leafminer, white mosquito, aphid, and pepper weevil, which can be fought with commercial products such as Folimat, Dimethoate, Thiodan, Orthene, and Basudín.

Photo.18 Mining galleries caused by *Liriomyza trifolii* in a chili pepper leaf

8-2 DISEASES

The most common diseases affecting chili pepper are fungal infection by *Phytophthora capsici*, which causes late blight, or by *Pythium* or *Rhizoctonia* spp. These infections can be combated with application of a commercial fungicide.

8-2-1 Phytophthora capsici

(1) Symptoms and damage

Phytophthora capsici infection can damage any part of the plant at any stage of development. Neck rot and sudden wilt are the most characteristic symptoms. In diseased plants, a blackish, depressed annular lesion is observed around the neck that affects first the cortical tissues and then the vascular tissues. The lesion develops both upstream and downstream from the point of infection, ultimately killing the plant, which occurs so quickly that the leaves are left hanging but still green. Infections at points higher up the plant are less common. In such cases, infection is usually the result of water droplets carrying zoospores being splashed on the stems, leaves, or fruits, and then the fungi entering the plant through a damaged peduncle or other wound. The zoospores are also spread by air currents. In arid areas, irrigation water is the main carrier of the disease, and irrigation systems can easily spread zoospores throughout a crop (Photo.19).

Photo.19 Damage by *Phytophthora capsici* in a chili pepper crop

8-2-2 Pythium and Rhizoctonia spp.

(1) Symptoms and damage

These species cause the damping off, the most common disease of seedlings. Symptoms usually consist of failure to emerge, seedling collapse, or growth arrest, which usually occurs in specific areas within the seedbed or the direct-sown field. Infection is characterized by brown spots on the neck of young plants at ground level (Photo.20). This damage prevents the flow of sap to the aerial parts, causing the seedling to die. When the infection occurs before emergence, the apex of the seedling is damaged and the seedling dies soon after. These fungi are found in the soil or on seeds and their activity is enhanced by the presence of undecomposed organic matter and high humidity. They more easily infect seedlings with little lignification. Some fungi, such as *Rhizoctonia* spp., *Pythium* spp., and *Botrytis cinerea*, are more active at low temperatures, while others, such as *P. capsici* and *Colletotrichum* spp., are more active at high temperatures.

Photo.20 Damage caused by *Pythium* or *Rhizoctonia* spp. in chili pepper seedlings under rolled irrigation

(2) Disease control

To reduce seedling losses, it is advisable to treat the seeds with a fungicide. It is also advisable to place the planting beds in well-drained soils. The planting beds and soil should be disinfected before planting. In seedbeds, adequate ventilation should be used to prevent high humidity and to facilitate hardening of the seedlings. In greenhouses where infection by *Pythium* spp. has occurred, it is advisable to disinfect work tables and pots with a 1% solution of copper sulfate. The incorporation of fungicides into the seedbed is also recommended.

8-3 SAMPLING

Plant supervision should be cultured at all stages of growth, twice a week, to allow for timely intervention should an infection be detected. Fungicides should be applied with hand pumps, preferably in the morning.

9. CROP MANAGEMENT

The cultivation of chili pepper requires adequate management of fertilizer, irrigation, and pest and disease control. Field capacity should always be maintained to ensure the greatest yield.

9-1 TRAINING

Wild chili pepper plants usually grow tall and bear many fruit; however, this is not conducive to obtain high yields. By training the plants, we can remove overloaded branches that touch the ground or to get broken. To train plants, wooden posts are placed at equal distances along the row and then strings are tied to the posts at about 15 cm above the ground to support the plants. Training in this way also increases ventilation and accessibility to the fruit for harvesting.

Photo.21 Trained chili pepper plants

To avoid bending or falling of the plantation, posts should be placed every 2 m along the plantation bed. The posts are joined by placing the first nylon rope at a height of 15 cm for the basic support of the plant. Later, as the crop develops, more additional cords 30-40 cm from each other at their height are added to the posts to support the plants. It is common to place the strings on both sides of the row of plants (Photo.22).

Photo.22 Placement of strings for training rows of chili pepper plants

9-2 FRUIT THINNING

To obtain a high yield of high-quality fruit, it is important to eliminate the first fruits that grow in the first fork as this fruit retards the growth of the plant. In other crops, this operation, known as pinching, induces vigor in the plant, resulting in a higher yield of higher quality fruit.

Photo.23 Placement of string between the stakes to support chili pepper plants

10. HARVEST

10-1 COLLECTION

Depending on the cultivar, the fruits sold as green matter are harvested at 45-55 days after flowering and the fruits sold as red matter or ripe are harvested at 60-70 days. The fruits are collected in boxes and packed according to their color and size. The yield depends on numerous factors, in particular the duration of the crop, the state of harvesting, and the cultivar grown. Chili pepper fruits are normally harvested from 90 days after transplantation, with the exception of very early hybrids, which are harvested from 80 days. Subsequent harvests are then conducted every 8 to 10 days. The harvest is conducted by hand, taking into account the size, shape, and color of each fruit. Fruits that have uniform color, are unblemished by the action of insects, and are free of rot from contact with the ground should be harvested. The fruit should be removed with care to avoid breaking any branches that are laden with immature fruit and to reduce the risk of pest or disease infection. The fruits are usually collected in boxes with a capacity of 12-15 kg, or in woven bags with a capacity of 15-20 kg (Photo.24).

Photo.24 Harvesting chili pepper fruit at 90 days after transplantation

10-2 PRESERVATION AND TRANSPORT

Chili pepper fruit continues to mature after harvest. While some changes are desirable, most of them are not desirable from the point of view of the consumer and should be moderated as much as possible. Harvested fruits should be protected from exposure to direct sunlight to prevent dehydration and refrigerated as soon as possible to slow down ripening. Normally, harvesting is synchronized with shipment to the market, so it is common for the fruit to be taken directly to a refrigerated trailer for immediate shipment.

10-3 PHYSIOLOGICAL CHANGES AFTER HARVEST

Maturity is determined by the color, flavor, and texture of the fruit. After harvest, the color of the fruit changes as the influence of chlorophyll wanes and new pigments appear, the taste changes with alterations in the acidity and sugar content of the fruit, and the texture can change. The postharvest conditions in which the fruit are kept can influence at least the color and texture, and perhaps the flavor.

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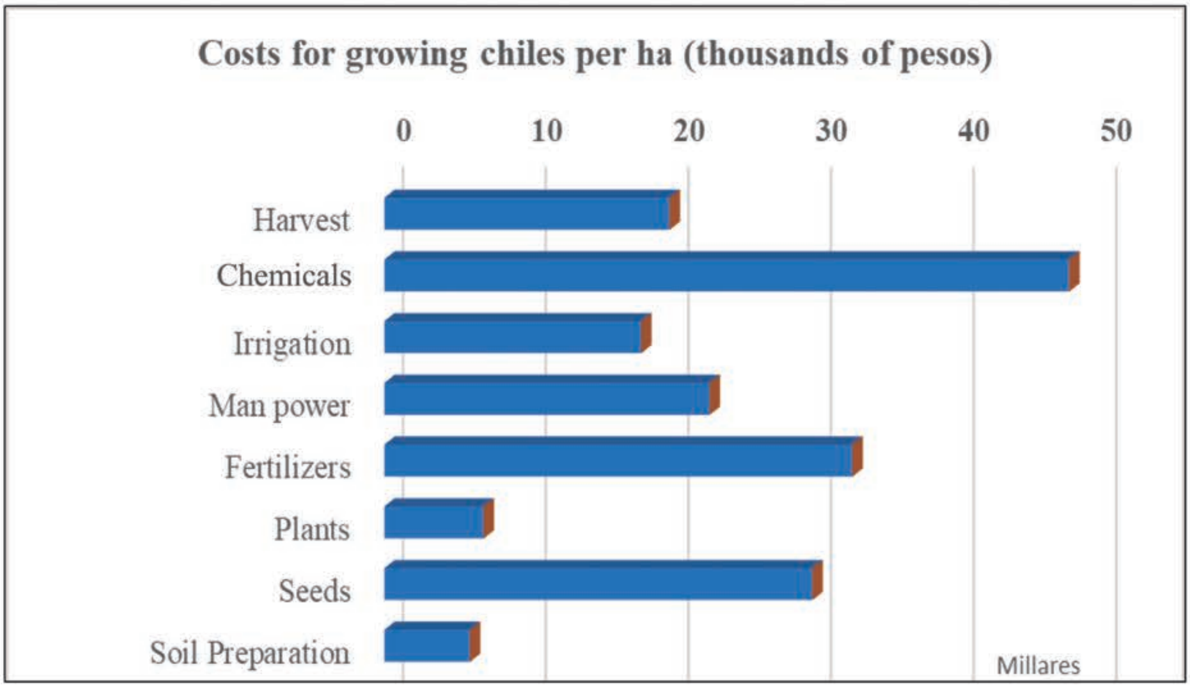
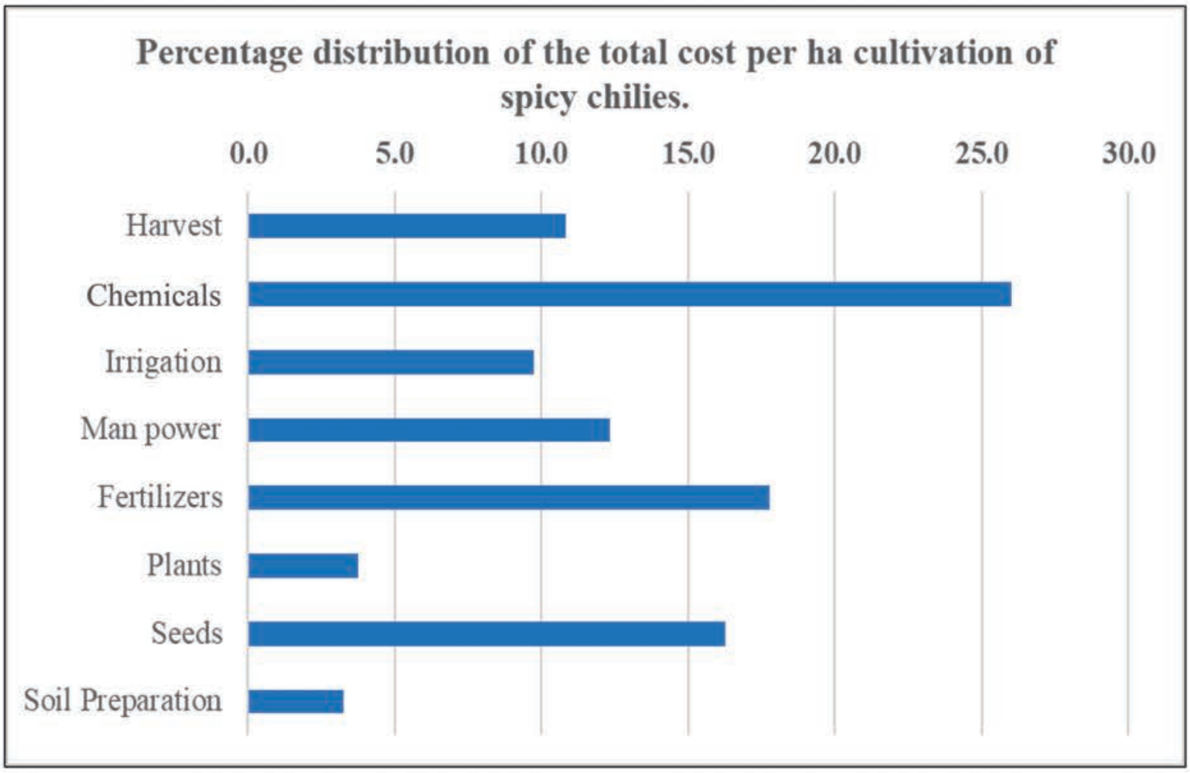
12. ANNEXES

Annex 1. Locations of the main chili pepper-producing areas of Southern Baja California State.

Annex 2 Cost of chili pepper production per hectare of plants grown using traditional agronomic management techniques with certified seeds germinated in a greenhouse





Annex 3 Chili pepper harvests using two different water sources at the aquaponic experimental plot in Los Planes, Baja California Sur

Tab. Cultivation of chili peppers in open field.

Variety	Water	Period of cultivation	Yield	Amount of Irrigation	Water use efficiency	Market price in Mexico (1 peso = 6.12 JPY)	
		(days)	(FW t/ha)	(L/ha/day)	(FW kg water/L)	(Yen/kg)	(Peso/kg)
Serrano	Ground water	133	17.7	18473	0.00719	152	24.9
	System water	133	21.3	18452	0.00867	152	24.9
Morron	Ground water	105	12.2	20534	0.00565	260	42.4
	System water	105	10.8	20674	0.00496	260	42.4
Habanero	Ground water	133	3.22	17617	0.00137	574	93.8
	System water	133	6.52	17959	0.00266	574	93.8

Yield, amount of irrigation and water use efficiency from transplanting (October 4th, 2019) to final harvesting in Los Planes were shown.Yield was the sum of 5, 3 and 2 harvestings in Serrano, Morron and Habaneno, respectively. System water means wastewater the aquaponics system. In the aquaponics, Swiss chard and epazote were hydroponically cultivated using wastewater of tilapia aquaculture. Then the hydroponics wastewater (nutrients rich water) was mixed with purchased fresh water so as to adjust EC to 4 dS/m. Ground water means the water feritilized underground water with nitrogen, phoshorous and potassium so as to adjust EC to the same value.

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2-3-3 Technical Manual for Coriander Production

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1. INTRODUCTION

Coriander is most likely native to the Eastern Mediterranean (Greece), North Africa, southern Europe and the Middle East. Its name is mentioned in the Bible, where the color of manna is compared to that of coriander. The Romans, who used it in cooking and medicine, introduced coriander into Britain, where it was widely used in English cuisine until the Renaissance, when new exotic spices became available. In Europe, it has also been used in beer production.

The usable parts of the coriander plant are the fruits, leaves, and roots, although the roots are generally used only in Thailand. The fruits and leaves have a very different flavor. Drying destroys most of the fragrance of the leaves, although there are references to the use of dried leaves. The fruits are currently produced mainly in Russia, India, South America, Morocco, and the Netherlands.

2. GENERAL DESCRIPTION

2-1 COMMON NAMES

Mainly, this crop is identified with the follow names around of world: Coriander, Chinese parsley, Arab parsley, anisillo. Coriander (*Coriandrum sativum*) is an annual herb of the Apiaceae family. Its generic name, *Coriandrum*, comes from the Greek word korios, which means bedbug, in allusion to the unpleasant smell produced by its still green fruits; its specific name, *sativum*, means that it is a cultivated plant.

Coriander (*Coriandrum sativum* L.) is an annual herbaceous, it is a medicinal and aromatic plant, and this plant belongs to the family Apiaceae. Its origins are uncertain, although it is generally considered to originate from North Africa and southern Europe. Coriander has been used in the traditional recipes of many cultures around the world for thousands of years. Its dried seeds are a fundamental ingredient in preparations such as Indian curries, and its fresh whole or chopped leaves are consumed in many Latin American countries, Coriander is used as spice and seasonings in the daily diet, being the subject of study because they are considered to be a potential source of phenolic compounds, which have high capacity antioxidants as well as in Cyprus, Greece, China, and Japan. In addition to its culinary uses, coriander is used by many cultures as a medicine or home remedy, being considered to have relaxing, antispasmodic, and stomach-settling properties Srinivasan, 2005; Nickavar y Abolhasani, 2009.

2-2 BOTANICAL CHARACTERISTICS

Coriander is an annual herbaceous plant, 40 to 60 cm high, with erect, smooth, cylindrical stems that are branched at the top. The lower leaves are petiolate, pinnate, with wedge-shaped oval segments; the upper leaves are bi-tripinnate, with acute segments. The flowers are small, white or slightly pink, and arranged in terminal umbels. The fruit is a globose schizocarp comprising two yellow-brown, strongly attached mericarps each characterized by ten longitudinal primary ribs and eight secondary ribs. They have a mild, pleasant smell and a strong, pungent flavor. The roots are thin and highly branched.

3. USES

The most commonly used parts of the plant are its fresh leaves and its mature and dry fruits, although sometimes the stems and roots are also used. Its fruit has a mild smell and a spicy flavor and is used whole to flavor oils and vinegars or ground as a spice. In the kitchen, coriander powder is used in a wide variety of preparations, including in soups, stews, sausages, curries, and pasta sauces, and even to flavor coffee. Its fresh leaves are often used in chutneys and guacamole, and its roots are used in many dishes in Thai cuisine.

As a traditional medicine, external application of coriander is said to help disinfect wounds and promote healing. Recent studies have shown that coriander has antibacterial properties against *Salmonella*. In Iraq, coriander is traditionally seen as a remedy for insomnia and anxiety. In other parts of the world, coriander infusions are said to improve appetite in people with anemia and to aid digestion in people with constipation and flatulence.

4. ECONOMIC IMPORTANCE AND GEOGRAPHICAL DISTRIBUTION

Coriander is an economically important spice because it is a crop with a good yield and a high price on the international market. An estimated US$6 billion of coriander spice is sold on the world market per year, and the sector is growing at between 5% and 6% per year.

The main coriander-producing countries are, according to information from the Agronet Engineering Department, Russia, India, Morocco, Mexico, Romania, Argentina, Iran and Pakistan. The main importing countries for coriander are Germany, the United States, Sri Lanka and Japan. In Mexico, coriander is one of the most coveted crops, as it is constantly used in various dishes, especially to season red meats, chicken, fish, tomato sauces, soups and tacos, among others. https://www.inforural.com.mx/

5. CLIMATE AND SOIL

Coriander requires a temperate climate, and although it can tolerate a warm-temperate climate, yields both leaf and seed are markedly decreased. The concentration of essential oil in the fruits decreases at temperatures above 21 °C, with the optimal temperature for the filling of the seed being between 15 and 18 °C. It grows at altitudes of up to 1200 m. It is undemanding of soils: it can grow in loam; siliceous clay; somewhat calcareous, light, sandy-loam, permeable, deep, and even slightly acidic soils; but it prefers calcareous soil.

Coriander normally grows well in arid regions, under irrigation, however, cold and waterproof soils are not appropriate for growing coriander.

6. PROPAGATION

To carry out the propagation of the crop in the field, it is necessary to consider that the sowing to the soil is carried out by seed directly on the prepared soil. It is also necessary to consider these basic data as the average weight of 1,000 seeds is 9.033 g and their germination power is greater than 90% at an average temperature of 15º C in the field. The seeds are sown in rows, at a distance between 30 to 60 cm from each other, putting the seed 1 cm deep; at greater depth they do not germinate or have a low emergence percentage.

Photo.1 Coriander seeds being direct-sown with a mechanical seeder

7. CULTIVATION

7-1 PLANTING

For the direct sowing of coriander seeds, the seeds are placed by squirting in the furrows, drawing rows 50 to 60 cm apart, and the plants of each row between 15 to 20 cm when the purpose is to harvest seeds . When the purpose is to produce leaves, these separations will be smaller, leaving the distance of the plants together. The best time of year to plant coriander is spring, after the last temperature drops of the year have passed.

Photo.2 Distance of furrows for the cultivation of coriander on both sides of an irrigation belt

Coriander plants are short lived, so they should be sown successively. Although coriander is easy to grow and germinates well, we recommend using a relatively loose soil. Seeds are placed inside shallow holes or furrows, which are then covered with soil and watered. The seedlings will sprout after about 2 weeks days. First, two small, strong leaves will appear, and then after 2 weeks the first stalked leaves characteristic of coriander will develop. After spring, it is advisable not to expose the plants to the sun for a long time (more than 4 hrs) during the first weeks of life, or, where appropriate, provide protection through cover to shade the crop, although once they have 6 leaves, greater sunlight will promote growth.

Photo.3 Coriander furrows in planting beds with drip irrigation

Staggered sowing during spring to early summer allows a staggered harvest. Sowing in the middle of summer leads to a delayed harvest. It takes 4 to 5 kg of seeds to sow 1 ha, and the seeds retain their germinability for 2 to 5 years.

7-2 FERTILIZATION AND IRRIGATION

Apply mature manure or compost during soil preparation. Mineral fertilization will depend on the richness of the soil. In general, 60 to 80 nitrogen units (kg/ha) in the form of NH_4-N; 80 to 100 units (kg/ha) of P in the form of lime and superphosphate; and 100 to 120 units (kg/ha) of K in the form of K_2SO_4 are needed. As for nitrogen, it should be applied two times. Fifty % is when preparing the sowing and the another 50% is in the course of growth through irrigation by the drip system.

Some authors, such as Gupta and Rams (2016), Sandoval and Escandón, (1990), have found an answer in seed yield in India with the application of 5 ppm of zinc. Ghosh (1985) reported the positive effect of the application of P (40 kg/ha P_2O_5) and N (60 kg/ha urea) on seed yield and quality. It is also necessary to apply frequent, light irrigation (minimal four time per week) to maintain the soil moisture and ensure sufficient leaf moisture content, since this crop is sensitive to a lack of water. For this, a drip irrigation system is recommended.

Photo.4 Distribution of irrigation in planting beds

7-3 CROP MAINTENANCE ACTIVITIES

In the dry season, irrigation should ensure adequate soil moisture. For this, it is necessary to apply the water daily in short time using a drip irrigation system, with a duration of 40 minutes. To benefit the aeration of the planting beds, weeding is recommended, that is, bringing soil to the base of the plant with the use of tools such as a hoe or another similar tool. To control the herbs, they can be done manually in crop areas with small surfaces. In the case of crops with a considerable extension, it is recommended to apply herbicides for their control. It is important for the farmer to understand how to carry out these activities to minimize losses in the plantation and at harvest time. Frequent weeding and cleaning of herbs, as well as fertilization and irrigation are essential activities for crop health.

Photo.5 Coriander cultivation with appropriate field management for plant health and quality at harvest

8. COLLECTION AND HARVEST

Depending on the purpose of the harvest for leaves or seeds, these can be harvested when it is leaf, between 40 and 60 days after sowing and up to 4 months for fruit or seeds. Fruits should be picked before they fully ripen, and umbels should be picked first thing in the morning. With an adapted mowershredder, harvesting can take a few days. Leaves should be harvested before the appearance of the stem to avoid collecting early seeds. If the older leaves are harvested, the plant will continue to produce new leaves until it flowers. Sometimes the plant is cut to a height of 2–3 cm above the ground and allowed to regrow for a second harvest; however, coriander does not regrow as effectively as other aromatics such as parsley. This is why it is common for coriander to be harvested only once per season.

9. PESTS AND DISEASES

Very few diseases of coriander are known. However, the most important agriculturally is the bacterium *Pseudomonas syringae*, which causes delimited, angular lesions that are transparent at first but then turn black or brown under dry conditions. When infection is severe, the lesions can join and cause wilting.. The pathogen is present in the seed, so the disease spreads through contaminated seed and is favored by rain and irrigation.

Photo.6 Harvested coriander packed in a mallet of 100 g each

Photo.7 Leaf yellowing in the field indicating the presence of disease

10. POSTHARVEST STORAGE

Like other leafy green vegetables, freshly harvested coriander has a moderately high respiration rate (15–20 mL CO_2/g·h) and a relatively low ethylene production rate (<0.2 µL/g·h) at 5 °C. It should be stored under high humidity and low temperature. Storage at around 0 °C will give a shelf life of between 18 and 22 days, during which time the plant will retain good visual quality; however, the aromatic quality will decrease after 14 days. Storage at 5.0–7.5 °C will maintain quality for 1 to 2 weeks. At 7.5 °C, the shelf life is 14 days in an atmosphere containing 5%–9% CO_2. Dark lesions will develop after 18 days at a CO_2 concentration of 9%–10% and after 7 days at 20%.

Photo.8 Manual harvest in the cool hours of the day

Coriander's high surface area to volume ratio makes it very susceptible to water loss. When refrigeration is not possible, wilting can be delayed by cooling the plants with water or ice and protecting them from sunlight.

11. APPLICATIONS AND CURIOSITIES

11-1 MEDICINAL APPLICATIONS

Coriander leaf and fruit is said to facilitate digestion and so be beneficial for the treatment of digestive disorders such as gastritis, pancreatic insufficiency, poor digestion, loss of appetite, and flatulence. It is also said to be an antispasmodic, slightly toning and stimulating the nervous system when taken in small doses (Muhammad Nadeem, 2013). Externally, coriander is also used as a fungicide, anti-inflammatory, anthelmintic, and analgesic. Research in rats has shown that coriander fruit reduces LDL cholesterol (often called "bad" cholesterol) and triglycerides and increases HDL cholesterol (often called "good" cholesterol) in the blood by decreasing the absorption of bile acids in the intestine.

Dried coriander leaf contains a high amount of vitamin K, which is involved in the hepatic synthesis of blood clotting factors and in the calcification of bone.

It has also been found that coriander has important chelating properties. Chelation therapies are used in people with heavy metal poisoning (Pandey, et al, 2016). It has been shown that the chelating properties of coriander are greater than that of the currently used chelating agent EDTA (ethylenediaminetetraacetic acid), needing only 2 weeks of treatment to remove heavy metals from the blood.

11-2 CULINARY APPLICATIONS

Coriander is antibacterial, so it can act as a natural protectant when used fresh on food. Coriander is a fundamental component of the curry powders used in Sri Lankan and Indian cuisine. Coriander leaves are very popular in much of Asia. In Thai cuisine, it is used to add flavor to soups, salads, and green curry paste. In southern Vietnam, chopped coriander leaves appear as decoration on almost all dishes, sometimes in combination with mint. In Latin America, the people use the leaves mainly. The most well known example is guacamole, a paste of avocados, tomatoes, lemon juice, garlic, onion, chili peppers, and coriander leaves.

11-3 CURIOSITIES

The name comes from the Greek word korios, bedbug, referring to the pungent smell of its green fruit.

Coriander leaves resemble European parsley leaves. They have a similar shape and both are better used fresh, since their flavor diminishes considerably after cooking. In both plants, the root has a leaf-like flavor, which is more tolerant of cooking.

12. ACTIVE COMPOUNDS

Coriander seed essential oil is slightly yellow or colorless and contains fatty oils, traces of glycoside, tannins, and calcium oxalate. Chemically, it contains D-linalool (70% to 90%), pinene (1 to 6.5%), dipentene, geraniol, felandrene, borneol, limonene, and other minor components.

13. ACKNOWLEDGMENTS

We thank the Cooperating Producer, Mr Jose Angel Rodriguez Casas and Prof. Cristóbal Rodríguez Pérez for the participation and support for the Aquaponics Project in the operation of aquaponic module in Los Planes, Baja California Sur, Mexico. We give the thanks to the technicians Mr. Héctor Rubén Castro Manríquez, Mr. Saúl Briseño Ruiz, Mr. Raymundo Ceseña Núñez, Mr. Adrian Jordán Castro, and also, Dr. Masako Hishida, for their support in compiling this manual for the open-field cultivation of coriander in combination with our aquaponic system.

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15. ANNEX

Planting schedule is shown in table below.

Tab. Coriander planting program

WEEKS	1	2	3	4	5	6	7	8	9
									
STAGES OF DEVELOPMENT	GERMINATION						LEAF DEVELOPMENT		
LABORS	IRRIGATION				IRRIGATION, WEEDING AND PEST MANAGEMENT			HARVEST OF FOLIAGE	

Programa Integral para el Desarrollo Rural 2014, SAGARPA. Elaborado Ing. Gamaliel López López, Mc. Natanael Magaña Lira, Ing. Cuauhtémoc Vázquez Romero.

2-3-4 Technical Manual for Table Beet Production

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1. FOREWORD

Table beet is grown in many parts of the world. It is in demand for human and animal consumption, as well as for other uses in the agricultural sector that as: in the food industry as a colorant, in the production of sugar known as "beet sugar" and day by day, the consumers demand and have more interest in table beets, mainly to improve their health. Due to its nutrient content, it is an ideal food for athletes, as it helps improve performance by 5 to 10 percent for its nitrate content, which when metabolized promotes greater vaso-dilation, which allows the muscles to be nourished and oxygenated. For its content of betaine, a substance that reduces muscle fatigue, helps to increase strength and decrease the inflammatory action of muscles and for its content of Riboflavin (vitamin B_2) Niacin (vitamin B_3), both energy generators. Just to mention some of the benefits for human health from its consumption (https://www.gob.mx/agricultura%7Ccolima/articulos/92141).

Table beets are well adapted to various climates and soils, including arid soils. It grows well in alkaline soils and can achieve good yields. The demand for this crop for human consumption is increasing, with high demand during most of the year. For this reason, it is a good alternative culture for integration into intensive food production modules, such as ours, which combines aquaponics (mentioned in the aquaculture and hydroponics section of the main document) with cultivation in the open field, using water brackish for food production.

This manual provides an overview of the management of the open field sugar beet crop using the effluent from an aquaponic system with brackish water to irrigate the crop to obtain acceptable food production per unit of water used.

In our aquaponics system, the water in the aquaculture section, which contains nutrients excreted by the animals (tilapia) reared in that section, are transferred to the hydroponic section where they are used to fertilize the plants in the hydroponic unit. The plants in the hydroponic section are acting as a biofilter to eliminate excess ammonium and nitrates, in addition to the sodium salts contained in the brackish water used by the aquaponic system, in addition to the implicit sodium salts in the food for tilapia fishes in the aquaculture section.

Because of the use and transfer of water from the aquaculture and hydroponics sections, an effluent is produced with mineral nutrient contents ideal for irrigating crops in the open field. Therefore, when using this effluent for irrigation, we can also fertilize the crop, considering fertilization as organic, which could give "added value" with the expectation of greater demand by the market.

2. INTRODUCTION

Although generally considered a root vegetable, table beet is actually a swollen stem base. A nutritious food is widely used in salads and juices. Table beet juice contains high amounts of vitamin B (thiamine, riboflavin, niacin, and vitamin B6), iron, magnesium, and potassium, which are essential components of a healthy diet. The whole of the beetroot plant is edible. The part most often consumed is the swollen stem base, which constitutes the storage organ of the plant and so contains mainly sugars and starches. However, the leaves, which are deep green with red or purple stems, are also edible. The plant prefers cold climates, and if grown in hot climates the stems will be of low quality. The ideal temperature for the development of beets is between 16 and 21 °C. For seed germination, the ambient temperature must be between 20 and 25 °C. Table beet develops best in sandy soils, and development in clay soils can result in deformed bulbs. The fine root system is very deep and branched.

3. SOIL PREPARATION

The use of 1-m-wide planting beds is recommended. Large clods should be broken up, and the soil should be amended with organic fertilizer (in our case, the water used for irrigation, which is the effluent from our aquaponics system, contains nutrients such as nitrogen, phosphorus, potassium, calcium, and others minors elements. In arid areas, planting beds should be 15-20 cm high to avoid the effects of warming the beds due to the incidence of abundant sunlight.

4. PLANTING

Table beet root is best planted in December and January, although it can be planted at almost any time of the year. Direct sowing is more common than seedling transplantation. For direct sowing, 10 to 15 kg of seed per hectare is needed. Seeds are sown directly in rows 25 cm apart with 20 cm between plants to obtain 20 plants per square meter. Weeding should be performed by hand after emergence, when the plant has 5 to 8 leaves.

Photo.1
Mechanized planting of table beets

Photo.2
Table beet culture with drip irrigation

If seedlings are used, they should be transplanted when they have three or four true leaves. The weakest plants should be removed before planting. Seedlings should be spaced at intervals of 10 to 15 cm with around 70 cm between rows to obtain 215,000 to 220,000 plants per hectare.

Plants that are removed during thinning or weeding can be transplanted to replace planting failures. They support transplanting well and it is a good activity to keep the growing area as complete as possible, so keep this in mind when planning the amount of seeds to sow and the area of sowing to cover.

5. FERTILIZATION

Table beet responds well to organic fertilizer management, and the nutrient load in the effluent from an aquaponic system will usually be sufficient to obtain high-quality harvests. However, if the effluent does not contain sufficient nutrients, they can be supplemented through the irrigation system at concentrations not higher than 300 mg/L for nitrogen, 120 mg/L for phosphorus, and 200 mg/L for potassium, and 50 mg/L for calcium, magnesium, and other nutrients. It is recommended to know the mineral content of the effluent to control fertilization levels. A dose of humic acid (1 L/ha), is recommended 20 days after thinning of the crop to improve the fertility condition of the soil and strengthen the plants.

6. WEED CONTROL

Manual weed control is essential. Two weedings are required before the start of harvest. The first can be done together with thinning within the first 10 days after sowing. The second should be done 20 to 25 days after the first. This will indirectly reduce the incidence of pests and diseases, improve soil moisture content, and reduce competition for nutrients.

Photo.3
Weed control in a table beet crop

7. PEST CONTROL

The most common pests are aphids and armyworm, which can be controlled by applying by a manual or mechanical pump a pyrethroid-containing insecticide at 1 mL/L in the early hours of the morning from 6 to 9 am. Depending on the degree of damage caused by these pests, doses up to 1.5 mL/L can be applied once a week. Another common pest is cutworm, which can be controlled by the application of *Bacillus thuringiensis* at 0.13 g of active ingredient per liter of water. At this dose, the plants can be harvested on the same day as the *B. thuringiensis* is applied.

Photo.4
Damage to beet leaf by *Phoma betae* (*Pleospora betae*)

8. DISEASE PREVENTION AND CONTROL

The high relative humidity near the soil surface can promote bacterial infection. *Pseudomonas* infection results in the formation of irregular brown spots of around 1 mm in diameter on beet leaves. When the damage is slight, the injured leaves can be removed. However, when the damage is severe, the crop can become unusable. Preventive measures include appropriate irrigation control and crop aeration, and hilling every 20 days. For the prevention of bacterial infection, an approved bactericide is recommended.

9. HARVEST

Table beets are harvested at around 50 days after planting when the stem base reaches a diameter of 8 to 10 cm. Once harvested, these are tied in packages of 4 pieces to have a weight of approximately 1.2 kg

Care should be taken not to injure the neck of the beet and young leaves when harvesting. Harvesting is carried out in several phases at intervals of 12 to 15 days, so it is important not to damage the plants intended for subsequent harvests.

Photo.5 Field table beet harvest for fresh consumption

10. EXPECT YIELDS

In practice, 15 bundles (300 g) per square meter can be harvested, totaling 4.5 kg/m^2 of beets. The harvest lasts approximately 2 months, but can last up to 5 months depending on the care given during the harvest process.

11. ACKNOWLEDGMENTS

We thank the cooperating producer, Mr. Jose Angel Rodriguez Casas and Prof. Cristóbal Rodríguez Pérez for their participation and support for the Aquaponics Project in the operation of the aquaponic module in Los Planes, Baja California Sur, Mexico. We thank the technicians Mr. Héctor Rubén Castro Manríquez, Mr. Saúl Briseño Ruiz, Mr. Raymundo Ceseña Núñez, Mr. Adrián Jordán Castro, and also, as well as Dr. Masako Hishida, for their support in compiling information and field work for this field table beet production manual.

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www.gob.mx/agricultura/es/articulos.

13. ANNEX

Planting schedule is shown in table below.

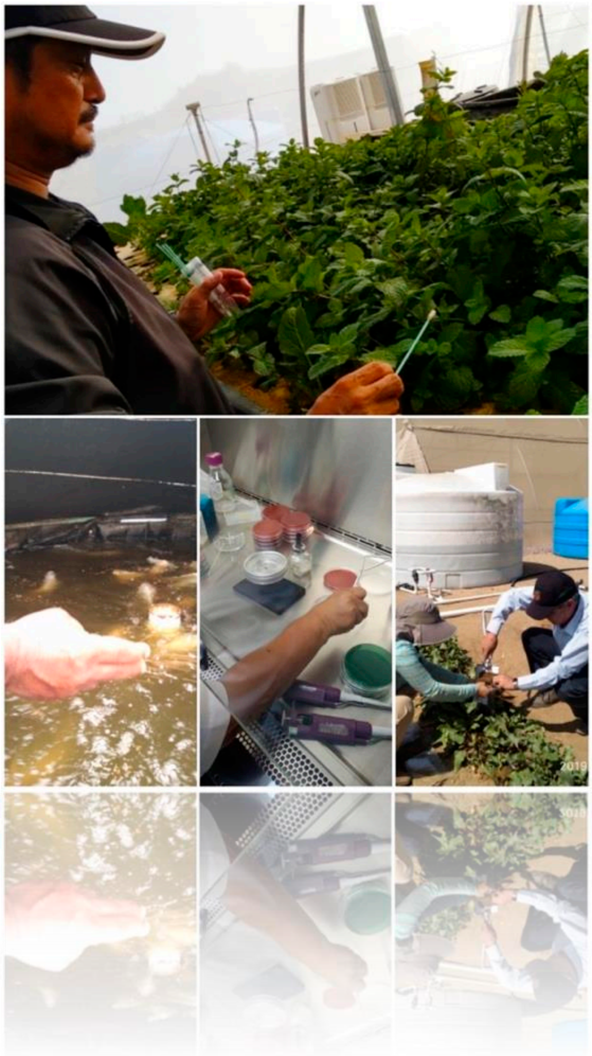
Tab. Table beet planting program

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13
													
STAGES OF DEVELOPMENT	GERMINATION		VEGETATIVE DEVELOPMENT		DEVELOPMENT OF THE ROSETTA								
LABORS	CONTROL OF PESTS OF THE SOIL		CONTROL OF WEEDS		FERTILIZATION		CONTROL OF PESTS AND DESEASES				HARVEST		

Guía técnica de Betabel, SAGARPA, Programa Integral de desarrollo Rural 2014.

3. Technical Manual for Maintenance and Management of Aquaponics Combined with Open Culture

3-1 Technical Manual for Hygiene Management



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1. INTRODUCTION

This manual is designed for producers who want to practice aquaponics for the first time. Despite being a relatively new concept, aquaponics is practiced in various parts of the world. Health concerns are driving growing demand for locally produced organic products, such as vegetables and fish, in the current market. Aquaponics can be presented to producers as one way to monetize this trend (HORTALIZAS, 2012).

Aquaponics is considered to be sustainable production systems because it has numerous characteristics that are beneficial for the environment. It represents not only a complete source of high-quality food but also an opportunity to improve people's socioeconomic conditions, contributing to both food security and sovereignty (Colagrosso, 2015).

Fish is used as a primary source of protein, and it is a rich source of many micronutrients that are not usually present in people's diets (HLPE, 2014). Vegetable products are also a very important food source. People's health and quality of life can be improved by obtaining essential nutrients (SAGARPA-SENASICA, 2018). Consumers appreciate such wholesome food. However, during the production process, both fish and vegetables interacts with various substances and contact surfaces from which they can acquire biological, chemical, and/or physical contaminants that can pose a risk to consumers' health. The market requires that these foods be "harmless," i.e., they should harm the health of people who consume them. Good Production Practices should be applied to activities carried out during the food production process to prevent food contamination and avoid foodborne illness.

This manual describes the minimum measures required to reduce the risks of contamination in the aquaponic production process.

The manual provides information on precautionary measures such as hygiene: both personal hygiene and daily cleaning up of equipment and materials used in aquaculture systems. Such measures protect production by preventing the introduction of pathogens or contaminants. The manual can be a reference for all those who are interested in the safety of fish and vegetable production for consumers.

We hope that this manual will provide valuable support for the success of your company.

2. OVERVIEW OF AQUAPONIC SYSTEMS

Aquaponic systems show real potential for sustainable food production in any location and at any time. According to the FAO (2014), more than 150 different vegetables, herbs, flowers, and small trees have been cultivated successfully.

In general, the principal components of aquaponic systems are as follows:

1. Tank for the maintenance of fish; 2. Clarifier; 3. Biofilter; and 4. Hydroponic tanks to folate the plants in the culture water.

1. The tanks used for fish farming are essential components in aquaponic systems. The tank dimensions must be appropriate to the extent of the fish farming operation. The tanks must be constructed from water resistant material, avoiding the use of metal containers as water can corrode metal.

Photo.1 Aquaculture

2 and 3. This system includes a biofilter comprising a container filled with porous materials, such as stones, sponges, or bio-rafts. Bio-rafts are plastic elements with a large surface area containing bacteria to promote nitrification and that also act as mechanical filters for removing suspended particles (Rakocy, 2006; Colagrosso, 2014).

Photo.2 Biofilter and Sedimentation tank

4. Rather than soil, hydroponic cultivation involves the use of several types of inert culture media, or substrates, and water in the case of floating root systems.

Photo.3 Hydroponics

3. FOOD SAFETY AND FOODBORNE ILLNESS

An innocuous food does not contain contaminants that can harm consumers' health. Food contaminants are either biological or chemical agents, foreign matter, or other substances and materials that are present in food and can endanger its safety. Foodborne illness is caused by the consumption of food contaminated with microorganisms or toxic substances that affect consumers' health. Each year, 600 million people (1 in 10 people) suffer foodborne illness, and 420,000 of these die (WHO, 2015).

A hazard denotes any component that may be present in a food product and may harm the consumer (Mortimore and Wallace, 2013). There are three basic types of contamination hazards: physical, chemical, and biological. If any of these are present in certain amounts in food, they can affect consumers' health.

3-1 PHYSICAL HAZARDS

The most common of the food hazards are physical hazards due to the presence of foreign matter in food. Unlike other hazards, they do not cause disease; however, they can cause choking and asphyxiation. These contaminants can be introduced into the food during the production process. Examples of physical hazards include glass, pieces of metal, and wood chips.

3-2 CHEMICAL HAZARDS

Photo.4 Pesticides or agrochemicals

Chemical food hazards refer either to contamination by chemical substances at high concentrations (heavy metals, chemical additives, pesticides, or agrochemicals) or the use of prohibited chemical substances. In agricultural production, chemical hazard contamination can occur at any phase of the production process. A very clear example is the inappropriate use of pesticides and synthetic chemical fertilizers. In fish production by aquaculture, potential chemical hazards include residues of veterinary drugs, medications, or other chemicals that are used in production and may exceed the permitted limits.

3-3 BIOLOGICAL HAZARDS

Biological or microbiological hazards are caused by microorganisms (e.g. bacteria, viruses, fungi, and parasites) in food. Undoubtedly, biological hazards are the most important and the most harmful source of risk for consumers.

Bacteria plays a very important role in food safety because they are the main causative agents of widespread outbreaks of foodborne illness. The most important harmful bacteria in vegetables are Escherichia coli, Salmonella spp, Shigella, Campylobacter, Listeria monocytogenes, and Bacillus cereus. Among viruses, hepatitis A virus has caused significant outbreaks of bloodborne illness.

Bacteria related to fish farming are as follows: *Aeromonas hydrophila*, *Plesiomonas shigelloides*, *Vibrio parahaemolyticus*, *V. vulnificus*, *V. cholerae*, *Clostridium botulinium*, *Listeria monocytogenes*, *Streptococcus initiae*, *Erysipelothrix rhusiopathiae*, *Leptospira interrogans*, *Yersinia enterocolitica*, *Pseudomonas* spp., *Mycobacterium* spp. (SAGARPA-SENASICA, 2008).

3-3-1 Microbiological analysis methods

(1) Plate counting method

This is a general microbiological analysis method that employs an agar medium. Specific bacterial species can be detected by using different selective media. Although live microorganisms can be trapped and the proliferation capacity used as an index, many bacteria in the environment cannot be cultured (detectable) by conventional methods.

(2) Microcolony Method

Many microorganisms in the environment do not form visible colonies using the culture method, but they can form fine colonies that are not visible to the naked eye. Microscopic examination enables detection of live microorganisms, using proliferation capacity as an index, faster and more accurately than does the culture method.

(3) PCR Method

Using microbial DNA extracted from samples, PCR is performed using a set of primers that target a specific genetic sequence, and microorganisms are detected by either the presence or the absence of gene amplification.

For detection, the gene sequence of the target microorganism must be known. Moreover, although PCR can confirm either the presence or the absence of microorganisms, it cannot determine the viability of the microorganisms.

Recently, a technique has been developed that can distinguish live or dead microorganisms by selecting genes, but this technique is limited to specific species of microorganisms and special skills must be learned to use it.

(4) Amplicon Sequencing Method

This method detects microorganisms present in a sample using a next-generation sequencer to target genes. As it enables thorough analysis of the microbial species present in the environment, it has become the mainstream of microbial community structure analysis.

With increased demand for this method, the number of contract analysis services has increased and the price of analysis has decreased. However, this method is still more expensive than other methods, and it takes time to obtain results because of the need to use a contract analysis service. However, in recent years, portable analyzers have been developed, and improvements in both the time and the price of analysis are expected. Thorough analysis using this method is recommended to understand microflora under normal operating conditions when establishing an aquaponics system.

4. CONTAMINATION SOURCES AND NECESSARY PREVENTIVE MEASURES

4-1 CONTAMINATION SOURCES

Contamination sources are the points of origin of the contaminant, and it is most important to be able to identify the potential sources of contamination in productive units. In the field, the main sources of pollution are as follows:

1 Water
2 Soil
3 Air
4 Utensils and equipment
5 Raw materials and ingredients used for production
6 Domestic and wild animals
7 Workers

4-1-1 Water

Water is essential for any food production system; it is used in crop irrigation, in the application of pesticides and fertilizers, in fish farming, in packing operations, and for workers' hygiene. Water carries microorganisms, chemical substances, and foreign materials to the cultivation site. Therefore, water is an important carrier of biological, chemical, and physical contamination hazards. The main biological contaminants of water include different bacterial, viral, and parasitic pathogens.

4-1-2 Soil

Soil contains a large number and variety of microorganisms. As microorganisms can multiply in the soil, they can be present in very large amounts. Many of these microorganisms contaminate food from the ground. In particular, soil contaminated with fecal matter may be the source of pathogenic bacteria and viruses in people’s food.

4-1-3 Air

In the air, microorganisms are present in dust and droplets of moisture. Air can contain the spores of some pathogenic bacteria.

4-1-4 Utensils and equipment

Many microorganisms present in the environment can adhere to production equipment and contaminate food. A broad range of equipment is used during harvesting, transportation, processing, and storage. All utensils and equipment used should always be kept clean.

4-1-5 Raw materials and ingredients used for production

Many kinds and different quantities of ingredients are used during the process of food production. Pesticides and fertilizer products are important sources of contamination in agricultural food production. In fish farming, raw materials and ingredients that are used, such as pesticides, heavy metals, and medicines, are hazards that can cause contamination (SAGARPA-SENASICA, 2008).

4-1-6 Domestic and wild animals

Food can be contaminated through contact with animals. The hairs and feathers of domestic animals contain many types of bacteria, some of which are pathogenic for people.

4-1-7 Workers

In food production, numerous people can come into contact with food in different phases of the process. Workers can be considered as an important source of food contamination because of being potential carriers of pathogenic microorganisms. The most common causes of contamination are inadequate hand washing and lack of proper hygiene management. Therefore, it is necessary to train workers in hygiene issues to reduce the risk of them contaminating food.

4-2 NECESSARY PREVENTIVE MEASURES

All foods are prone to contamination, and ingestion of a food contaminated with either pathogenic microorganisms or certain other substances may result in foodborne illness. Therefore, it is necessary to identify and control the sources of contamination present in the production process and implement preventive measures.

Sources of contamination exist in the soil, water, air, inputs used for production, utensils, and all surfaces with which that food comes into contact, including the workers.

Everyone involved in the food production process (from cultivating the product on the farm to the final consumer) are responsible for controlling contamination hazards. To produce contaminant-free food, producers must implement a GPP (Good Production Practices) application program.

GPP is defined as the set of recommendations and the application of the necessary measures to reduce the risks of food contamination, as applied in production and processing units. They are also designed to ensure the safety of the working environment and protect the health of workers.

These measures are as follows:

4-2-1 Selection of production site

Appropriate site selection is critical to the success of any food producing unit. Producers are recommended to obtain information about the previous use of the land and the adjoining properties to ascertain the probable impacts on safety in production. The use of adjoining land should be evaluated to identify potential sources of contamination and to establish physical barriers to prevent contamination by runoff, animals, or other risk factors associated with such land (SAGARPA-SENASICA, CESAVEJAL, 2007).

4-2-2 Facilities

GPP requires basic facilities to facilitate their appreciate operation.

(1) Perimeter fences and entrance doors

Perimeter fencing is used to prevent unwanted entry of domestic and wild animals, in addition to people, to the production unit.

(2) Sanitary

Sanitary facilities are installed to ensure that workers do not defecate outdoors. Moreover, they should incorporate a place for handwashing. Producers must comply with the following stipulations (SAGARPA-SENASICA, 2018; CESAVEMICH, 2006a):

- Provide toilet paper, liquid soap, drinking water, paper towels for hand drying, and trash cans.
-Place signs that indicate the need to wash one’s hands after using the toilet.
-Provide disinfectant solution for hands.
-Place exclusive cleaning and disinfection equipment.
- Install sanitary facilities far enough from the production area not to represent a risk of contamination. They should not be in the production area.
-Ensure that there are no sewage leaks.

(3) Meal Place (Rest Place)

Producers are required to provide an area for workers to eat their meals. Such areas must comply with the following requirements:

-They must be outside the food production area.
-They must have material and accessories for sanitation and trash storage.
-They must be protected to prevent the entry of domestic and wild animals.
-They should not be sited in storage areas of chemical substances or other materials that endanger human health.

(4) Trash Cans

Trash cans must be provided to prevent cluttering by garbage in the production unit.

(5) Signaling

All facilities must be labeled for identification purposes. The objective is to inform both workers and visitors of prohibited activities, obligations, and safety aspects. Labels must comply with the following:

- Be clear, visually and written in the worker's language.

(6) Education and Training

Food producing companies must have a person responsible for application of the BPP and must be able to demonstrate that all workers comply with the measures to prevent contamination risks. Likewise, a training plan for implementing the GPP must be provided.

4-3 HYGIENE

Hygiene is defined as all washing and disinfection measures to ensure cleanliness of the production areas, food contact surfaces, and the hands of workers. To prevent contamination of food by either pathogenic microorganisms or chemical residues, hygiene must be maintained throughout the production process, and the facilities, tools, machinery, work equipment, and surroundings of the production unit must all be kept clean. Hygiene measures must be continuous and respected by both workers and visitors to the facilities. They include the following washing and disinfection processes:

-Removal of excess material.
-Rinsing with water.
-Washing with detergent and a brush.
-Draining excess water.
-Applying sanitizing substances.
-Keeping the environment dry.

4-3-1 Hygiene facilities

Hygiene facilities should be kept clean during all production processes. The waste derived from hygiene facilities should neither be brought into the production area nor leaked to water sources used by people (CESAVEMICH, 2006b).

4-3-2 Hygiene of tools and equipment for work

All tools and equipment for work must be washed and disinfected. The daily use equipment and utensils, such as scissors, tables, and buckets, that come into direct contact with the product must be washed and disinfected both before and after use.

4-3-3 Personnel health and hygiene

One of the most important factors in food contamination is the health and hygiene of the workers. Production unit workers must know and apply hygiene practices to reduce the risk of contamination of food during its preparation.

A training program should be implemented to ensure that all personnel, including those not involved directly in food handling, adhere to the established hygiene practices. (Martinez-Tellez et al, 2007).

According to CESAVEMICH (2006b), workers and visitors must comply with the following hygiene practices:

-Do not defecate outdoors.
-Wash and disinfect their hands.
-Keep their nails clean and short.
-Consume food in the dining space.
-Do not litter inside the productive unit.
-Report any wound that causes blood to be shed.

4-3-4 Preparation of a chlorine-based solution for disinfection

The concentration of chlorine for disinfection is measured in parts per million (ppm). The concentration recommended for disinfecting surfaces, toilets, floors, tables, tables, and work tools is 50–100 ppm.

4-3-5 Product transportation

Products must be transported in conditions that minimize the possibility of contamination. Vehicles used for transport must be constructed in a way that reduces product damage, prevents access by either pests or dust, and allows for easy cleaning. The platforms or containers must be designed in such a way that the product is protected by either shade mesh, tarpaulins, or closed transport (refrigerated box or dry box). Product transportation must be done both carefully and in a timely manner.

4-3-6 Training

All workers should participate in continual training to develop and update their knowledge of the hygiene measures required during food processing and food handling to prevent consumers from becoming sick through eating contaminated food. Both established and eventual employees must be trained from the start, during the season, each time new personnel enter, and when the procedures are changed. Some of the basic training topics are as follows (SAGRAPA-SENASICA, 2018):

-Basic microbiology.
-Management of fauna.
-Workers' hygiene practices.
-Preparation of disinfectant substances.
-Cleaning and disinfection of machinery and equipment.
-Water management.
-Equipment calibration.
-Storage of material and supplies.
-Transport of the product.

5. HYGIENE MANAGEMENT ON SITE

5-1 PERSONAL HYGIENE PRACTICE

-It is advised to prepare a set of clothes that will be used only in the work area; these clothes must be kept clean at all times.
-Nails must be kept short.
-Hands must be washed with soap (for example, after using the bathroom, before and after changing activities). This is very important, because the hands can transport microorganisms harmful to the health of both humans and fish.
-It is important to remember that the best disinfectant is soap and water.

5-2 PRACTICE OF HYGIENE IN FACILITIES

5-2-1 Prevention of contamination

For the purpose of preventing contamination of facilities, the following measures for hygiene are defined:

-Fishing nets and buckets must be clean. When workers have finished using them, these items must be washed and dried in the sun.

-Equipment and materials for cleaning in the aquaculture area must be stored in sufficient quantities and in good condition.

-It is important that equipment and cleaning materials are assigned to a specific area of the module and used exclusively for that area to prevent cross-contamination.

-Food residues (organic matter) that stick to the tank walls in the fish farming tanks must be cleaned off daily.

-In the settler, the organic matter found on the surface must be removed daily. This includes intestinal organisms (such as Coliforms, Salmonella, Shigella, and Vibrio).

-In the clarifier, the organic matter floating on the surface must be removed daily. This includes intestinal organisms (such as Coliforms, *Salmonella* spp., *Shigella* spp., and *Vibrio* spp.).

5-2-2 Food storage

-Balanced foods should be stored in cool and dry places to prevent decomposition of their ingredients and contamination by bacteria and fungi, because these could generate toxins that can harm fish when in a favorable environment.

-Stored food must be separated from fuels, pesticides, or other chemical agents that pose a safety risk.

Photo.5 Rodents

-It is important to have a control program for harmful fauna, such as rodents and insects, to prevent them entering the system and contaminating food.

-Food should not be stored in places that smaller mammals, such as cats and dogs, can reach.

-It is important to wash one's hands before handling balanced food.

-The food should be placed in dry containers.

5-2-3 Harvest

During the process of harvesting, care must be taken to ensure the hygiene of the participants, the utensils, the containers used, the environment, the water and drinking ice to ensure the safety of the food and avoid bacterial contamination. Before harvesting, fasting should be implemented to purify the fish.

The purpose of purification is to eliminate possible bad odors and flavors from the flesh of the fish. Moreover, it can improve microbiological safety.

Purification consists of suppressing the fishes' feed and transferring them to clean water; this involves a 50–90% water exchange. The water level of the fish tank is lowered by 10–50 %, and the tank is recharged with new water up to the original level.

This treatment reduces the risk of contamination by microorganisms such as coliforms. Groups of coliform bacteria have the highest pathogenicity (they produce diseases with greater frequency and virulence), and they are intestinal microorganisms. Other intestinal organisms include *Salmonella* spp., *Shigella* spp. and *Vibrio* spp.

Harvesting must be done as early as possible, as temperature is a determining factor for deterioration of the product. Therefore, the equipment and tools used for harvesting must meet the following conditions:

-Scoop nets must be clean
-Containers and buckets must be clean
-Plastic tables must be clean and disinfected
-Scissors must be clean and disinfected
-Anti-skid gloves must be clean
-Coolers must be clean
-Ice

Immediately after being cut, the fish are placed in clean water in a container to accelerate bleeding and are then moved to another container filled with clean water for rinsing by removing the remnants of blood from the surface.

The cooler box is prepared by placing crushed ice (the fragments of ice should be small) at the bottom, and the fish are then placed horizontally on the ice until the surface is covered. The fish are then covered with ice, and another layer of fish is created and covered with ice. This ensures that the product is surrounded completely by ice so that it cools uniformly and is preserved well.

The process of bleeding, washing, and storage on ice should be very fast and is better to be performed by two or three people.

Photo.6 Harvest

5-2-4 Monitoring of hygiene management

It is necessary to maintain the safety of the product and the aquaponics system. Regular monitoring should be conducted to avoid contamination by foreign substances and pathogens.

Therefore, it is very important to register and control the physicochemical parameters for immediate detection of any sudden changes that may affect the health of organisms. Moreover, it is necessary to keep the farming area clean, as this inhibits the proliferation of microorganisms. Therefore, the following is recommended:

(1) Understanding the Normal Condition

An aquaponics system uses a large amount of water, the quality of which declines during the farming process because of the accumulation of organic matter generated by food that is not consumed and the feces of the fish, which favors the proliferation of microorganisms. In particular, there is a high risk of contamination by enteric bacteria, so they must be monitored carefully. During the farming period, from the beginning of the cycle to the first harvest, the water is monitored periodically via bacteriological analyses. These are recommended to be carried out every week at first, and then every 15 days while the system stabilizes. The results of this monitoring allow the variation in the number and type of microorganisms in normal times to be understood.

(2) Microbiological Inspection Before Shipment

To ensure the safety of the product, it is important to perform a microbiological analysis of the product before the first shipment.

(3) Regular Sampling

If the standards for i) and ii) are reached, sampling can be conducted approximately once a month. Water samples (approximately 500 ml) are collected periodically and transported to an analytical institution for analysis. Moreover, analysis is conducted one week before shipment (before the process of fasting in the case of aquaculture) to confirm that there are no abnormal results. The method of analysis is based on the method of cultivation. When an abnormal result is found, shipping must stop immediately and the necessary measures must be taken.

(4) Temporary Sampling

When there is either a change in the hygiene management procedure method or an abnormal result is found, the operator will take samples to clarify the cause. The system must be stopped temporarily until the cause becomes clear and countermeasures are taken.

(5) Regular Visits

Even if the aquaponics system is functioning normally, it is important to ensure sanitary management and take immediate measures if there is any deficiency.

(6) Emergency Response

1) Abnormalities of the Aquaponics System and/or the Product

If any abnormality is found in either the aquaponics system or the product, this should be reported immediately to the manager and the necessary measures taken. The operator should contact the relevant agencies and verify the situation. The cause should be analyzed as necessary, and the operator should record the situation.

2) Workers' Poor Physical Condition or Injury

If a worker becomes either ill or injured, immediate action, such as seeing a doctor and reporting the situation to the manager, should be taken. The manager should confirm the situation promptly.

3) Serious Abnormal Situations

When serious anomalies are observed, such as the mass death of fish or the crop dying, the situation must be reported to the manager immediately and the cause of the problem identified. Such a problem may be due to either a technical fault, a mechanical fault, or contamination.

If the problem is due to illness, the entire batch of product should be discarded to avoid contamination and remedial measures, such as sanitary cleaning, disinfection, and drying, should be taken.

4) System Disinfection

After the system water is disinfected with chlorine, it should be discarded. Then, the aquaponics system must be cleaned with a brush. After cleaning the aquaponics system with a brush, a chlorine solution (4-3-d) should be sprayed into the water tank and left for 30 minutes or more. Disinfection should be carried out twice. After completion, the water should be drained and new water introduced.

As residual chlorine has a great influence on marine products, the concentration of residual chlorine should be measured at this point and, if required, corrective measures should be taken, such as adding sodium thiosulfate.

After confirming the security of the aquaponics system with stakeholders, it can be restarted. After restarting, the processes 1) and 2) must be re-implemented.

5) Ensuring the Safety of Workers During Disinfection

Ingestion of a chlorine solution (50–100 ppm) will not affect the human body, but chlorine gas generated from a high concentration of chlorine in water is toxic. Workers should be careful to avoid inhaling chlorine gas, and should use either a gas mask or an oxygen respirator. Workers must also avoid skin contact with chlorine, so they must use personal protective equipment such as gloves, safety glasses, overalls, boots, and masks. When using this product, producers must ensure that there is adequate ventilation.

6. MEXICAN LEGISLATION

NOM-003-SEMARNAT-1997 Establece los límites máximos permisibles de contaminantes para las aguas residuales tratadas que se reúsen en servicios al público.

NOM-009-PESC-1993 Establece el procedimiento para determinar las épocas y zonas de veda para la captura de las diferentes especies de la flora y fauna acuáticas, en aguas de jurisdicción federal de los Estados Unidos Mexicanos.

NOM-010-PESC-1993 Que establece los requisitos sanitarios para la importación de organismos acuáticos vivos en cualesquiera de sus fases de desarrollo, destinados a la acuacultura u ornato, en el territorio nacional.

NOM-027-SSA1-1993 Bienes y Servicios - Productos de la pesca - Pescados frescos-refrigerados y congelados - Especificaciones sanitarias.

NOM-011-PESC-1993 Para regular la aplicación de cuarentenas, a efecto de prevenir la introducción y dispersión de enfermedades certificables y notificables, en la importación de organismos acuáticos vivos en cualesquiera de sus fases de desarrollo, destinados a la acuacultura y ornato en los estados unidos mexicanos.

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NOM-115-SSA1-1994 Bienes y servicios - Métodos para la determinación de *Staphylococcus aureus* en alimentos.

NOM-128-SSA1-1994 Establece la aplicación de un sistema de análisis de riesgos y control de puntos críticos en la planta industrial procesadora de productos de la pesca.

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8. COOPERATORS

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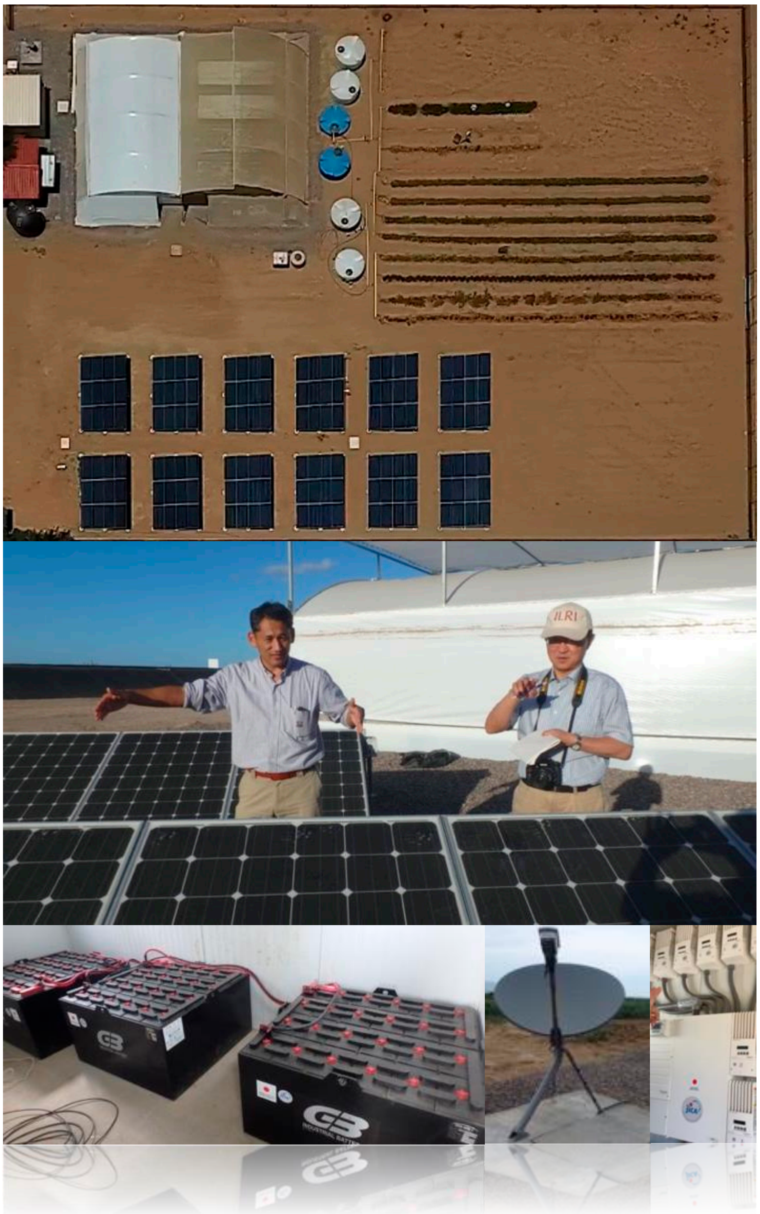
3-2 Technical Manual for Power Supply System: Maintenance and Management



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Dr. Kotaro Tagawa *(Associate Professor, Faculty of Agriculture, Tottori University)*

Table of Contents

1. POWER SUPPLY SYSTEM

Configuration of power supply system for aquaponics combined with open culture is designed primarily in consideration of power grid services at the installation site. There are three configurations of power supply system based on the sources of photovoltaic and power grid:

I. Photovoltaic system and emergency generator
II. Photovoltaic system, power grid, and emergency generator
III. Power grid and emergency generator

1-1 PHOTOVOLTAIC (PV) SYSTEM CONNECTED WITH EMERGENCY GENERATOR

This system is to supply electric power for food production in aquaponics combined with open culture at farmland without power grid. The advantage of this power supply system is to generate and consume the electricity on site. This system is configured by combining a stand-alone PV system with an emergency generator (Fig. 1). The stand-alone PV system is consisted of a PV array, charge/discharge controllers, inverter(s), and battery bank.

The emergency generator works and supplies automatically the electricity to battery bank when voltage level of battery bank become lower than a reference voltage, as well as by a failure in the inverter of the PV system to supply directly the power to the electrical loads.

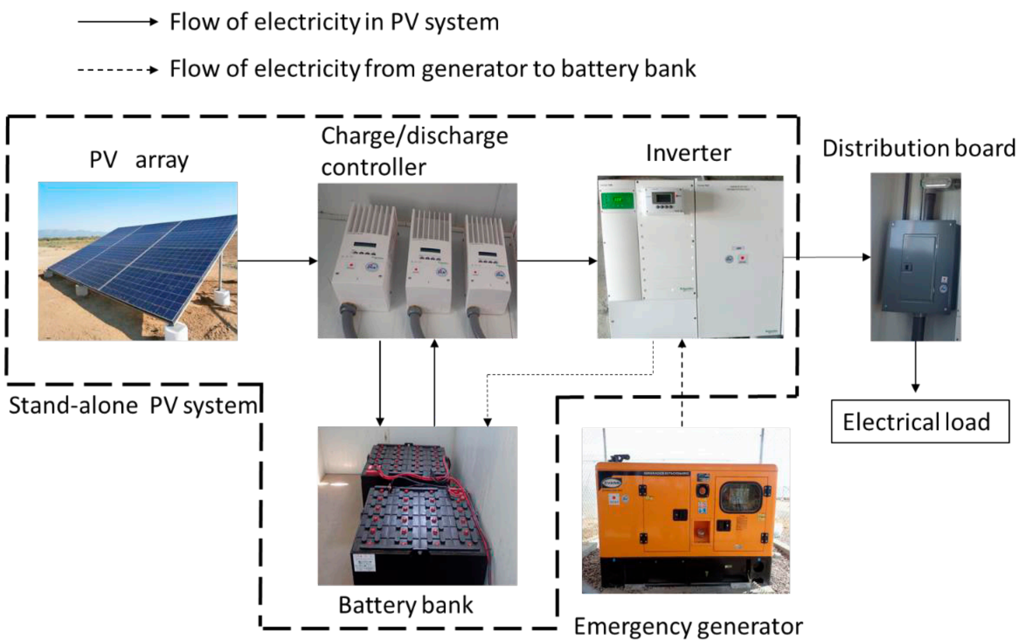

Fig.1 Typical design of power supply system consisted of stand-alone PV system and emergency generator

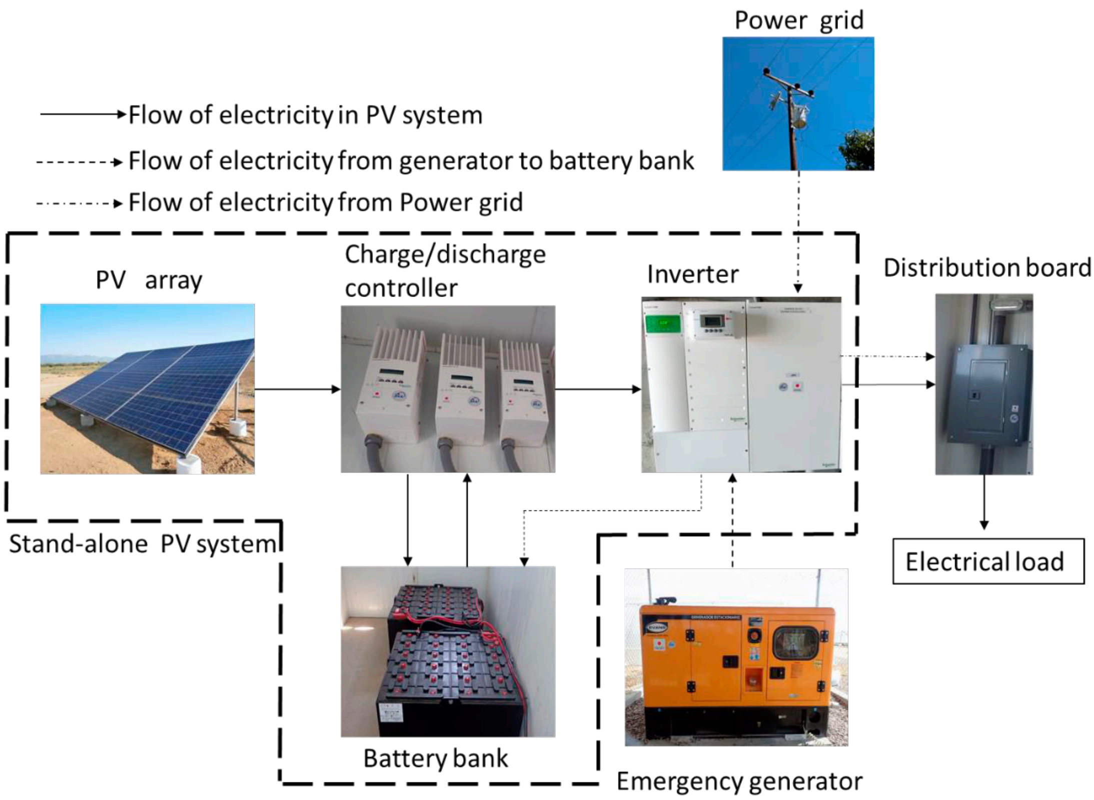

Fig.2 Typical design of power supply system consisted of PV system, power grid, and emergency generator

1-2 PHOTOVOLTAIC (PV) SYSTEM, POWER GRID, AND EMERGENCY GENERATOR

The typical configuration of power supply system consisted of photovoltaic system, power grid, and emergency generator is shown in Fig. 2. This power supply system is useful in the area where power grid is developed. The advantage of this system is to supply to the electrical load by combination of PV system and power grid. For example, PV system is generally operated in daytime, while power grid is used in night time. Power grid is also useful to supply electricity smooth and quickly when the shortage of electricity in battery bank happened. On the other hand, if the power failure occurred suddenly, the emergency generator work to charge the battery bank.

1-3 POWER GRID AND EMERGENCY GENERATOR

This configuration is generally consisted of power grid and emergency generator in the area where power grid is fully developed. The emergency generator should be equipped for the power failure and unexpected accident. In situation of small capacity of electrical loads, a portable type generator can be used.

2. OPERATION AND MAINTENANCE FOR POWER SUPPLY SYSTEM

Power supply system consisted of PV system and generator is electric facility with the generation of high voltage and electrical current. Generally, the contractor who has special knowledge and skill for electrical engineering must perform the periodic maintenance and inspection works. Therefore, the owners/users should not repair and modify the connection and equipment of power supply system by their own decision. User actions for the preventive maintenance of the PV system are following:

2-1 CLEANING AND CLEARANCE SURROUNDING PV ARRAY

- Do not put anything above or below the PV array
- Cleaning the periphery of PV array
- Removing high-growth weed surrounding PV array
- Care for small stone scatter on PV array (avoid vehicle pass)

2-2 CLEANING SURFACE OF PV ARRAYS

- Cleaning the sand, dust, and bird dropping accumulated on the surface of PV array using soft and dry material once two week (Photo. 1)
- Great care must be taken for hurting a surface of PV array
- Use of ground water is not recommended because salt deposit on the surface after cleaning. Moreover, it is expected that salt deposition causes the corrosion and deterioration of metal at electrical connector

Photo.1 Cleaning surface of PV arrays

2-3 MANAGEMENT OF SURROUNDING ENVIRONMENT OF ELECTRICAL EQUIPMENT

- Do not put anything surrounding the control devices, such as charge/discharge controllers, and power conditioner, to ensure safety
- Do not put anything surrounding the electrical equipment, such as battery bank and distribution board, to ensure safety (Photo. 2)

- Clean up the room in which control devices and electrical equipment are installed
- Full the battery cell with the battery fluid at the given liquid surface in the battery cells to keep the charge/discharge performance of the battery
- Perform the ventilation inside of the room to remove heat emitted from the devices and any fumes generated by the chemical reaction inside the battery
- Do not touch and approach to electrical equipment with wet hands and body

(a) Battery bank

(b) Inverter

Photo.2 Surrounding environment of electrical equipment

2-4 MANAGEMENT OF EMERGENCY GENERATOR

- Generator automatically start to work and supply electric power (Photo.3)
- Ventilation must be allowed for removing heat and any exhausted gases due to burning fuel when the generator is installed indoors
- Check the leakage of cooling liquid from the pipe
- Check and remove any nest of animals inside or outside of generator
- When the generator is installed outdoors, clean the soiling on the body and remove any debris and vegetation near the unit
- Run the generator once-a-month to ensure proper operation
- Check and record the fuel level. If the fuel level is lower, full up the fuel tank

Photo.3 Emergency generator

2-5 PROPER MANAGEMENT OF POWER PLUG AND RECEPTACLE

- It must be taken care that liquids, such as rearing water or nutritious, do not spill on the electrical outlet or the power source plug in green house for aquaponics and hydroponics
- Clean up soiling and salt attached on the electrical outlet or the power source plug to prevent electric leakage and short-circuit

2-6 VISUAL INSPECTION OF EQUIPMENT

- Perform regular inspection of PV system, generator, electrical devices

2-7 SECURITY MEASURE OF POWER SUPPLY SYSTEM

- Set a sign saying ‘Danger! Keep out!’ to prevent the approach of people who is not concern at PV system and power supply system (Photo.4)
- Perform the locking control of room, in which control devices and electrical equipment are installed, to prevent the access to the device of PV system without permission of an owner and manager

Photo.4 Sign and warning for electrical equipment

2-8 MEASURES FOR HURRICANE

- Before hurricane comes, check and fix the looseness of bolts for fixation of PV panel
- Visit the site after hurricane passes and check with safety the damage of PV system, such as loosening of the ground, the collapse of PV array, crack of PV panel, disconnection of cable, so on, in case that natural disasters as hurricane, earthquake, floods, heavy rain, and lightning occur (Photo.5)
- When failure of devices in power supply system or abnormality operation caused by PV system are found, make contact with contractor/manager quickly and follow the instruction to take countermeasures

Photo.5 Damage of PV array by hurricane

2-9 POST OF EMERGENCY CONTACT INFORMATION

- Post the detail (name, emergency contact information) of all the concerned people at the door of room for control device to contact them in any emergency (Photo.6)

Photo.6 Emergency contact information

3. REGULAR VISUAL INSPECTION FOR FACILITY AND EQUIPMENT

Owners/users must maintain the usage environment of operating power supply system and carry out the daily visual inspection of equipment to prevent a significant performance degradation and the equipment failure, as well as the facilities. The details for daily visual inspection are described as follows:

3-1 PV ARRAY AND PANELS

- Soiling condition on the surface of PV panel (dust, bird's dropping, …) (Photo.7)
- Shade occurred by weeds
- Scar and damage on the surface of PV panel
- Deformation and damage of frame of PV panel
- Breakdown and burning of terminal box on the rear panel
- Deformation and damage of mounting frame of PV panels
- Looseness and deformation of bolts for fixation of PV panel
- Breakage of a cable sheath connecting to PV panels

Photo.7 Soiling on PV panel

3-2 CONTROL DEVICES

- Breakdown and corrosion of charge/discharge controller or inverter box
- Breakage of a cable sheath within range of vision
- Looseness and deformation of bolts and terminals within range of vision
- Presence and absence of strange noises, vibration and bad smells emitted from the working devices
- Check heat generation or high temperature on the outside of control devices (Check temperature condition on it at nominal operation)
- Check the contents indicated on the display
- Displaying error message
- Clean up the room

3-3 BATTERY BANK

- Check expansion, recess, and crack on outside of battery
- Check the liquid surface of battery fluid in the battery cells
- Looseness and corrosion of connecting terminals
- Breakage and looseness of a cable sheath
- Remove things made of metal on upper surface of battery to prevent the short-circuit between terminals of battery
- Ventilation indoor of the battery room
- Check the air temperature in the battery room
- Presence and absence of bad smells emitted from battery
- Check the obstacles surrounding the battery
- Remove dust accumulated on the upper surface of battery
- Clean up the battery room

3-4 DISTRIBUTION BOARD

- Breakage of a cable sheath and looseness of terminal
- Check ON/OFF state of switching on distribution board

3-5 CONNECTION STATUS OF POWER RECEPTACLE IN GREENHOUSE

- Connecting the electrical cable for equipment with power receptacle firmly
- Check the exposed plug of electric wires
- Cover or uncover the exposed plug of electric wires to prevent from wetting
- Check the dust adhesion on the power receptacle

4. TROUBLE SHOOTING FOR OWNERS/USERS

Trouble shooting for PV system and power supply is shown in Tab.1.

Tab.1 Trouble shooting

Typical failures	**Measures/Solutions**
Soiling condition on the surface of PV panel	Cleaning soiling accumulated on the surface of PV array using soft and dry material.
Collapse and clack of PV panel	Contact with the contractor using post of emergency contact information, and then follow the contractor's instructions.
Electrical equipment (pump, blower, etc) in greenhouse doesn't work when the electric power is supplied.	1. Check the connection of plug of electric cable for the equipment. If the plug is disconnected, connect the plug to electrical outlet. 2. Check ON/OFF state of switching for electrical equipment (pump, blower, etc) on distribution board in battery room. If the switch is OFF state, turn on the switch. 3. Replace with spare pumps and blowers
Electric power supply is stopped.	1. Check the error message indicated on the display of control device. 2. Check that the generator automatically is working and supplying electric power. 3. Check ON/OFF state of switching for electrical equipment (pump, blower, etc) on distribution board in battery room after the generator is working. 4. If the switch is OFF state, turn on the switch to work the electrical equipment again. 5. Check that the electrical equipment work again.

	6. Check that the electric power is supplied stably. 7. Contact with the contractor using post of emergency contact information, and then follow the contractor's instructions.
After the generator is working at the failure of power supply, the operation and stopping of electrical equipment is repeated.	1. Check ON/OFF state of switching for electrical equipment (pump, blower, etc) on distribution board in battery room after the electrical equipment stops. 2. Turn on the switch to work the electrical equipment again. 3. Check that the electrical equipment works stably.
Generator doesn't work when electric power supply is stopped.	1. Check and record the fuel level. If the fuel level is lower, full up the fuel tank. 2. Check the leakage of cooling liquid from the pipe 3. Check and remove any nest of animals inside or outside of generator 4. Work the blower for the aeration of aquaculture using portable generator. 5. Contact with the contractor using post of emergency contact information, and then follow the contractor's instructions.
Fire occurrence in PV system and related devices.	1. If a fire is small, extinguish a fire 2. If a fire becomes large, stay away from the PV system and related devices during and after a fire. 3. Call the firefighting station. 4. Contact with the contractor using post of emergency contact information, and then follow the contractor's instructions.
Failure and abnormality in power supply system including PV array, battery bank, control devices and generator.	Contact with the contractor using post of emergency contact information, and then follow the contractor's instructions.

5. COOPERATORS

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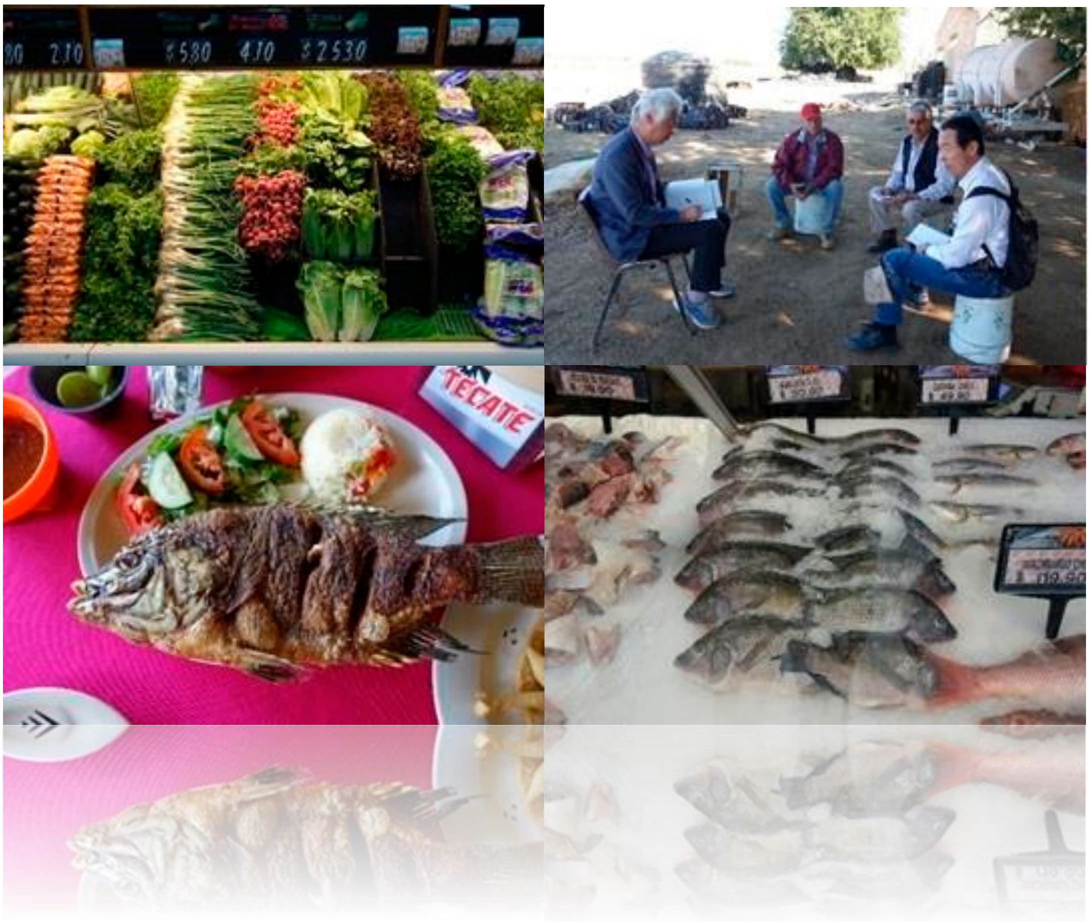
- Mr. Yu Takaki, Graduate school student, Tottori University

4. Technical Manual for Management of Aquaponics Combined with Open Culture



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1. PRACTICE OF APPROPRIATE BUSINESS MANAGEMENT AIMING AT ESTABLISHMENT OF AQUAPONICS MANAGEMENT COMBINED WITH OPEN CULTURE

Aquaponics combined with open culture is predicated on expensive capital investment and precise production technology, and there is a risk on management. Therefore, in order to lead aquaponics management to growth, it is important to effectively establish a business management method that suits own management body.

The main functions that make up business management include production, labor, sales, purchasing, finance, and information. In promoting aquaponics management, the method of adopting these functions varies depending on the management life cycle and corporate characteristics.

For example, from the aspect of the life cycle, in the introduction period of aquaponics management, in order to put management activities on track early, priority is given to the production management function so that stable production is possible first. At the same time, manager must strive to establish a financial management function in order to shift to profitable management as soon as possible. When shifting to the management development period, in order to promote the expansion of production scale, the emphasis will be on business management functions such as finance, sales, and information.

If the character of the management body working on aquaponics combined with open culture is different, the behavioral pattern reflecting the management function will also be different. If the management body is a family management, management will be given priority to the realization of income, and there will be an issue of organic cooperation between aquaponics management and households. On the other hand, if the management body is a corporate, it will concentrate on activities that pursue corporate profits by clearly separating the management of aquaponics from households.

It is necessary to clarify what kind of aquaponics management the manager wants to create, and to establish a management method suitable for their own management body. When faced with management problems, it is necessary to make efforts to acquire knowledge and experience so that appropriate selection actions can be taken as to which business management function corresponds to problem solving.

2. PLANNED MANAGEMENT ACTIVITIES

In order to lead aquaponics management to growth, it is important to strive for systematic business management in accordance with the PDCA cycle. The PDCA (Plan-Do-Check-Action) cycle is used to develop management by steadily accumulating management activities according to a series of flow of planning, management practice, analysis of the management results, and management improvement. It bases on the idea of taking operational management according to the plan, analyzing and summarizing management results, and taking effective measures to improve management.

In order to carry out systematic business management, it is important to first accumulate the data related to the management of aquaponics by using facility operation diaries, labor diaries, business bookkeeping, etc. Next, management analysis is performed using their book data to clarify the current characteristics of aquaponics management. Through this work, it becomes possible to identify items that require management improvement. If management improvement items become clear, measures for those will be incorporated and a management plan for the next term will be created. It is possible to promote management growth by accumulating such daily and administrative business management activities. The prospect of management innovation will be opened on the extension line of the strategic management activities.

3. MANAGEMENT IMPROVEMENT TACKLING BASED ON MANAGEMENT ANALYSIS

In the case of small-scale management body, managers can steer management based on experience and intuition. However, in the case of increasing of facilities size and business size, the need for scientific management based on business records increases, such as aquaponics management. In particular, the role of management analysis is important in order to accurately identify problems in management and take appropriate improvement measures.

For management analysis, many methods have been developed and practiced with the analysis target, the management body and management department to be analyzed, comparison methods of analysis results, and analysis indicators. Here, based on the understanding that as many people as possible should understand the characteristics of aquaponics management developed through the SATREPS project, we will explain about commonly used management analysis methods.

What we introduce as management analysis methods are productivity analysis, profitability analysis, production cost analysis, and breakeven point analysis. By applying these analytical methods to the model site in Los Planes, Southern Baja California, where field verification test was conducted, the technical and management characteristics of for aquaponics combined with open culture will be clarified and the conditions for popularization will be clarified. The results of management analysis will be useful information for managers and leaders of related organizations working on aquaponics practices.

In order to conduct management analysis more accurately, book data relating to management performance is required. Business bookkeeping, labor diary, production management ledger, sales ledger, etc. fall under this category, but financial statements based on management bookkeeping and labor diary are indispensable data for business analysis. Enforcement of making book data is demanded aiming at the practice of scientific business management.

4. PRACTICE OF MANAGEMENT ANALYSIS ON AQUAPONICS COMBINED WITH OPEN CULTURE

4-1 OVERVIEW OF THE MODEL SITE MANAGEMENT FOR MANAGEMENT ANALYSIS OF AQUAPONICS COMBINED WITH OPEN CULTURE

4-1-1 Management elements

<Labor>

Family labor; Owner

Employment labor; 2 permanent employees, hiring temporary workers as needed

<Land>

Own farmland area 10 ha (Including aquaponics land 2,372m^2)

<Machinery and facilities>

A list of machinery and facilities introduced to the model site for the field verification test of aquaponics combined with open culture is shown as following.

Tab.1 Machinery and facilities used in field demonstration of aquaponics combined with open culture, Model site in Los Planes

Item		Acquisition value (peso)	Service life of component (year)	Annual depreciation expenses (peso)	Annual repair expenses (peso)
For Aquaponics	Aquaculture component	179,294	10	17,929	8,965
	Hydroponics booth	129,316	10	12,932	6,466
	Open culture booth	173,321	10	17,332	8,666
	Solar insallation	2,800,249	10	280,025	140,012
	Net room facilites	2,132,241	10	213,224	106,612
	Other common items	39,116	10	3,912	1,956
Sharing with existing cultivation sector	Tractor	720,000	10	72,000	36,000
	Pick-up truck	400,000	5	40,000	20,000
	Total: peso	6,573,537	–	657,354	328,677
Reference	Total: US$	348,397	–	34,840	871
	Total: Japanese yen	40,197,179	–	4,019,718	2,009,859

Note 1) The service life of machinery and equipment is based on Mexican government standards.

Note 2) Depreciation is calculated using the straight-line method.

Note 3) Annual repair expenses were calculated by applying a value of 5% of the acquisition price with reference to the Japan Agricultural Research Association "New Edition Farming Handbook",Japan Agriculture and Forestry Statistics Association, 1985.

Note 4) The exchange rate of peso was 6.11516 yen / peso and 18.8 peso / US $.

4-1-2 Production target and production scale in field verification test of aquaponics combined with open culture

<Aquaculture (tilapia)>

6 two-ton tanks, 1,800 fishes (300 fishes / 2-ton tanks x 6) Facility operation: 3 rotations per year

Annual production 2,700 kg (5,400 fishes × 500 g / tail), selling price 51.8 peso / kg

<Hydroponics (swiss chard)>

4 beds for hydroponics (48m^2, 12 m^2×4 beds)

Facility operation: 3 rotations per year

Annual production 1,248 kg, selling price 24.13 pesos/kg

<Open culture (chili pepper (habanero))>

Site area 283 m^2, Acreage 250 m^2

Annual production, production 1,000 kg, selling price 93.18 pesos / kg

Note) For the sales price of the product, the average value for 3 years was applied using the data of the market price survey of fish and vegetables conducted in La Paz by the SATREPS project (Reference: Appendix 1 and Appendix 2 at the end of the reference material).

4-2 PRODUCTIVITY ANALYSIS

Productivity analysis is one of the basic methods of management analysis. By clarifying the relationship between the labor, land, and capital goods used in production of the harvest that will be commodities, and technical connection between them, the characteristics of the production technology of the management department can be revealed.

The productivity indicators obtained from the field verification test of the SATREPS project for the items that are the target of production of aquaponics combined with open culture is shown as the following.

＜Aquaculture, tilapia＞

Annual production volume with two-ton tank: 450 kg (900 fishes, 500 g/fish)

Annual production per ton of water supply: 66.7 kg / 1 square meter (Water used 6.75 t / 2-ton water tank, 6 tanks)

Working hours per 100 kg of production: 98 hours (total working hours 2,646 hours)

Feeding rate (ratio of feed cost to sales): 38.9%

＜Hydroponics, swiss chard＞

Annual production per 1 square meter of hydroponics bed:

26 kg (hydroponics bed area, total 48 square meters)

Annual production per ton of water supply:

30.8 kg (total water supply 40.5 t)

Working hours per 100 kg of production:

65.4 hours (total working hours 816 hours)

＜Open culture, chili pepper (habanero)＞

Annual production per 10 a planted area:

4,000 kg

Annual production per ton of water supply:

5 kg (total water supply 100 t)

Invested working hours per 100 kg of production:

6 hours (total working hours 60 hours)

4-3 PROFITABILITY ANALYSIS

4-3-1 Analysis indicators used for profitability analysis

Profitability analysis is a method for clarifying the characteristics of management by analyzing the acquisition results of profits that are management goals and the factors that form them. Revenue is the best indicator of the level of management results, and profitability analysis plays a central role in management analysis.

However, the profit indicators that represents “profit” for management varies depending on the characteristics of management. Usually, profitability indicator is grasped by income in the case of family management and corporate profit in the case of corporate management. Family management is dominant in agriculture and fisheries in Southern Baja California. However, in some cases, there is corporate management that operates in the form of a corporation, and aquaponics management is also challenged as a group or individual company.

<Profitability indicators of family management>

*Income = Gross income – Operating cost

(Operating cost do not include estimated family labor cost, estimated own capital interest, and estimated own land rent.)

Related indicators:

*Income rate = Income / Gross profit x 100

*Family labor in come = Income - Estimated own capital interest
- Estimated own land rent

According to Mexico government statistics, the average annual income per household in Southern Baja California in 2016 is 225,404 pesos. In the case of aquaponics management by family management, the target is that the annual income exceeds this value.

<Profitability indicators of corporate management>

*Corporate profit = Family labor income - Estimated family labor cost

In the case of corporate management, the goal is to create as large a positive value as possible without corporate profits becoming deficit.

4-3-2 Practice of profitability analysis in aquaponics combined with open culture

A concrete example of profitability analysis will be shown with reference to the results of field verification test for aquaponics combined with open culture of SATREPS project. The following assumptions were made for the profitability analysis. (1) Realize advantageous sales at market store prices through management efforts to the sales of fish produced by aquaculture (tilapia), vegetables by hydroponics (swiss chard), and vegetable by open culture (chili (habanero)) (2) Introduction of aquaponics machinery and facilities by own capital.

However, the aquaponics combined with open culture, which was set up at the model site in Los Planes for the field verification test, has a strong character as a technology verification. Since the investment amount to machinery and facilities is very large and the production scale by the installed equipment is small, it is not suitable from the economical aspect to handle it as a management verification. Therefore, the indicator value is posted as reference data by assumption that all investments in machinery and facilities are subsidized.

In the profitability analysis, first, the status of earning is confirmed for the overall management. Next, we will examine the realization of revenue by management department and analyze the factors that form these revenues.

In the field verification test of the aquaponics combine with open culture at the model site, family management is assumed as the management body. Therefore, when paying attention to income as a profitability indicator, it becomes clear that the overall management and all three management departments including aquaculture, hydroponics, and open culture, are in the red. It is still difficult to get out of the red even if we take measures to reduce operating cost by assumption of the case where the total investment in aquaponics machinery and facilities is subsidized as shown as a reference indicator. (Tab.2, Fig.1)

The following three points can be pointed out as the main factors behind the poor profitability. First, the capital investment of the aquaponics combined with open culture is large, and operating costs are greatly increased. Secondly, the introduced production equipment size is small, and the production quantity is small. Thirdly, the tilapia of aquaculture and swiss chard of hydroponics that have been taken up as production targets have the technical characteristics that they can be produced even within salt-containing water, but the market price as a product characteristic is low level. Therefore, the following issues can be pointed out according to the three main factors as measures to improve the profitability of the aquaponics combined with open culture at the model site. In line with the first factor, pursuing a reduction in the cost of machines and facilities to be introduced. In line with the second factor, increasing in size of production equipment while reducing the procurement price of machinery and facilities. In line with the third factor, productivity improvement in items, promotion of advantageous sales in the selected production items, selection of items with superior market price conditions, etc.

In addition to the above, measures to improve profitability include diversification of management business by aquaponics. From the aspect of management form, aquaponics combined with open culture is a mixed management that horizontally combines the three management departments of aquaculture, hydroponics, and open culture using of water containing salt. If this horizontal department is combined with direct sales of products, food supply by restaurants using ingredients, etc., it will be available to develop as diversified management through vertical

Tab.2 Profitability o faquaponics combined with open culture, Model site in Los Planes

(Prerequisites: Advantageous sales of products, full subsidy for machinery and facilities)

(Unit: peso)

	Account	Overall management	Aquaculture (Tilapia)	Hydroponics (Swiss cfard)	Open culture (Chili)
1)	Amount of sales	263,154	139,860	30,114	93,180
2)	Seed and seeding cost	31,865	27,000	4,105	760
3)	Fertilizers and manures cost	623	0	0	623
4)	Chemical cost	1,500	0	0	1,500
5)	Feed cost	54,410	54,410	0	0
6)	Various material cost	14,715	2,965	683	11,067
7)	Employment labor cost	64,400	60,750	2,925	725
8)	Machinery and facilities repair cost	283,397	106,437	75,085	101,875
9)	Depreciationscost of machinery and facilities	566,794	212,873	150,171	203,750
10)	Land improvement and water use cost	324	59	5	260
11)	Shipping and selling cost	14,495	9,485	4,382	628
12)	Othe variable cost	0	0	0	0
13)	Management cost (1)+ … +12))	1,032,523	473,979	237,356	321,188
14)	Income (1)-13))	-769,369	-334,119	-207,242	-228,008
15)	Estimated own capital interest	82,602	37,918	18,988	25,695
16)	Estimated own land rent	949	504	109	336
17)	Family labor income (14)-15)-16))	-852,920	-372,542	-226,339	-254,039
18)	Family labor cost	22,050	16,200	3,600	2,250
19)	Corporate profit (17)-19))	-874,970	-388,742	-229,939	-256,289
Reference	Total yield (kg)		2,700	1,248	1,000
	Unit price (peso/kg)		51.8	24.1	93.2
	Total input labor hours (hour)	3,522	2,646	816	60
《When subsidizing all investment in Aquaponics machinery and facilities》					
20)	Income (14)+9))	-202,576	-121,246	-57,071	-24,258
21)	Family labor income (17)+9))	-286,126	-159,669	-76,169	-50,289
22)	Corporate profit (19)+9))	-308,176	-175,869	-79,769	-52,539

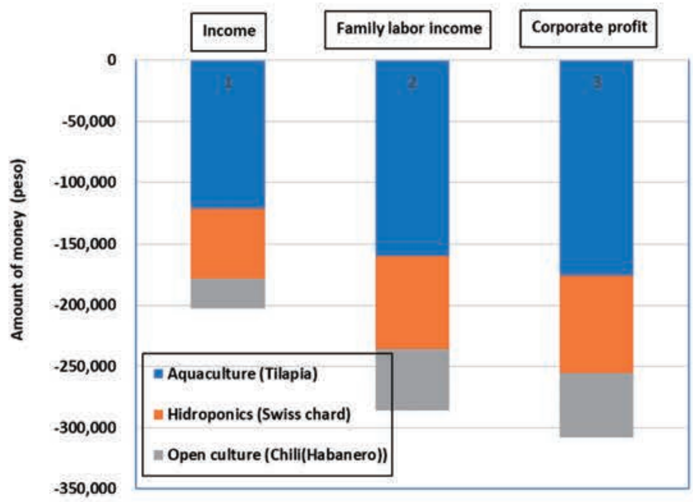


Fig.1 Profitability of aquaponics combined with open culture, Model site in Los Planes (Advantageous sales of products, full subsidy for machinery and facilities)

department of management to form greater added value. This is a matter that has been introduced as a high value-added management by building a value chain in business administration.

In fact, such advanced management cases exist in Jalisco and other provinces where tilapia production is thriving in Mexico. Same examples in Southern Baja California who are pursuing aquaponics management through subsidies from the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) are confirmed. The following photo introduces the example of diversified management combined fishing ponds and restaurants with ordinary aquaponics that combines aquaculture of tilapia and hydroponics of vegetables such as lettuce and swiss chard on the outskirts of Guadalajara City in Jalisco. This is an example of activities as a management body corresponding to green tourism.

The SATREPS project worked on direct sales of products and production of processed products in line with the aim of diversifying the management business. Regarding sales of tilapia and swiss chard, sales were made directly to stores without the intervention of wholesalers. For swiss chard, in addition to selling as fresh vegetables, a prototype of soft drink was prepared using squeezed juice to meet health preferences. Although soft drinks have not yet been commercialized, this is an example of challenging the production of processed products using primary products by aquaponics combined with open culture.

Photo. Example of business diversification by Aquaponics (“A” management body in Guadalajara, Mexico)

4-4 PRODUCTION COST ANALYSIS

4-4-1 Analysis indicators used for production cost analysis

Production cost analysis is a method for revealing how to reduce production costs and improve production technology by analyzing how labor and production goods used in the production process are used and lead to the production of main products. The point of the calculation process is that only the labor and production goods that are used to produce the main product as a commodity are converted into money and converted into costs. Expenses related to shipping / sales and business management are not included in production costs.

Cost that make up production cost consists of material cost and labor cost. Material cost include seed and seeding cost, fertilizer cost, feed cost, chemical cost, photothermal power cost, various material cost, depreciation cost and repairs cost for machinery / facility and buildings, land improvement and irrigation fees, etc. are applicable. Labor cost includes cost related to family labor and employment labor. In family management, labor wages are generally not paid for family labor, but in the production cost analysis, the estimated cost of family labor is recorded with reference to the wage unit price of the general labor market in the region.

Three indicators, production cost (by-product value deduction), production cost including payment interest / payment rent, and production cost full amount including capital interest / land rent are used as indices representing the production cost. Production cost full amount including capital interest / land rent is an analytical indicator suitable for corporate management.

* Total cost = Material cost (seed and seedling cost + fertilizer cost + ... + depreciation cost for machinery/ facilities/building + repair cost + land improvement and water use cost) + Labor cost (family labor cost + employment labor cost)
* Production cost = Total cost - By-product value
* Production cost including payment interest and payment rent = Production cost + Payment interest + Payment rent
* Total production cost including full amount capital interest and land rent = Production cost including payment interest and payment rent + Estimated own capital interest + Estimated own land rent

In the Aquaponics management in Southern Baja California, there are many cases where the fish and vegetables produced are directly sold to supermarkets, wholesale markets, and neighboring households in the region. In such a case, it is essential to negotiate with the purchaser, so it is important to accurately grasp the production cost in advance so as not to make a deficit sale.

4-4-2 Practice of production cost analysis in aquaponics combined with open culture

The actual production cost analysis will be explained using a case study of management of aquaponics combined with open culture in the SATREPS project.

(1) Aquaculture (tilapia)

In the field verification test of aquaponics combined with open culture, the aquaculture sector picked up tilapia as a production target. Six tanks with a storage capacity of 2 tons will be used, and 300 fries purchased per tank will be carried in one production, finished at 500 g / with tail and shipped to the market. The facility will be rotated three times in a year. The annual production volume is 5,400 with tail (2,700 kg).

Indicating the indicator value as a result of production cost analysis, the production cost is 17,803 pesos per 100 kg of living body with tail of tilapia, the production cost including payment interest and payment rent is 17,803 pesos, and the production cost including full amount capital interest and land rent is 19,227 pesos. Depreciation and repair cost related to fixed assets of machinery, facilities and net house account for high share of 66.4% of production cost. Employment labor cost and feed cost are the second most expensive after depreciation and repair cost for machinery, facilities and net house. Since tilapia's sales per 100 kg is 5,180 pesos, it is clear that the production cost is currently much higher than the sales and it does not have economic reproduction conditions (Tab.3 and Fig.2).

In order to reduce production cost, first, reduce the input of materials and labor related to production equipment, as can be seen from the results displayed as production cost per 2- ton tank, and second, increasing the yield of tilapia is major subject. The main issue for reducing the material and labor input is measures to reduce depreciation and repair cost for machinery, facilities and net house that account for high percentage of production cost. In particular, the improvement of energy efficiency in the generation and electricity use, which has an extremely large investment, plays an important role in reducing production cost. And, regarding the increase of the tilapia yield, there are the following two main subjects to be studied. The first is volume expansion of the breeding tanks which is supported by the improvement of energy efficiency in solar power generation, the second is change of breeding density in a tank by shortening of breeding period until shipping.

(2) Hydroponics (swiss chard)

In the field verification test of aquaponics combined with open culture, the hydroponics department selected the soft vegetable swiss chard. Swiss chard is a vegetable with a salt removal function and is widely cultivated in Southern Baja California. At the model site, wastewater generated from the aquaculture department was stored in four tanks with an area of 12 square meters per a tank and cultivated three times in a year. The wastewater supplied from the aquaculture tank contains a large amount of tilapia feed residue and manure, which are the nutrient supply sources for vegetable production. Therefore, fertilizer is not used. According to the results of field verification test, it is possible to get the yield of 1,248 kg annually with no fertilizer in a hydroponics bed with a total cultivation area of 48 square meters.

In this case, the production cost per 100 kg of swiss chard will be 18,956 pesos, production cost including payment interest and payment rent is 18,956 pesos, and production cost full amount including capital interest and land rent is 20,486 pesos. Looking at the proportion of cost by account item, the depreciation and repair cost for machinery, facilities and net house account for the overwhelming portion of 95.2%. To examine measures to reduce production cost for swiss chard, it becomes clear that the reduction of input cost to machinery, facilities and net house is more important than tilapia (Tab.3 and Fig.2).

An increase in yield of swiss chard is also an indispensable element for reducing production cost. To increase the yield of swiss chard, the following subjects are needed, increasing yield per unit area based on thorough basic technology, establishment of year-round cultivation technology overcoming high temperature environment in summer, expansion of tank volume supported by improvement of energy efficiency in solar power generation. In connection with the establishment of year-round cultivation technology that overcomes the high-temperature environment in the summer, field verification test at the model site demonstrated that it is possible to produce albahaca and mint during the summer season when it is difficult to grow swiss chard.

(3) Open culture (chile (habanero))

In the field verification test of aquaponics combined with open culture, the open culture department picked up the chili (habanero orange, hereinafter referred to as “habanero”) as the production target. Habanero is a variety to have very spicy taste, and although the demand is not large, it is traded at a high price in the market. The wastewater generated from hydroponics is received and mixed with water collected from the atmosphere by six dehumidifiers installed in the net house and use it as irrigation water. Also, well water, which is normal irrigation water, will be used for the parts that lack the water supply from the hydroponics department. In consideration of the amount of wastewater supplied from the hydroponics department, a cultivation area of 250 square meters was secured adjacent to the hydroponics net house.

The production cost per 100 kg of habanero is 32,281 pesos, production cost including payment interest and payment rent 32,281 pesos, and total production cost including estimated own capital interest and estimated own land rent is 34,884 pesos. Looking at the proportion of production cost by account items, depreciation and repair cost for machinery, facilities and net house accounted for 94.7%, the same tendency as that for swiss chard. It clarifies that, in order to take measures to reduce production cost for habanero, it is important to reduce input cost for machinery and facilities (Tab.4 and Fig.3).

An increase in the yield of habanero is also an important factor for reducing production cost. In order to increase the harvest of habanero, in addition to the general cultivation techniques adopted in the Los Planes area of the model site, effective use of wastewater supplied from the aquaculture and hydroponics department establishing is a challenge. As with the aquaculture and hydroponics departments, the expansion of cultivation area supported by the improvement in energy efficiency of solar power generation is also an issue to be considered.

In addition, the open culture department is supplied with a fixed amount of wastewater throughout the year from the aquaculture and hydroponics departments, other hand the crop production is generally difficult in the Los Planes area during the summer period from July to early September by the heat. Therefore, it is necessary to select crops and establish cropping system that can constantly use wastewater. In the field verification test at the model site, it was proved that it is effective to grow common beans and plow it as green manure during the summer period as a subsequent crop of habanero to cope with this problem.

Tab.3 Production cost of aquaponics combined with open culture Aquaculture (Tilapia), Model site in Los Planes

(Unit: peso)

Account		Aquaculture (Tilapia)	
		Per 2 t tank	Per 100 kg
1)	Fry procurement cost	4,500	1,000
2)	Feed cost	9,068	2,015
3)	Various material cost	494	110
4)	Light, heat and power cost	0	0
5)	Machinery and facilities repair cost	17,739	3,942
6)	Depreciation cost of machinery and facilities	35,479	7,884
7)	Land improvement and water use cost	10	2
8)	Other materials cost	0	0
9)	Family labor cost	2,700	600
10)	Employment labor cost	10,125	2,250
11)	Total cost (1)+ … +10))	80,116	17,803
12)	By-product value	0	0
13)	Production cost (by-product value deduction) (15) − 16))	80,116	17,803
14)	Payment interest	0	0
15)	Payment rent	0	0
16)	Production cost including payment interest and payment rent (17)+18)+19))	80,116	17,803
17)	Estimated own capital interest	6,320	1,404
18)	Estimated own land rent	84	19
19)	Production cost including full amount capital interest and land rent (20)+21)+22))	86,519	19,227

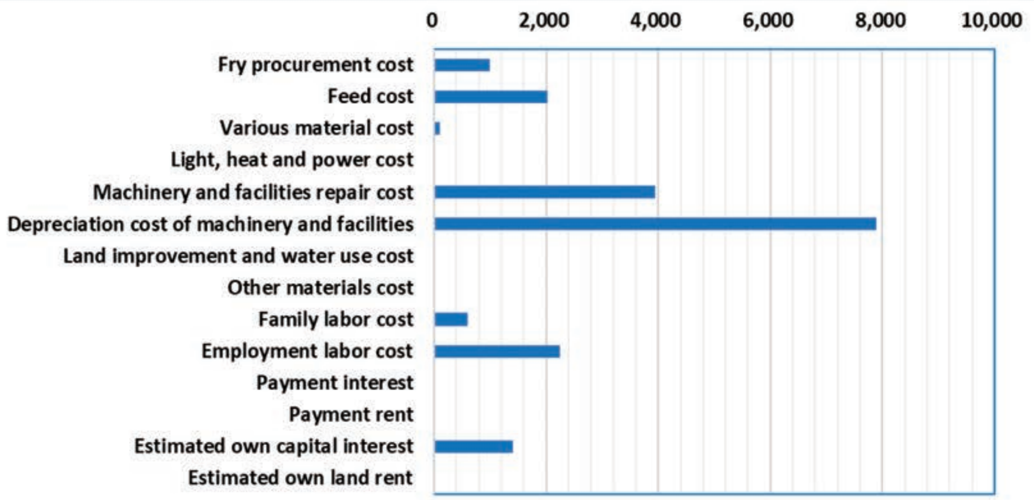


Fig.2 Production cost of aquaponics combined with open culture, Aquaculture (Tilapia), Model site in Los Planes

Tab.4 Production cost of aquaponics management combined with open culture Hydroponics division (Swiss chard), Model site in Los Planes

(Unit: peso)

	Accont	(Swiss chard)	
		Per 10 a	Per 100 kg
1)	Seed and seeding cost	85,521	329
2)	Fertilizers and manures cost	0	0
3)	Chemicals cost	0	0
4)	Various material cost	14,229	55
5)	Photothermal power cost	0	0
6)	Machinery and facilities repair cost	1,564,278	6,016
7)	Depreciation cost of machinery and facilities	3,128,555	12,033
8)	Land improvement and water use cost	103	0
9)	Family labor cost	75,000	288
10)	Employment labor cost	60,938	234
11)	Total cost (1)+ … +10))	4,928,624	18,956
12)	By-product value	0	0
13)	Production cost (by-product value deduction) (11)－12))	4,928,624	18,956
14)	Payment interest	0	0
15)	Payment rent	0	0
16)	Production cost including payment interest and payment rent (13)+14)+15))	4,928,624	18,956
17)	Estimated own capital interest	395,583	1,521
18)	Estimated own land rent	2,271	9
19)	Production cost including full amount capital interest and land rent (16)+17)+18))	5,326,478	20,486

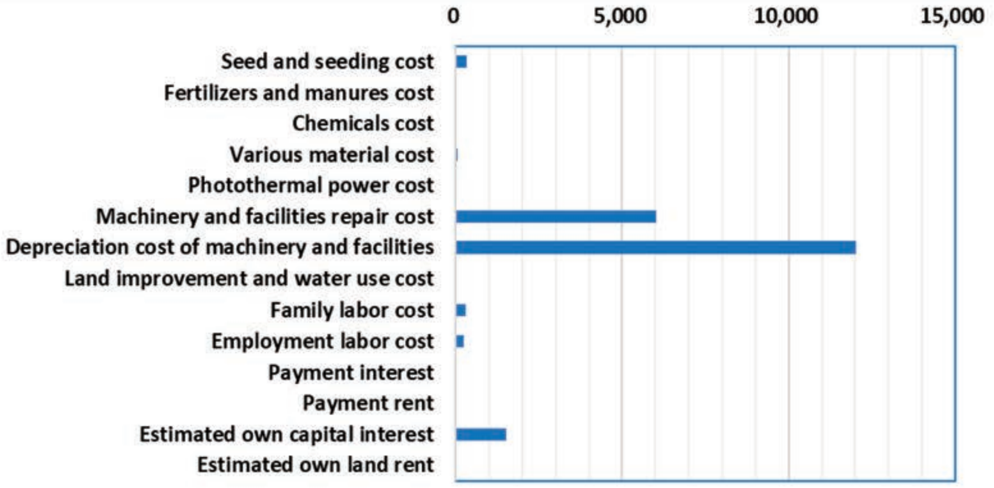


Fig.3 Production cost of aquaponics management combined with open culture Hydroponics department (Swiss chard), Model site in Los Planes

Tab.5 Production cost of aquaponics management combined with open culture Open culture department (Chili (Habanero)), Model site in Los Planes

(Unit: peso)

	Account	Open culture division (Chili (Habanero))	
		Per 10 a	Per 100 kg
1)	Seed and seeding cost	3,040	76
2)	Fertilizers and manures cost	2,492	62
3)	Chemicals cost	6,000	150
4)	Various material cost	44,268	1,107
5)	Photothermal power cost	0	0
6)	Machinery and facilities repair cost	407,500	10,187
7)	Depreciation cost of machinery and facilities	814,999	20,375
8)	Land improvement and water use cost	1,040	26
9)	Family labor cost	9,000	225
10)	Employment labor cost	2,900	73
11)	Total cost (1)+ … +10))	1,291,239	32,281
12)	By-product value	0	0
13)	Production cost (by-product value deduction) (11) − 12))	1,291,239	32,281
14)	Payment interest	0	0
15)	Payment rent	0	0
16)	Production cost including payment interest and payment rent (13)+14)+15))	1,291,239	32,281
17)	Estimated own capital interest	102,780	2,570
18)	Estimated own land rent	1,344	34
19)	Production cost including full amount capital interest and land rent (16)+17)+18))	1,395,363	34,884

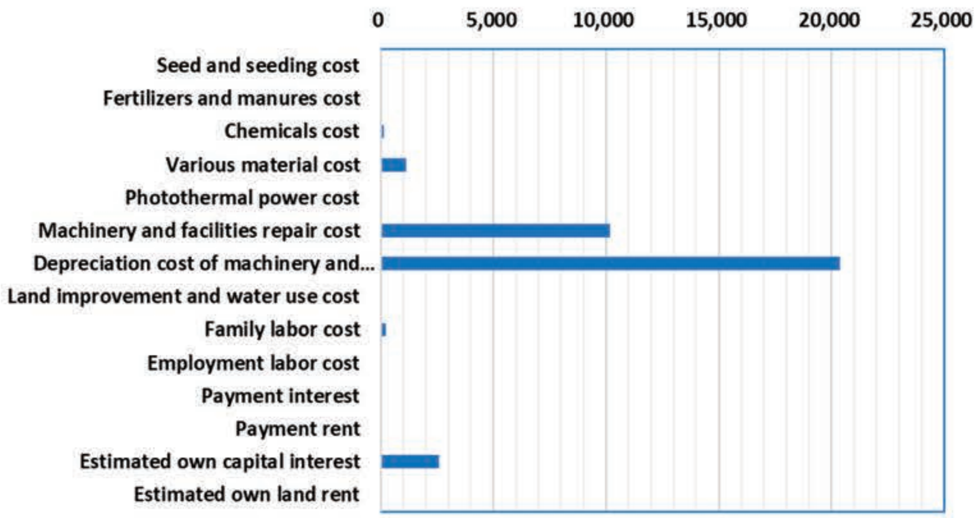


Fig.4 Production cost of aquaponics management combined with open culture Open culture department (Chili (Habanero)), Model site in Los Planes

4-5 BREAK-EVEN POINT ANALYSIS

4-5-1 Analysis indicators used for break-even point analysis

The purpose of the break-even point analysis is to grasp the sales amount of the marginal point of profit and loss, and to examine the future direction of business management based on this. The break-even point is calculated based on the correlation between the sales amount of management and the cost required to achieve it. At the same time, costs are handled separately as fixed costs and variable costs, but care must be taken because the handling of fixed costs differs between family management and corporate management. Generally, break-even analysis is a method applied to management with corporate character.

Analytical indicators often used in break-even point analysis and their calculation formulas are as follows.

Variable cost:

This is a cost related to the liquid capital consumed in one production period, and the cost changes according to the fluctuation of production volume. Account items include seed and seeding cost, fertilizer cost, feed cost, chemical cost, drug cost, photothermal power cost, materials cost, repair cost, temporary labor cost, etc.

Fixed cost:

This is a cost related to fixed capital used throughout plural production period, and the cost is constant even if the production volume changes. Account items include land improvement and water use cost, depreciation cost, family labor cost, annual employment labor cost, payment rent, estimated own land rent, payment interest, estimated own capital interest, etc.

*Break-even sales = Fixed cost / (1 - (Variable cost / Amount of sales)

*Safety margin rate = (Break - even sales - Amount of sales) / Amount of sales×100

*Net sales to make a certain profit

Required sales = (Fixed cost + Required profit) / (1 - (Variable cost / Amount of sales)

4-5-2 Practice of break-even point analysis in aquaponics combined with open culture

With reference to the results of the field verification test in the SATREPS project, the analysis is performed assuming the following conditions. The income is taken up as a profitability indicator, the sales of products are favorably sold at market prices, the machinery, facilities and net house for aquaponics is introduced by full subsidy.

According to the results of the field verification test of aquaponics combined with open culture, the total cost including fixed cost and variable cost is over the sales amount for the overall management and for all three management departments, aquaculture, hydroponics, and open culture, and all income is in the red. The safety margin rate that indicates how far the amount of sales differs from the breakeven point show negative values (Tab.5 and Fig.4).

Considering the production requirements that income convert to be plus, it is necessary to raise the current sales to the break-even point or higher. Specifically, it is required to secure sales that overall management is more than 465,729 pesos that compares with the current 263,154 pesos. aquaculture department is more than 261,106, hydroponic department is more than 87,185 pesos, and open culture department is more than 117,438 pesos. In addition, the amount of harvest that satisfies this condition is calculated to be 5,041 kg for tilapia, at least 3,613 kg for swiss chard, and 1,252 kg for habanero. Whether such an increase in yield is feasible or not must be examined in detail considering the conditions of the production site and the level of current development technology.

According to Mexican government statistics, the average annual income per household in Southern Baja California in 2016 is 225,404 pesos. Considering based on this statistics value, the management body that is engaged in aquaponics combined with open culture as family business in this region needs to generate income of the same amount or more by it. However, based in the case of assuming the current field verification test of aquaponics combined with open culture, it must be said that getting same level income of it is not easy.

**Tab.6 Break-even analysis of aquaponics combined with open culture
Model site in Los Planes
(Advantageous sales of products, full subsidy for machinery and facilities)**

(Unit: peso,%)

Item	Overall management	Aquaculture division	Hydroponics division	Open culture division
【Income】				
Total sales volume	4,948	2,700	1,248	1,000
Amount of sales	263,154	138,860	30,114	93,180
Fixed cost	324	59	5	260
Variable cost	465,405	261,047	87,180	117,178
Break-even sales	-422	-68	-3	-1,010
Safety margin rate	100	100	100	101
【Corporate profit】				
Total sales volume	4,948	2,700	1,248	1,000
Amount of sales	263,154	138,860	30,114	93,180
Fixed cost	105,925	54,682	22,702	28,541
Variable cost	465,405	261,047	87,180	117,178
Break-even sales	-137,822	-62,143	-11,980	-110,820
Safety margin rate	152	145	140	219

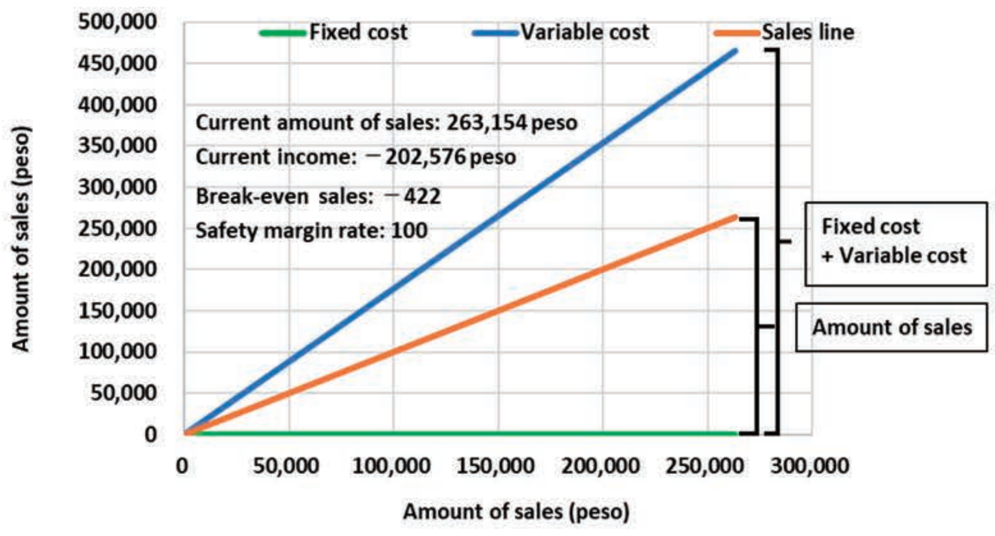
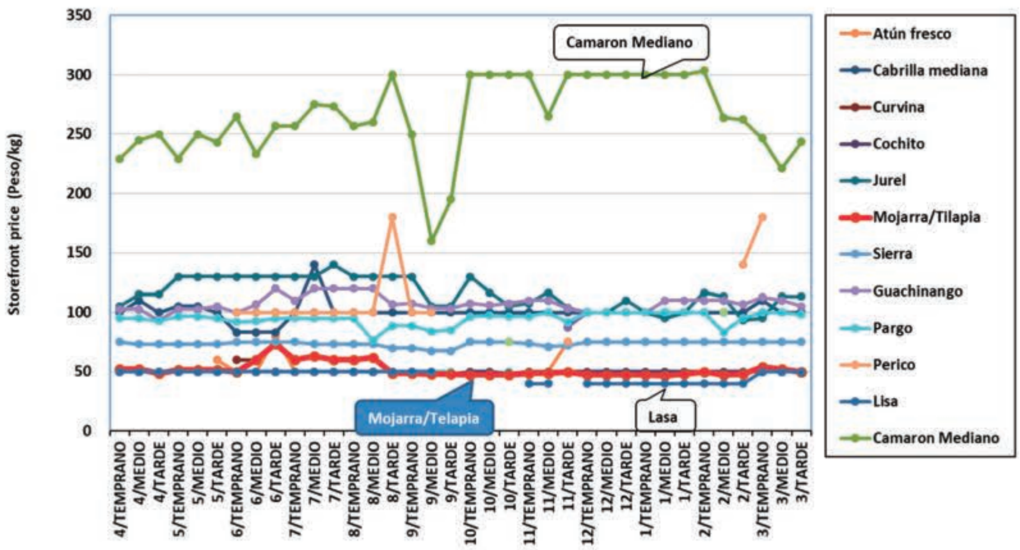


**Fig.5 Break-even analysis of aquaponics combined with open culture, Overall management, Model site in Los Planes
(Advantageous sales of products, full subsidy for machinery and facilities)**

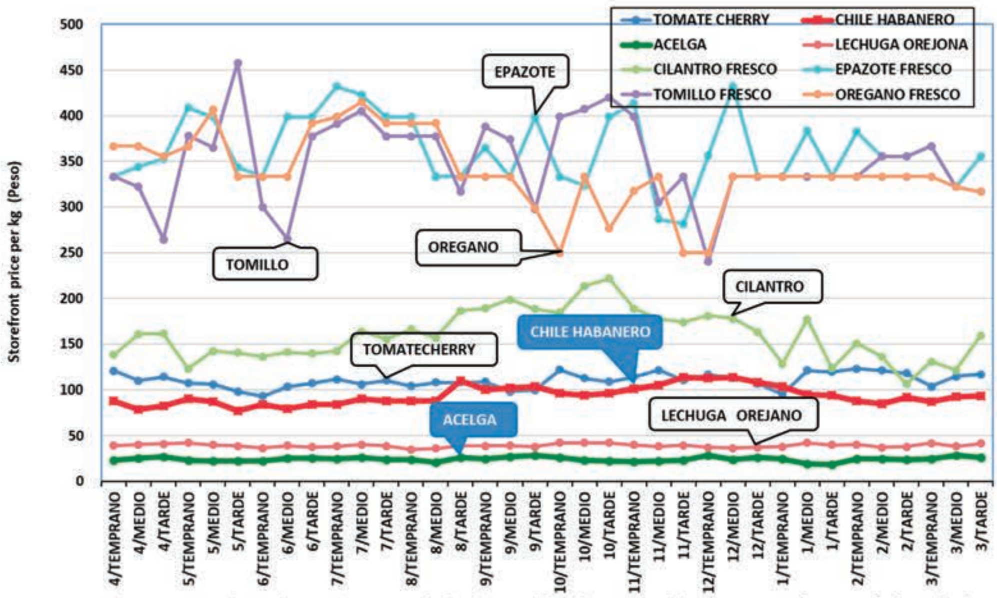
<Reference document>

Main results of market price survey of fish and vegetables by SATREPS project - Southern Baja California, La Paz, 3-years average from April 2016 to March 2019-



Appendix 1 Fishes (with taol) market sales price trend in La Paz (Extract) (per kg)
(3-years average of 4-stores from April 2016 to March 2019)

Data) Market price survey by the SATREPS project.



Appendix 2 Annual market price trend of selected fresh vegetables in La Paz (Extract) (per kg)
(3-year average of 6 stores from April 2016 to March 2019)

Data) Market price suevey by the SATREPS project.

Note 1) The market price survey of fish and vegetables was conducted by extracting relevant items in accordance with the purpose of determining the production target of open culture combined with aquaponics in the SATREPS project. The survey was conducted on 45 items for fishes and 32 items for vegetables.

Note 2) Market price survey were conducted at 10-day intervals, with the cooperation of 4 stores for fishes and 6 stores for vegetables.

Note 3) According to the result of market price survey between three years from April 2016 to March 2019, the average price per kg of above-mentioned goods that were selected the survey target in the field verification test of open culture combined with aquaponics, is following.

Aquaculture: tilapia 51.80 pesos / kg
Hydroponics: swiss chard 24.13 pesos / kg
Soil cultivation: chili (habanero) 93.80 pesos / kg

5. ACKNOWLEDGEMENTS

In preparing the management manual, we were able to ask for assistance from Mr. Jose Angel Rodriguez as cooperating farmer for the field verification test of aquaponics combined with open culture, on collecting management data. We thank to him with writing. He is a manager who is expected to play an important role for extension of the aquaponics combined with open culture which SATREPS project has developed to Southern Baja California. We expect him to continue to cooperate after the end of project.

The following eight stores were cooperators who we obtain cooperation for the market price survey for fish and vegetables, which was conducted over a little over three years as part of the basic survey for preparing the management manual. We thank to them with writing.

Fresh fish store: PESCADERIA MOLARES, PESCADERIA SINALOA

Vegetable wholesale store:

SEM. Y CERARES CENTRAL, FRUTAS Y LEGUMBRES ELTRIUNFO, FRUTERIA LO VEO Y LO NO CREO, FRUTAS FINAS COLIMAN

Supermarket: CASA LEY-LAS GARZAS, ARAMBURO

In addition to the above, we have obtained cooperation from many farmers and representatives of Ejido in Southern Baja California in conducting a basic survey to prepare a management manual. The listing is omitted due to space limitations, but we would like to thank everyone who helped to promote the project.

Postface

On the project of SATREPS (Science and Technology Research Partnership for Sustainable Development Program), we developed the aquaponics combined with open culture adapting to arid regions. Adapting to arid regions involves to use saline water, unsuitable for food production, to produce salt-tolerant aquatic and agricultural products and to use electric power generated by photovoltaics driven by abundant solar radiation. Combining with open culture means to utilize wastewater from aquaponics system (combined system between aquaculture and hydroponics) for open field culture.

The aquaponics developed possesses several environmental and economic impacts as described in Chapter 1. It namely realizes to utilize saline water, unsuitable for food production, to use water 3 times (aquaculture, hydroponics and open culture) efficiently, to produce aquatic and agricultural products simultaneously, to prevent from soil salinization, to reduce global warming, to operate in the area without electric transmission and to secure hygiene safety of products.

Technologies in this aquaponics are divided into food production technology (aquaculture, hydroponics and open culture), maintenance technology of the food production system (hygiene management and power supply) and management. It is greatly thankful, if readers refer to their requiring chapters.

Target groups to introduce this aquaponics system are agriculture and aquaculture producers and companies in B.C.S., Mexico. Many agriculture and aquaculture producers participated in the exhibition of verification model system in Los Planes, while many primary school, junior high school and polytechnic students participated in the exhibition of verification model system in CIBNOR. It is greatly meaningful that young generation were interested in this aquaponics system, an environment-friendly food production system.

This aquaponics system is difficult to install by ordinary individuals due to high total installation cost. Subsidies and financing from state and state agencies are needed. Considering that the United Mexican States is promoting an environment-friendly food production system and the introduction of renewable energy, I believe that it is possible to receive assistance.

To prepare this technical manual, two aquaponics combined with open culture were set up in La Paz, B.C.S., Mexico. One was installed on the CIBNOR site and the other was on a production farm of a general farmer. Both are classified as desert climates with low precipitation and the underground water salinity is such that the growth of salt-sensitive crops is reduced. However, looking at the arid regions of the world, the natural environment, such as climate, soil, topography, and the quantity and quality of underground water, is quite diverse. This technical manual was designed to be as versatile as possible so that the aquaponics technology could be introduced in such areas. I hope that this technical manual will be utilized by people in arid regions around the world who seek sustainable food production methods by maximizing the efficiency of the scarce and under-salinized groundwater, which leads to the establishment of an environment-friendly food production system.

Finally, I would like to express my greatest gratitude and respect to those who supported the implementation of this project. Large amounts of funding for international cooperation and research and technology development have been invested by JICA (Japan International Agency) and JST (Japan Science and Technology Agency), respectively. Valuable human and advisory supports were provided by SADER, CONAZA, CONACyT and the Government of B.C.S. Family support of research members of CIBNOR, Tottori University and Tokyo University of Marine Science and Technology was essential. In addition, there were comrades who passed away in the midst of being involved in this project. Thank you very much.

Sincerely,

Dr. Satoshi Yamada
Project Manager for the Group of Japanese Researchers
Professor, Faculty of Agriculture, Tottori University

Annex

Tab. SATREPS member list

NAME	POSITION	AFFILIATION	RESEARCH GROUP*1 OR CONTRIBUTION						REMARK
			G1	G2	G3	G4	G5	G6	
MEXICAN SIDE									
Dr. Alfredo Ortega Rubio	Director	Director, CIBNOR	Manager Director						Oct. 2019 - May 2020
Dr. Daniel Bernardo Lluch Cota	Director	Director, CIBNOR	Manager Director						Apr. 2015 - Sep. 2019
Dr. Ilie Racotta Dimitrov	Researcher	Institutional Management Department, CIBNOR	Project Manager						
Dr. Juan Ángel Larrinaga Mayoral	Researcher	Agriculture for Arid Zones (PAZA), CIBNOR	Research Leader Manager	○			○	●	
Dr. Francisco Javier Magallón Barajas	Researcher	Aquaculture (PAC), CIBNOR	●						
Dr. Bernardo Murillo Amador	Researcher	Agriculture for Arid Zones (PAZA), CIBNOR		●			○		
Dr. Joaquin Gutierrez Joaguey	Researcher	Environmental Planning and Conservation Program (PLAC), CIBNOR			●				Feb. 2017 - May 2020
Dr. Miguel Angel Porta Gándara	Researcher	Environmental Planning and Conservation Program (PLAC), CIBNOR			●				Apr.2015 - Jan. 2017
Dr. Ramón Jaime Holguín Peña	Researcher	Agriculture for Arid Zones (PAZA), CIBNOR				●			
Dr. Enrique Troyo Diéguez	Researcher	Agriculture for Arid Zones (PAZA), CIBNOR					●		
Dr. Pedro Cruz Hernández	Researcher	Aquaculture (PAC), CIBNOR	○						
Dr. Rafael Campos	Researcher	Aquaculture (PAC), CIBNOR	○						
Dr. Dariel Tovar	Researcher	Aquaculture (PAC), CIBNOR	○						
Dr. Juan Carlos Pérez	Researcher	Aquaculture (PAC), CIBNOR	○						
Ing. Enrique Murillo Moreno	technician	Aquaculture (PAC), CIBNOR	○						
Ing. Gilberto Colado	technician	Aquaculture (PAC), CIBNOR	○						
Dr. Hector Salmon Acosta	Researcher	Aquaculture (PAC), CIBNOR	○						
Dr. Yenitze Elizabeth Fimbres Acedo	Researcher	Aquaculture (PAC), CIBNOR	○						

* Group 1 (G1); Aquaculture, Group 2 (G2); Crop cultivation, Group 3 (G3); Power supply, Group 4 (G4); Sanitary security, Group 5 (G5); Irrigation, Group 6 (G6); Extension. Closed circle means leader of research group.

Tab. SATREPS member list

NAME	POSITION	AFFILIATION	RESEARCH GROUP*1 OR CONTRIBUTION						REMARK
			G1	G2	G3	G4	G5	G6	
MEXICAN SIDE									
Ing. Saul Edel Briseño Ruíz	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○			○	○	
Tec. Pedro Luna Gracía	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○			○		
Tec. Adrian Jordán Castro	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○			○	○	
Tec. Raymundo Ceseña Núnez	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○			○	○	
Dr. Gregorio Lucero Vega	Technician	Agriculture for Arid Zones (PAZA), CIBNOR					○		
Tec. Maria Sofia Ramos Galvan	Technician	Agriculture for Arid Zones (PAZA), CIBNOR				○			
M.C. Martin Aguilar Garcia	Technician	Agriculture for Arid Zones (PAZA), CIBNOR				○			
Dra. Carmen Mercado Guido	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○					
M.C. Lidia Hirales Lucero	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○					
Ing. Mario Benson Rosas	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○					
M.C. Alvaro González Michel	Technician	Agriculture for Arid Zones (PAZA), CIBNOR					○		
M. D. A. Manuel Salvador Trasviña Castro	Technician	Analytical laboratories, CIBNOR					○		
Dr. Arturo Cruz Falcón	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○					
M.C. Norma Ochoa	Technician	Analytical laboratories, CIBNOR					○		
Ing. Juan Manuel Mandujano	Technician	Servicies Departement, CIBNOR			○				
Dr. Diana Medina Hernandez	Technician	Agriculture for Arid Zones (PAZA), CIBNOR				○			
M.C. Luis Landa Hernández	Technician	Agriculture for Arid Zones (PAZA), CIBNOR		○	○	○	○	○	

* Group 1 (G1); Aquaculture, Group 2 (G2); Crop cultivation, Group 3 (G3); Power supply, Group 4 (G4); Sanitary security, Group 5 (G5); Irrigation, Group 6 (G6); Extension. Closed circle means leader of research group.

Tab. SATREPS member list

NAME	POSITION	AFFILIATION	RESEARCH GROUP*1 OR CONTRIBUTION						REMARK
			G1	G2	G3	G4	G5	G6	
JAPANESE SIDE									
Dr. Hiromitsu Nakajima	Professor	Tottori University	Manager Director						Apr. 2019 - May 2020
Dr. Ryota Teshima	Professor	Tottori University	Manager Director						Apr. 2015 - Mar. 2019
Dr. Satoshi Yamada	Professor	Tottori University	Project Manager						
				●					
Dr. Masato Endo	Associate Professor	Tokyo University of Marine Science and Technology	●						
Dr. Shigehide Iwata	Assistant Professor	Tokyo University of Marine Science and Technology	○						
Dra. Ayako Matsui	Project Researcher	Tokyo University of Marine Science and Technology	○						
Dr. Hideyasu Fujiyama	Professor Professor Emeritus	Tottori University		○					
Dra. Mina Yamada	Project Researcher	Tottori University	○	○	○	○	○	○	
Dra. Emi Kaburagui	Assistant Professor	Tottori University	○	○	○	○	○	○	
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Dr. Takashi Baba	Project Researcher	Tottori University				●			
Dr. Koji Inosako	Professor	Tottori University					●		
Dr.Tadaomi Saito	Associate Professor	Tottori University					○		
Dr. Takayuki Ando	Professor	Tottori University						●	
Dr. Hajime Kobayashi	Director	The Open University of Japan						○	
	Professor Emeritus	Tottori University							
Dra. Masako Hishida	Doctoral Researcher		○	○	○	○	○	○	
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Mr. Tomohiro Okabe	Project Coordinator	Japan International Cooperation Agency	Project Coordinator						Jun. 2015 - Jun. 2017
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* Group 1 (G1); Aquaculture, Group 2 (G2); Crop cultivation, Group 3 (G3); Power supply, Group 4 (G4); Sanitary security, Group 5 (G5); Irrigation, Group 6 (G6); Extension. Closed circle means leader of research group.

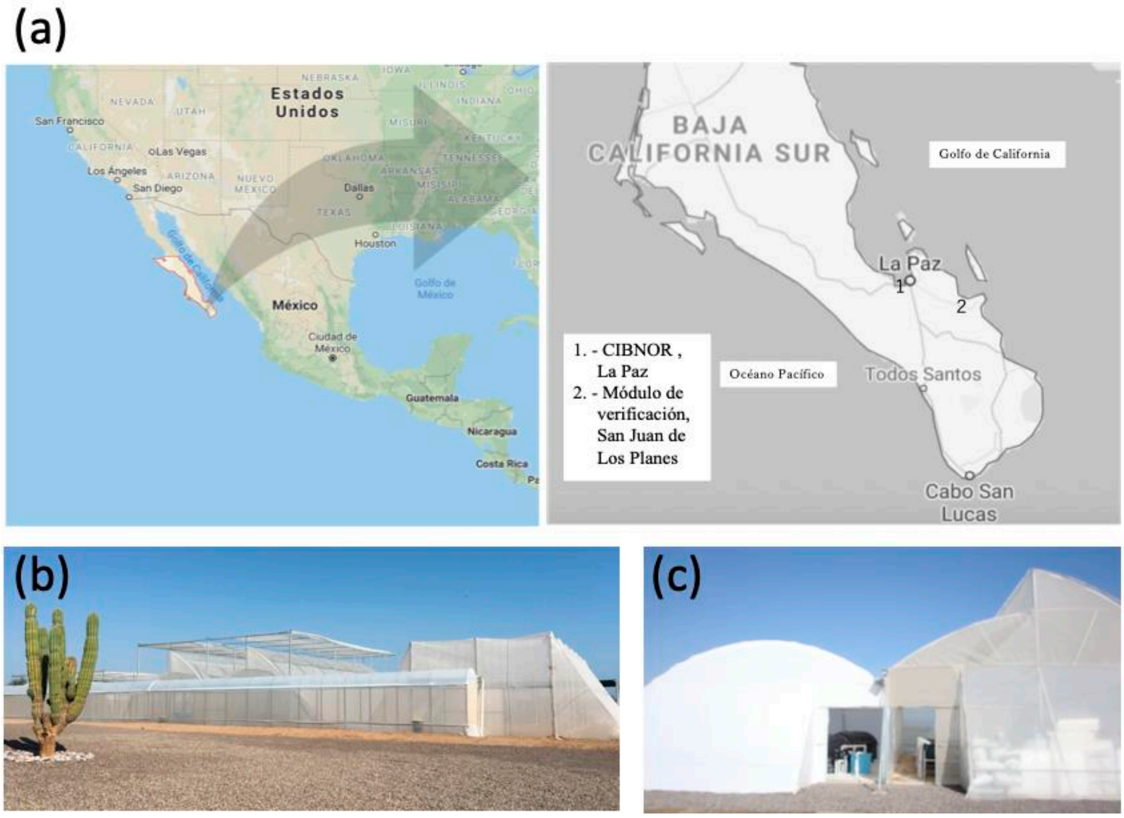

Fig. Location (a) and appearance (b and c) of 2 aquaponics combined with open culture

Geographical location (a) shows that 1 is in the site of the Northwestern Biological Research Center, S. C. (Latitude: 24° 08' N, Longitude: -110° 18' W) and 2 is in the site of verification test (Latitude: 23° 97' N, Longitude: -109° 94' W). (b); Appearance of module in the Northwestern Biological Research Center, S.C. established in July 2016.

(c); Appearance of the verification module in San Juan de Los Planes established in August 2018.

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