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Recirculating Aquaculture Tank Production Systems

Integrating Fish and Plant Culture

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Recirculating aquaculture systems are designed to raise large quantities of fish in relatively small volumes of water by treating the water to remove toxic waste products and then reusing it. In the process of reusing the water many times, non-toxic nutrients and organic matter accumulate. These metabolic by- products need not be wasted if they are channeled into secondary crops that have economic value or in some way benefit the primary production system. Systems that grow additional crops by utilizing by-products from the production of the primary species are referred to as integrated systems.

Plants are an ideal secondary crop in integrated systems because they grow rapidly in response to the high levels of dissolved nutrients that are generated from the microbial breakdown of fish wastes. In closed recirculating systems, which employ very little daily water exchange (1 to 5 percent), dissolved nutrients accumulate and approach the concentrations that are found in hydroponic nutrient solutions. Nitrogen, in particular, occurs at very high levels in recirculating systems. Fish excrete waste nitrogen directly into the water through their gills in the form of ammonia. Biofilter bacteria convert ammonia to nitrite and then to nitrate (see SRAC Publication No. 451 on critical considerations). Ammonia and nitrite are toxic to fish, but nitrate is relatively harmless and is the preferred form of nitrogen used by higher plants, such as vegetables.

Integrated systems can be used for the hydroponic culture of high value cash crops such as tomatoes, lettuce and sweet basil. Recirculating systems may also be used for the culture of aquatic plants.

Aquatic plants

Aquatic plants grow rapidly in recirculating systems that are located outdoors, in greenhouses or in buildings with adequate artificial light. Plants are typically grown in shallow tanks that are separate from the fish rearing tank. Three types of aquatic plants can be cultured: floating, emergent and submerged.

Floating plants, which are naturally buoyant, grow with their roots suspended in the water and their leaves in the air. They reproduce vegetatively (without seeds) by dividing in half and grow so rapidly that they can completely cover the surface of the tank within a short time. When this occurs, about one third of the plants

Leaf lettuce grown in deep flowing channels is an ideal crop for integrated recirculating systems.

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should be removed to avoid crowding and nutrient limitations and to keep the remaining plants in a state of rapid growth.

Common floating plants that can be cultured in recirculating systems include water hyacinth *(Eichhoria crassipes)*, water lettuce *(Pistia* sp.), duckweed *(Spirodela* and *Lemna* spp.) and water fern *(Azolla* sp.). These plants can be sold as ornamental (water hyacinth, water lettuce) or used as food (duckweed, water fern) for herbivorous fish such as grass carp and tilapia. Floating plants are also useful in inhibiting the growth of phytoplankton by blocking light penetration into the water and removing excess nitrogen from the system. Water hyacinth can remove more than 1 gram of nitrogen per square meter of surface area per day during periods of optimum growth.

Emergent plants need an underwater substrate for their roots while their stems and leaves grow above the water surface. Emergent plants with economic value that can be cultured in a recirculating system include watercress *(Nasturtium officinale)*, water chestnut *(Eleocharis dulcis)* and water spinach *(Ipomoea aquatica)*. Substrates for these plants may be mud, sand or an artificial medium (e. g., vermiculite). Watercress may be cultured without a substrate if it is supported near the water surface on window screen, which allows its roots to grow into the water column. Watercress and water spinach grow very rapidly and can be harvested on a continuous basis. Water chestnut requires a 7-month growing season to produce a thick stand of reed-like plants and a high density of underground tubers, which develop as the weather cools. Water chestnut yields of 0.6 pounds per square foot have been obtained in recirculating systems.

Submerged plants grow entirely underwater and are held in place by their roots which grow in substrates of mud or sand. Submerged aquarium plants such as eel grass *(Vallisneria* sp.) and anacharis *(Elodea* sp.) can be grown successfully in recirculating systems where filters maintain clear water. These plants have economic value as aquarium plants. They also benefit the system by inhibiting the growth of phytoplankton and producing dissolved oxygen on sunny days.

Hydroponic vegetables

The production of vegetables without soil is referred to as hydroponics. Hydroponics requires media other than soil, or some structure to support the plant. Water must contain the 13 essential nutrients for plant growth.

Hydroponic culture is usually identified by type of support media that is used: water culture, sand culture or gravel culture. Water culture is further subdivided into nutrient film technique (NFT), deep flowing channels and aeroponics. NFT consists of many narrow plastic troughs or gutters in which the plant roots are placed and exposed to a continuously flowing film of nutrient solution. Deep flowing channels are much wider and deeper so that the plant roots are completely suspended in a slow moving stream of water. The plants are supported at the surface with polystyrene sheets. In aeroponics, the plant roots are suspended in air inside an opaque container and sprayed with a fine mist of nutrient solution.

Although these media have all been used successfully in integrated systems, fish culture water has some special characteristics that must be considered in the design of the hydroponic subsystem. Fish produce feces that must be removed from the system through sedimentation or filtration (see SRAC Publication No. 453 on components). Although these methods remove most of the solid waste, a relatively small amount remains suspended as small (colloidal) particles. Hydroponic systems that use fine support media for plants, such as sand or gravel, may eventually become clogged with sludge. The roots of plants grown by NFT may become fouled with a blanket of sludge. Excessive sludge accumulation has a harmful affect on plant growth because it blocks the flow of water and creates zones without oxygen. Plant roots need oxygen for healthy growth. Dissolved oxygen is utilized by the roots for nutrient uptake and other vital cell functions.

There are techniques to prevent sludge buildup and maintain adequate oxygen. A false bottom of rigid screen can be used to separate the root growing area from the bottom of deep flowing channels. The rigid screen can also support plant roots in the NFT method or support growth media such as gravel. Settleable solids accumulate on the bottom of the tank under the root zone. If a few fish are placed under the false bottom, their swimming action can keep sludge from accumulating. To maintain adequate oxygen, gravel and sand media can be flooded intermittently, allowing time for the culture water to drain out of the media and draw air (oxygen) into the root zone. Long, deep flowing channels must be aerated at intervals with diffused air delivered through air stones.

Essential nutrients

Essential plant nutrients are divided into two categories; macronutrients which are required in relatively large quantities, and micronutrients which are needed in very small (trace) amounts. Macronutrients consist of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S), and magnesium (Mg). Micronutrients include iron (Fe), chlorine (Cl), manganese (Mn), boron (B), zinc (Zn), copper (Cu), and molybdenum (Mo). For optimum growth, plants need a balanced quantity of these essential nutrients (Table 1).

Hydroponic solutions may contain 10 to 20 percent of total nitrogen as ammonium (NH_4), which stimulates vegetative growth. However, ammonium is never added to integrated systems since sufficient am-

Table 1. Typical hydroponic nutrient solution.[1]

Nutrient	Concentration (mg/liter)	
Ca	197	
Mg	44	
K	400	
N (as NO3)	145	(642)
P (as PO4)	65	(199)
S (as SO_4)	197.5	(592)
Cl	—	
Fe	2	
Mn	0.5	
Cu	0.03	
Zn	0.05	
B	0.5	
Mo	0.02	

[1]Modified after Resh, 1989.

monium is produced by the fish. Although chloride ions are required by plants, they are not added to hydroponic or integrated systems because sufficient amounts of this element occur in fish feed and most water supplies.

The total concentration of nutrient salts in this typical hydroponic solution is approximately 2,100 mg/liter. Total nutrient concentrations that exceed this maximum safe level become toxic to many vegetable varieties and decrease production. When this solution is used in standard hydroponic systems, concentrations of all the essential elements decline as they are absorbed by the plants. Eventually the solution must be discarded and replaced with a new, balanced solution.

A different relationship exists in integrated recirculating systems. Through the addition of feed and the production of metabolic wastes by the fish, nutrients are usually generated faster than they can be absorbed by the plants. As a result, levels of nutrient salts steadily increase, and when the total concentration exceeds 2,100 mg/liter, the culture water must be exchanged or diluted. Water that is used for integrated systems should initially have low levels (<100 mg/liter) of total dissolved solids (salts). A good source is rainwater, which has low salt levels but will require buffering to raise pH.

The rate of salt buildup can be decreased by increasing the water exchange rate or using the optimum ratio between the number of plants and the number of fish, or more precisely, the daily feed allotment. An optimum ratio is achieved when plant production is maximized and salt build-up is low. For example, the optimum ratio for the number of leaf lettuce plants (summer Bibb) to fish (tilapia) is 1.9:1 in a closed recirculating system using a deep flowing channel with rainwater, a complete fish diet of 36 percent protein, and a water exchange rate of 1 percent/day. Lettuce production is maximized at this ratio, which is equivalent to a daily feeding rate of 2.4 grams/plant. The waste nutrients from this amount of feed become available to the plant after the feed is digested by the fish. This daily feeding rate is equivalent to 3.2 grams/cubic meter/square meter when system volume and plant growing area (23.9 plants/ square meter) are considered.

For example, at the optimum ratio, a 10,000-gallon integrated system with a daily feed input of 8.8 pounds requires a plant production area of 800 square feet for 2,100 heads of leaf lettuce. At the 1.9 ratio, total salts still increase at a rate of 135 grams/kilogram of feed. Very little is presently known about the optimum ratio for other types of vegetables, fish, system designs, feeds, and water sources. In general, properly designed integrated systems have very large plant growing areas relative to the fish production components.

When an integrated system is put into operation, the fish should be fed a few weeks before the first planting to allow time for all of the essential nutrients to accumulate to the minimal levels required for good plant growth. Although nutrient salts accumulate in integrated recirculating systems, not all of the essential nutrients are present in sufficient quantities. Nutrients that require supplementation are potassium (as potassium hydroxide), calcium (as calcium oxide or calcium hydroxide) and iron (as iron chelate containing 10 percent iron by weight).

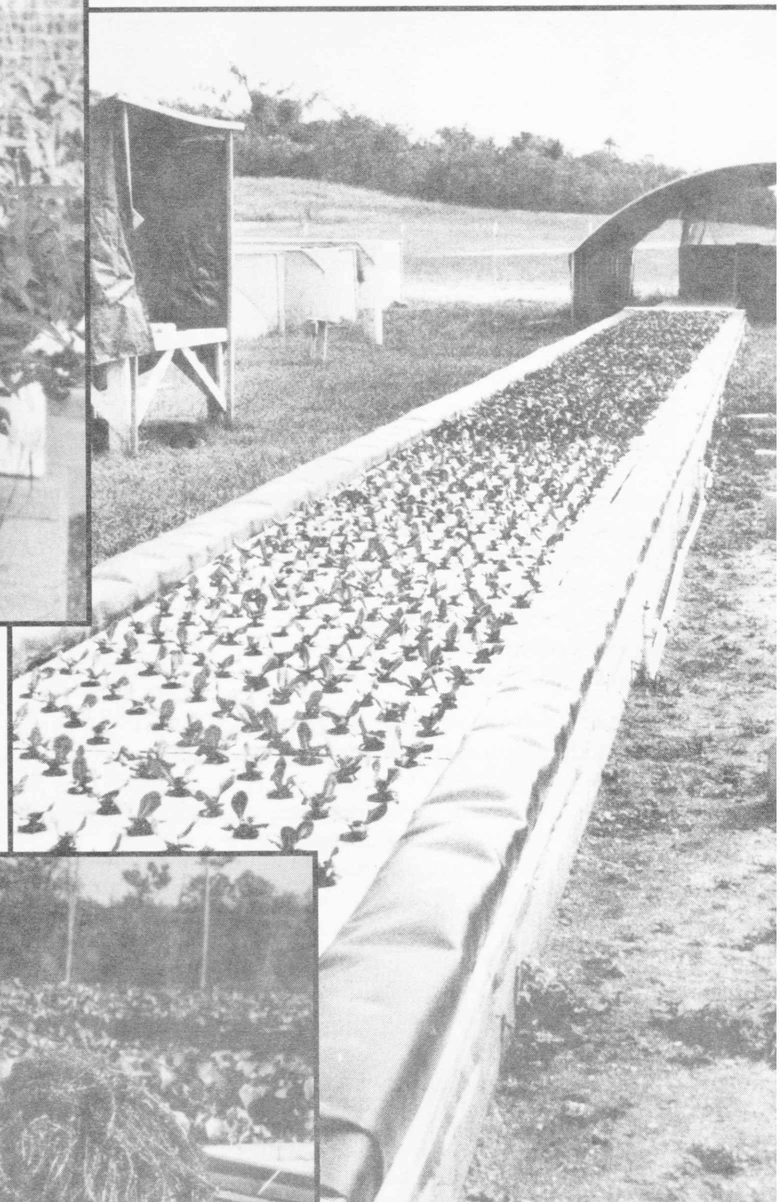
The addition of strong bases such as potassium hydroxide and calcium oxide also neutralize acids that are produced when ammonia (NH_3) is converted to nitrate (NO_3) in the biofilter. These bases must be added daily to maintain the pH of the system near 7. As a result, potassium and calcium contribute substantially to the build-up of nutrient salts, but they are also required in large amounts by plants (Table 1). Iron is supplemented less frequently (perhaps monthly) by adding 2 mg/liter. Supplemental nutrients may be applied directly to the plants through foliar sprays. Nutrient deficiencies may vary depending on the water source (chemistry), fish feed and hydroponic substrate used.

Insect and disease control

Insect and disease control techniques for vegetables in integrated systems are limited to the use of biological control, resistant varieties, screening and specialized cultural practices. One successful biological control method is the use of the bacterium *Bacillus thuringiensis*, which is effective in the control of caterpillars. In general, pesticides should not be used because most are very toxic to fish, and none have been approved for use in food fish culture. Similarly, most therapeutants for treating fish parasites and diseases should not be used in an integrated system because they harm the biofilter and vegetables may readily absorb and concentrate them.

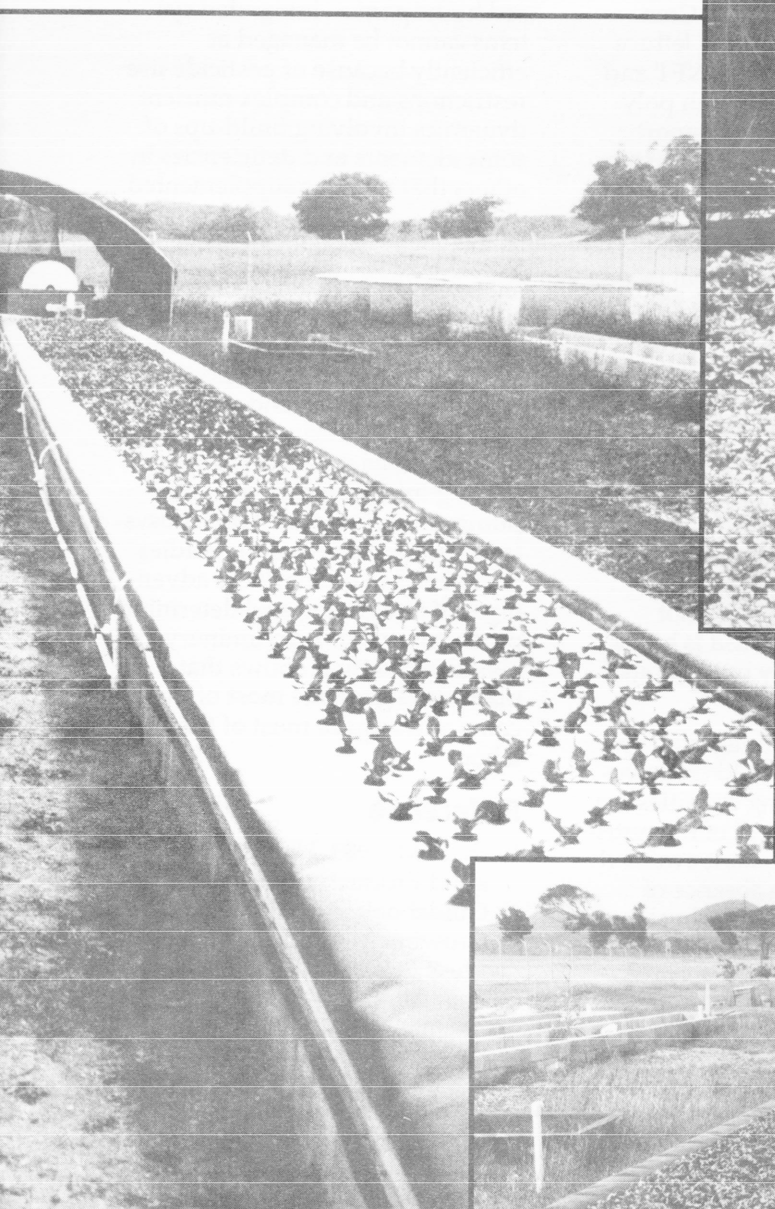
A possible approach to avoid the restrictions of pesticide usage is to establish the hydroponic unit as a flow- through system, thereby allowing the vegetables to be managed independently of the fish.

Tomato plants in a gravel substrate being cultured along with tilapia in an integrated recirculating system.

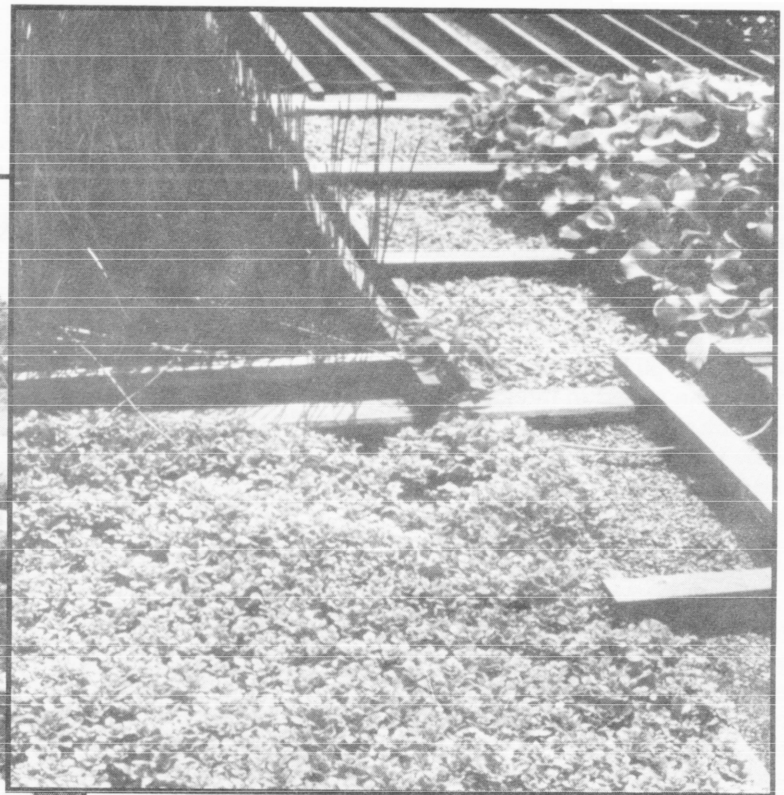


A commercial-scale integrated recircula
tilapia. Water from the fish rearing tank
before it returns to the rearing tank thro

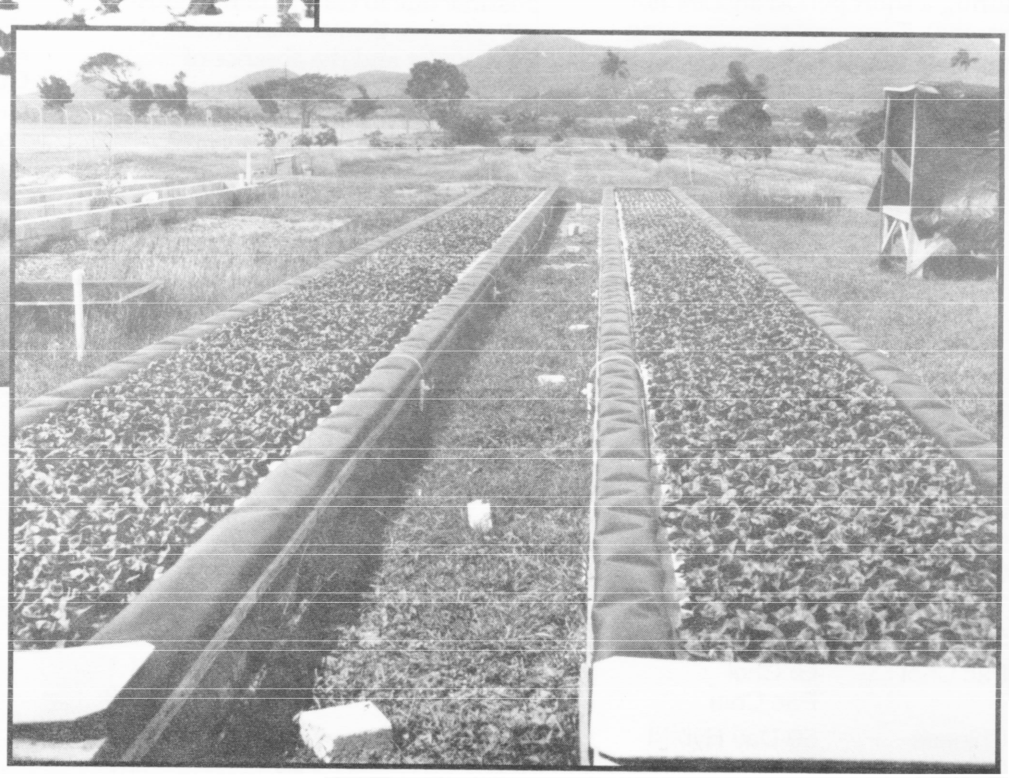
Baskets of anacharis *(Elodea)* being harvested from an integrated recirculating system. In the background are stands of water chestnut (left) and water hyacinth (right).



system for the production of lettuce and
through the right hydroponic tank first
he left hydroponic tank.



Watercress (foreground) being cultured in an integrated recirculating system. In the background are stands of water chestnut (left) and water hyacinth (right).



Annual production of leaf lettuce from the integrated recirculating system is projected to be 35,000 heads.

Water can be diverted to the plants from the recirculating system when optimum nutrient levels are reached. Water should be diverted at a rate (e.g., 5 percent daily) that allows nutrients to be maintained at optimum concentrations for plant growth.

Vegetable production

More than 30 kinds of vegetables have been raised in integrated systems on an experimental basis. A wide range of systems has been used in a number of different environments from greenhouses in northern states that are heated in the winter to outdoor systems in the subtropics. Production levels have varied greatly in response to environment, system design and management. Table 2 lists yields of some of the vegetable varieties that have been grown in integrated systems.

Crops that have been studied most intensively include tomatoes and lettuce. Tomatoes appear to be most productive in outdoor gravel systems with varieties that are determinant (i.e., they set their fruit during a short period and are not pruned). Tomatoes require a long growing period and are therefore at greater risk to damage from pests and diseases.

Lettuce is a popular plant for integrated production because it grows well in response to high nitrogen levels, yields a high proportion of edible product, and is subject to less pest pressure due to its short production cycle. Common methods for growing lettuce in integrated systems are NFT and deep flowing channels with polystyrene sheets for plant support. Plants are started in peat pellets in trays outside the system. After 3 weeks, the seedlings are transferred to the system for 3 more weeks of growth, which will bring them to harvest size under ideal conditions. Two additional weeks of growth are required during the winter in heated greenhouses. Lettuce production is usually staggered so that one crop is harvested each week, and a new one is immediately planted.

Another crop with good potential for integrated systems is sweet basil. Production data are not available, but sweet basil is being grown commercially in integrated systems.

Vegetable yields in integrated systems exceed that of field crops because higher planting densities are possible due to control of the nutrient solution, the constant availability of water and the absence of competition from weeds. In some cases, as with lettuce, production from integrated systems has equaled that of standard hydroponic systems. For the most part, however, production from integrated systems will probably fall slightly short of that from standard hydroponics. Integrated systems cannot be managed as efficiently because of pesticide use restrictions and complex nutrient dynamics involving build-ups of some elements and deficiencies in others that must be supplemented.

The primary attraction for integrated systems is financial. Nutrient recovery from aquaculture effluents reduces hydroponic chemical costs. High quality water is repeatedly used to support the growth of both fish and vegetables, further reducing costs. Additional savings can be realized by sharing infrastructure (e.g., one pump can be used for both subsystems). Detailed economic studies are needed to quantify the advantages of integration and determine profitability, but a preliminary analysis with lettuce shows that plants will generate most of the income and require most of the labor.

Reference

Resh, H.M. 1989. Hydroponic Food Production: A Definitive Guidebook of Soilless Food Growing Methods. Woodbridge Press Publishing Co., Santa Barbara, CA.

Table 2. Production of vegetable varieties in integrated recirculating aquiculture systems.

Crop	Variety	Density (no./ft^2)	Growing Period (days)[1]	Production in lbs. per plant	Production in lbs. per ft^2	System
Tomato	Floradel	0.36	133	20.0	3.3	Gravel
	Floradade	0.17	112	20.0	3.3	Gravel
	Sunny	0.17	112	22.0	3.7	Gravel
Lettuce	Summer Bibb	2.32	21	0.4	0.9	Channel
	Buttercrunch	2.32	21	0.4	1.0	Channel
Cucumber	Triumph	—	—	8.9	—	Gravel
	Burpee Hybrid II	0.62	—	5.2	3.2	Sand
Squash	Golden Bar	—	—	5.5	—	Gravel
Pac Choi	Le Choi	1.77	28	1.1	1.8	Gravel
	Pac Choi	1.77	28	0.9	1.6	Gravel
Chinese	50-Day Hybrid	1.77	28	1.4	2.3	Gravel
Cabbage	Tropical Delight	1.77	28	1.3	2.2	Gravel

[1] From date of transplanting.

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