The significance of aquaponics in Controlled Ecological Life Support System in space

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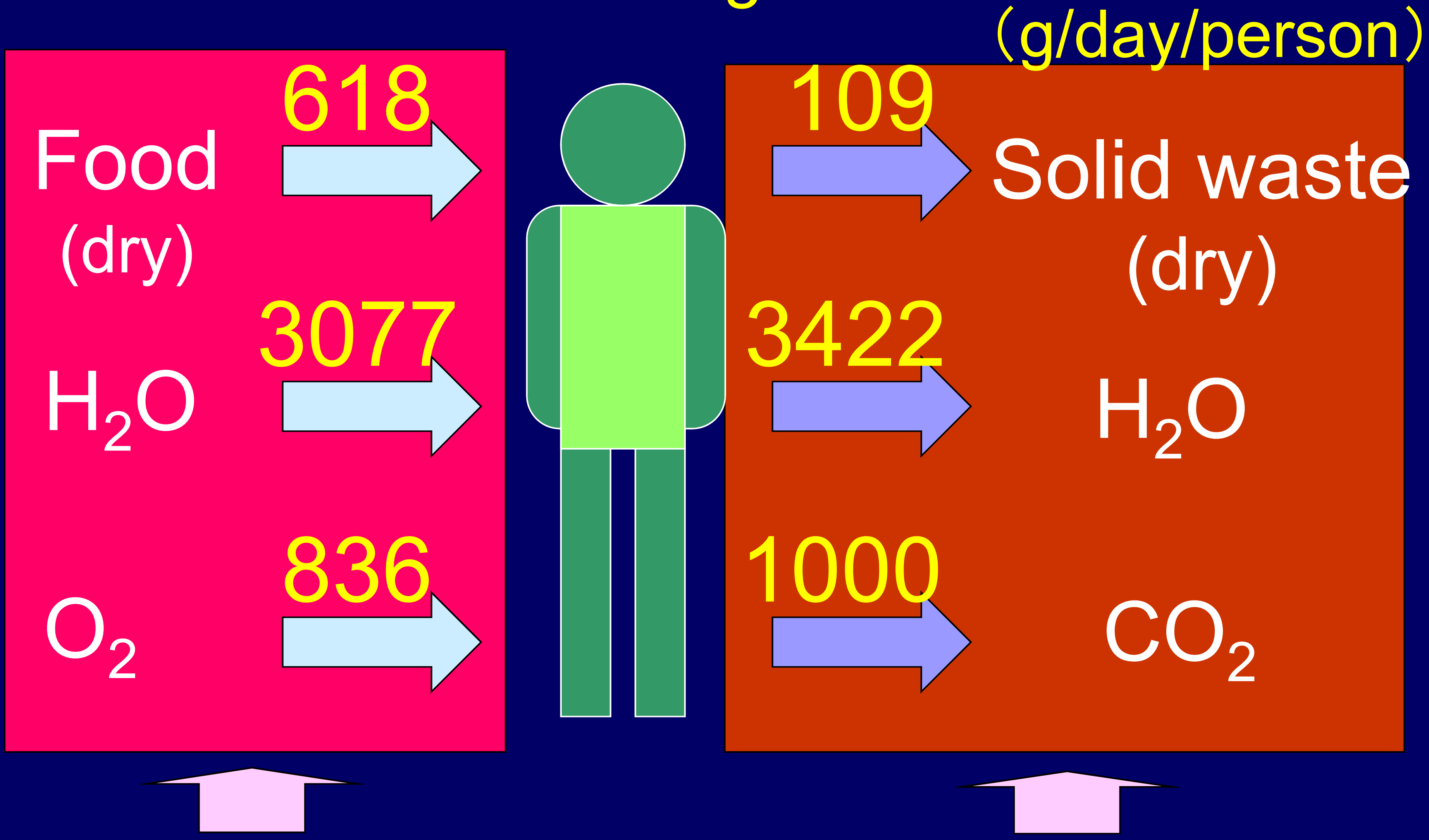
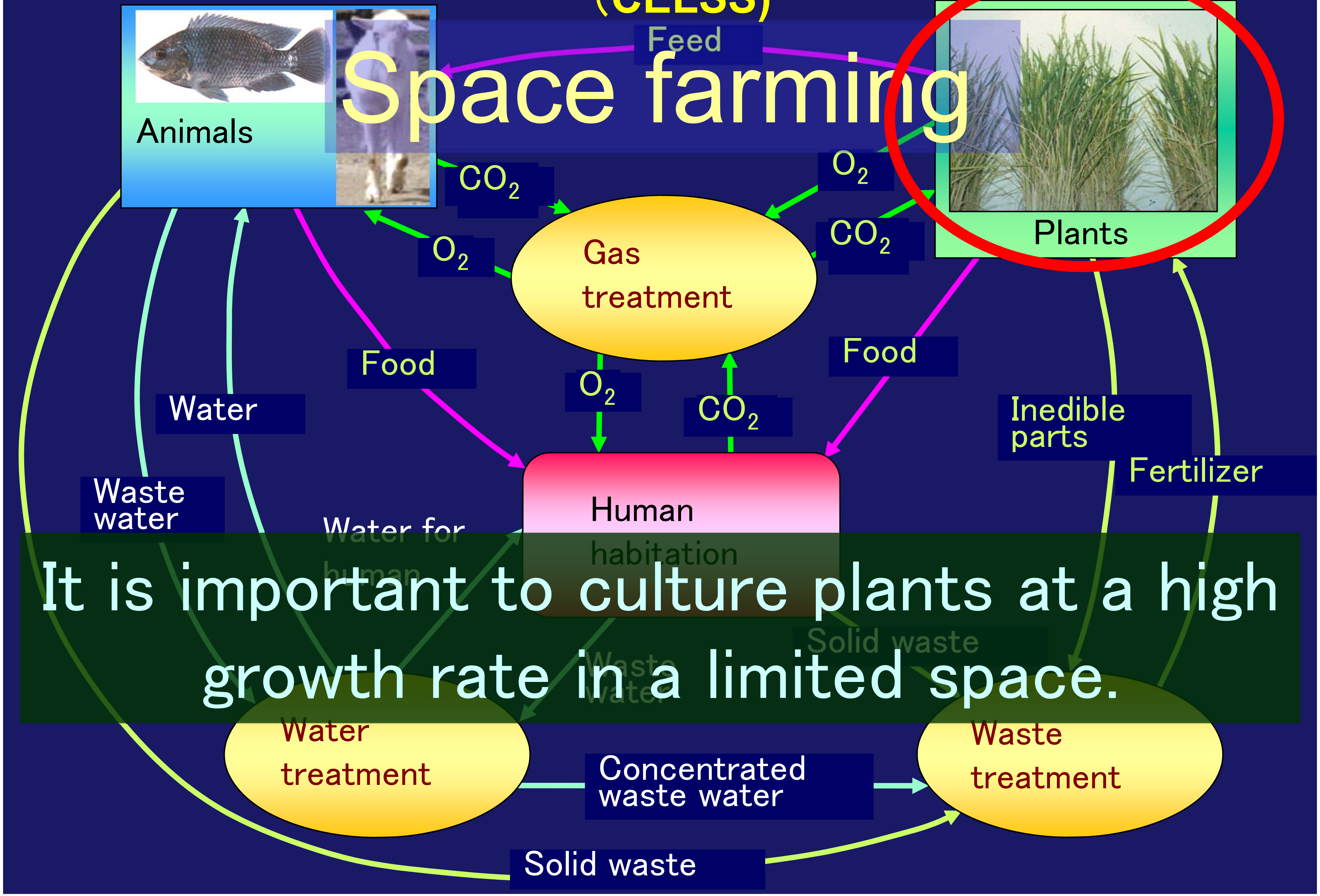
Metabolic material budget of an adult man

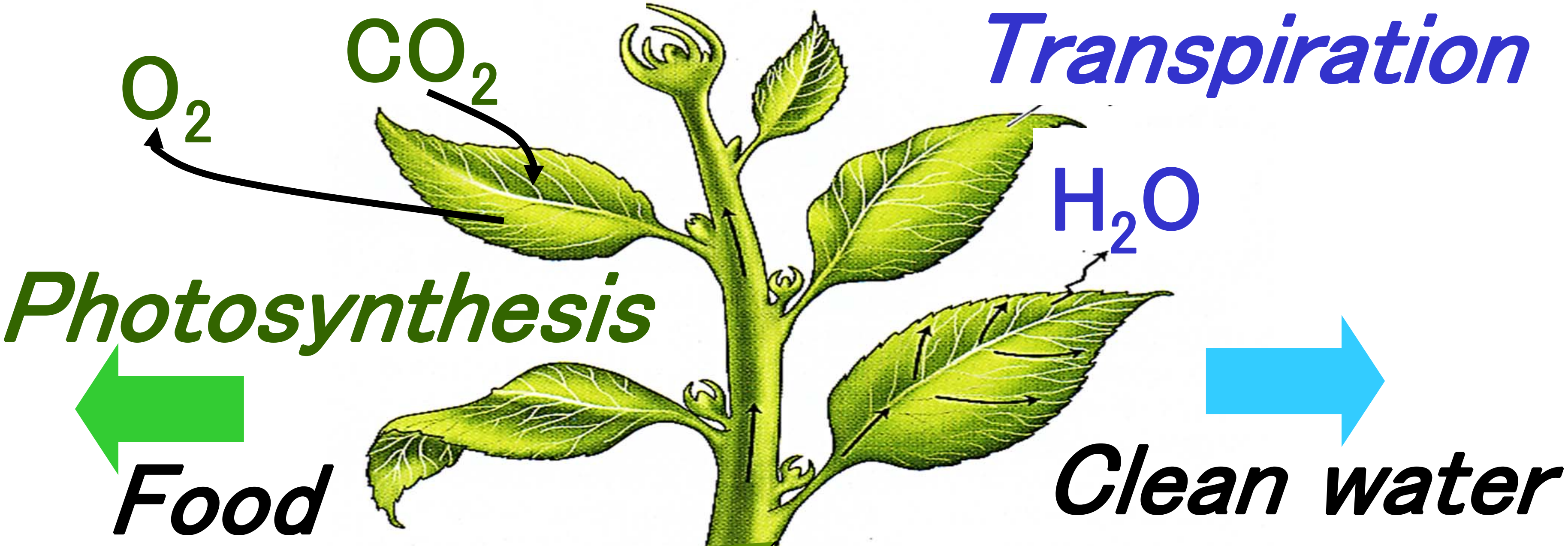


Most of these materials must be recycled by using functions of plants

Controlled ecological life support system (CELSS)



Roles of plants in space farming



Plants play important roles in food production, CO_2/O_2 conversion, water purification, etc. in the center of material circulation.

Candidates in space agriculture

Wheat, Rice, Sweet potato, White potato,

Soybean, Peanuts,

Lettuce, Carrot, Tomato, Strawberry, ・・・

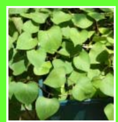
Why sweetpotato?

Sweetpotato is a promising pioneer crop in space farming as the vegetable crop as well as the root crop allowing a little waste.

Sweetpotato tubers cultured hydroponically
(Osaka Metro. Univ.)

Sweetpotato leaves and stems as high functional vegetable

Nutritional values of edible parts of crops (per 100 g fresh weight)

Crop plants	Energy (kcal)	Protein (g)	Lipid (g)	Carbo-hydrate (g)	Dietary fiber (g)	Ca (mg)	K (mg)
Sweetpotato tuberous roots 	132	1.2	0.2	31.5	2.3	40	470
White potato	76	1.6	0.1	17.6	1.3	3	410
Rice	350	6.8	2.7	73.8	3.0	9	230
Wheat	337	10.6	3.1	72.2	10.8	26	470
Soybean	417	35.3	19.0	28.2	17.1	240	1900
Peanut	562	25.4	47.5	18.8	7.4	50	740
Sweetpotato leaves 	(22)	4.0	(0.1)	(3.1)	5.7	142	(380)
Leaf Lettuce	16	1.4	0.1	3.3	1.9	58	490
Cabbage	23	1.3	0.2	5.2	1.8	43	200
Spinach	20	2.2	0.4	3.1	2.8	49	690

From standard tables of food composition in Japan 2010, and
https://www.naro.affrc.go.jp/project/results/laboratory/karc/2002/konarc02-10.html

Nutritional values of edible parts of crops (per 100 g fresh weight)

Crop plants	Fe (mg)	P (mg)	Ascorbic Acid (mg) V C	β–Carotene (mg) V A	α–Tocopherol (mg) V E	Vitamin K (mg)
Sweetpotato tuberous roots 	0.7	46	29	23	1.6	(0)
White potato	0.4	40	35	–	Tr	Tr
Rice	2.1	290	(0)	1	1.2	(0)
Wheat	3.2	350	(0)	—	1.2	(0)
Soybean	9.4	580	Tr	6	1.8	18
Peanut	1.6	380	(0)	–	10.1	Tr
Sweetpotato leaves 	2.0	(44)	31	9.4	4.3	1016
Leaf Lettuce	1.0	41	21	2.3	1.3	160
Cabbage	0.3	27	41	0.05	0.1	78
Spinach	2.0	47	35	4.2	2.1	270

From standard tables of food composition in Japan 2010, and
https://www.naro.affrc.go.jp/project/results/laboratory/karc/2002/konarc02-10.html

Many varieties of sweetpotato

Variety preservation field of Crop Research Institute, Japanese Ministry of Agriculture, Forestry and Fisheries

Sweetpotato is a promising crop in space farming because of

- utilizing for the vegetable crop as well as the root crop allowing mostly 100% edible
- high nutritive value
- high yields with a rapid turnover rate and easy reproduction with cuttings as vegetative propagation
- high capability for converting atmospheric CO_2 to O_2 by photosynthesis and purifying water by transpiration

Space food and nutrition systems must be based on space farming with scheduling of crop production, obtaining high yields with a rapid turnover rate, converting atmospheric CO_2 to O_2, purifying water, etc.

However, plant materials alone can hardly satisfy the nutrients necessary for maintaining human health.

Animal food Ingredients are also needed especially for promoting physique and longevity.

Importance of amino acids from animal Ingredients

Essential amino acids	**Cannot be synthesized in the human body**	Isoleucine Leucine Methionine Tryptophan Lysine Valine Histidine Threonine Phenylalanine
Semi-essential amino acids	Produced in the body, but desirable to be taken from food	Arginine Glutamine Cysteine Tyrosine
Non-essential amino acids	Can be synthesized in the body from carbohydrates and lipids	Aspartic acid Alanine Glycine Glutamic acid Serine Proline

Aquaponics as a biological production system consists of hydroponics and aquaculture systems and will be useful for supplying plant and animal Ingredients in Space.

We are developing biological production systems with aquaponics in Space as well as on Earth.

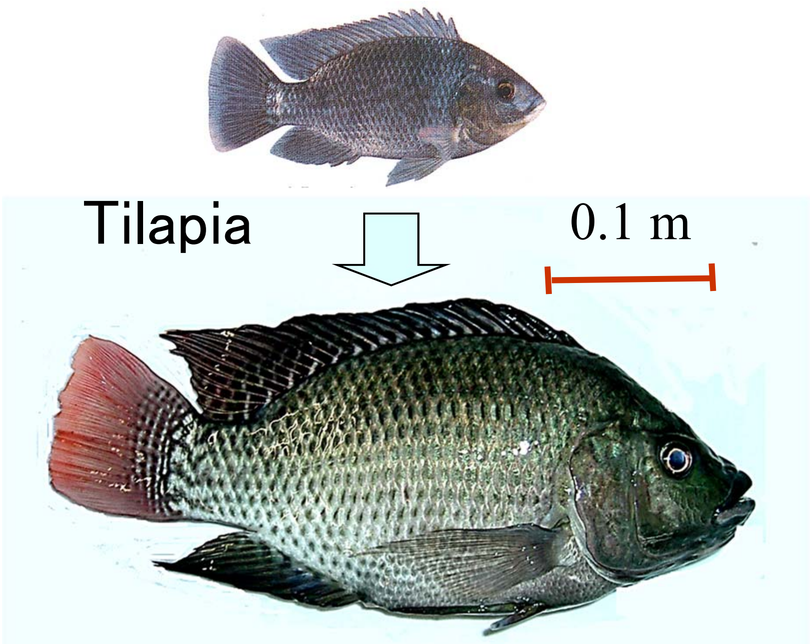
Aquaponics with sweetpotato and tilapia fish for producing nutritional crops and animal protein

Styrofoam boxes with holes on the bottom side were used to culture sweet potato on the water surface. Nylon net containers filled with hydroballs were placed in styrofoam boxes.

(Islam et al., 2022)

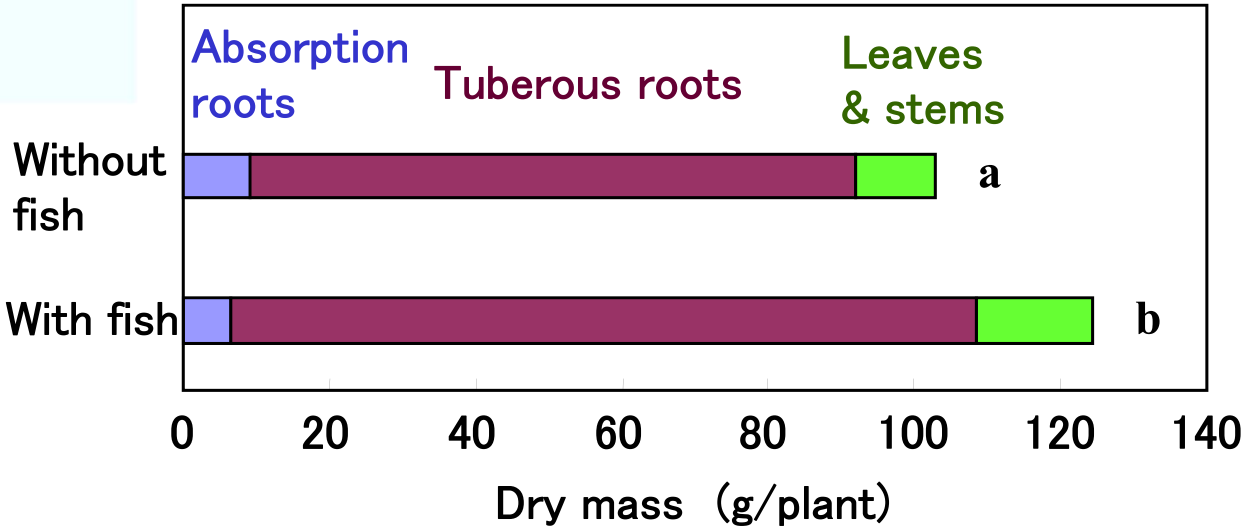
Aquaponics with sweetpotato and tilapia fish for producing nutritional crops and animal protein

Culture period: 3 months

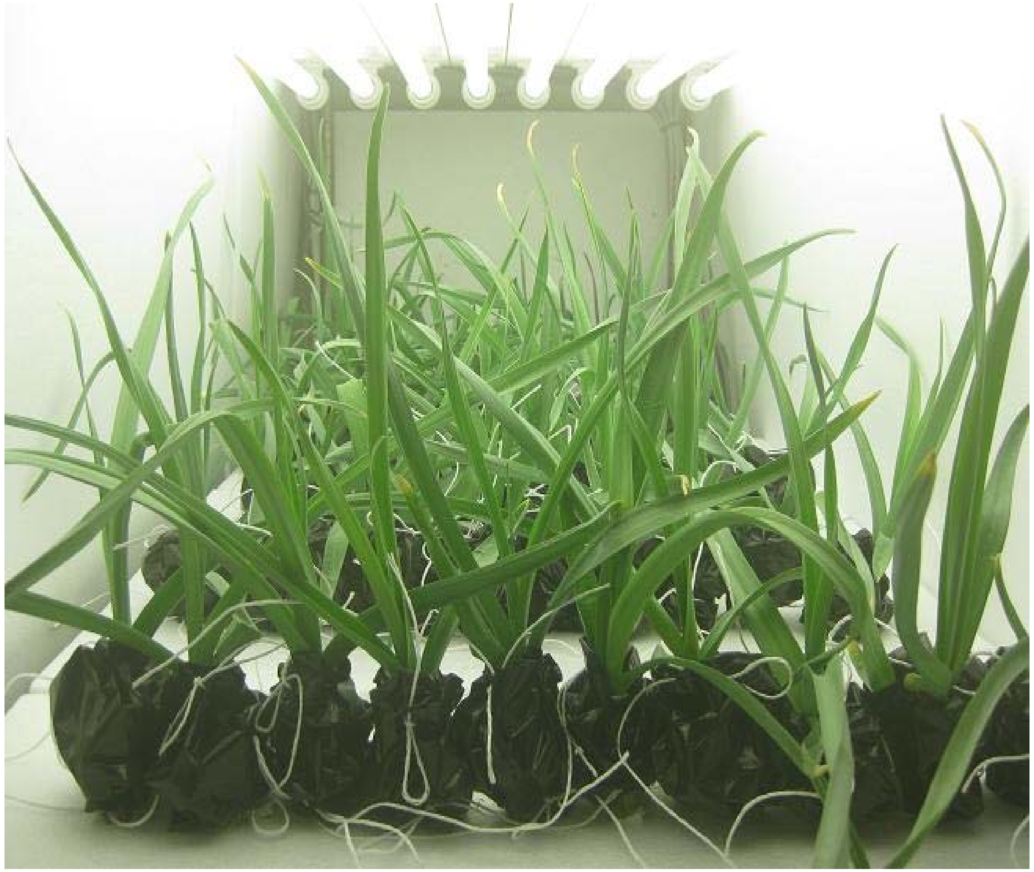


The average length and weight of tilapia fishes increased by 10 cm and 188 g and those were 1.8 and 6.9 times, respectively, greater than at the start.

Sweetpotato ‘Kokei-14’ at harvest



Aquaponics with garlic plants and tilapia fish



(Naznin et al., 2015)

60 days after setting the aquaponics

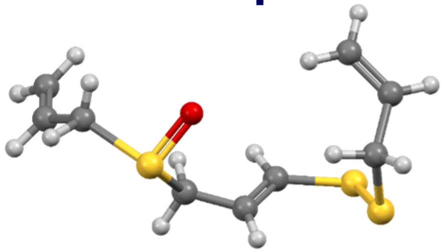
Dry mass (g/plant)

2.0	Leaves	1.3
3.6	Bulbs	2.3
3.4	Roots	2.1

100 mm

(Naznin et al., 2015)

Medicinal component in garlic



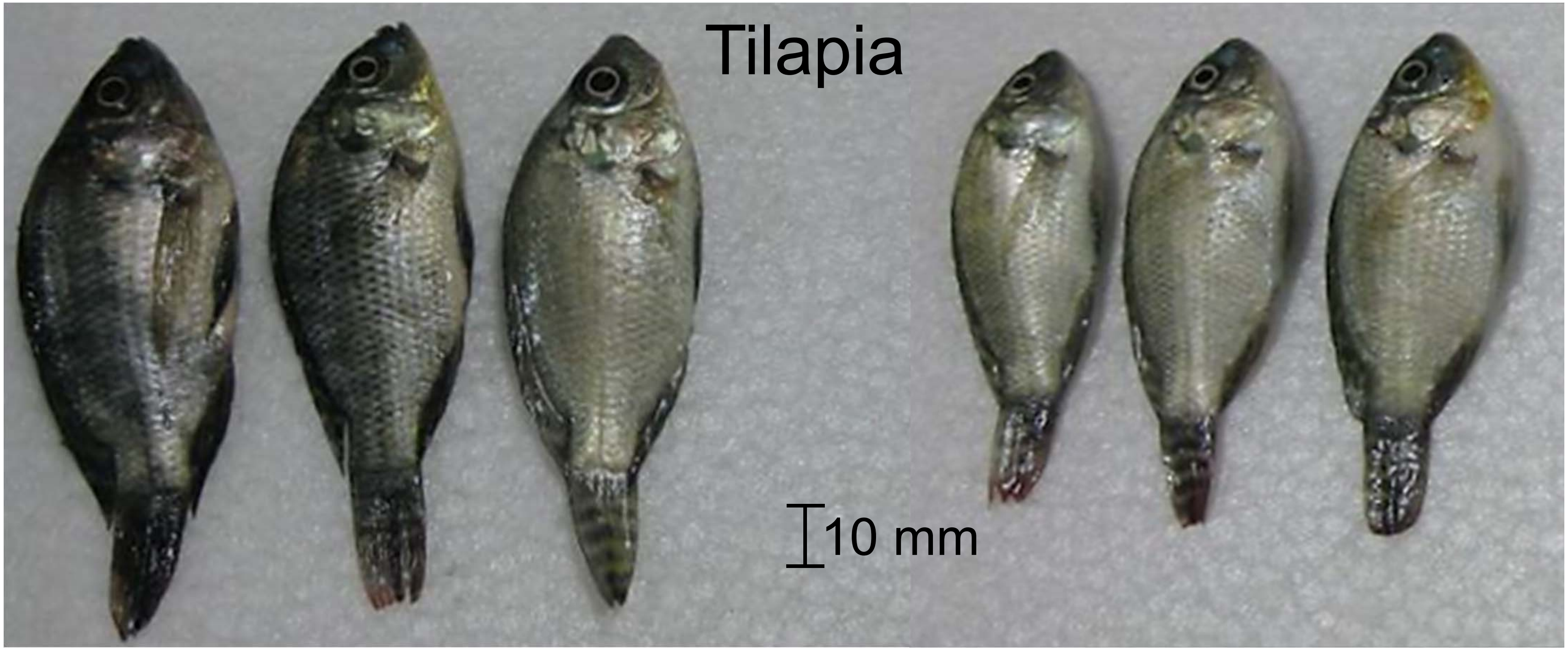
Ajoene (mg/plant)

16.3	Leaves	5.6
9.5	Bulbs	2.8
6.2	Roots	2.6

100 mm

(Naznin et al., 2015)

60 days after setting the aquaponics

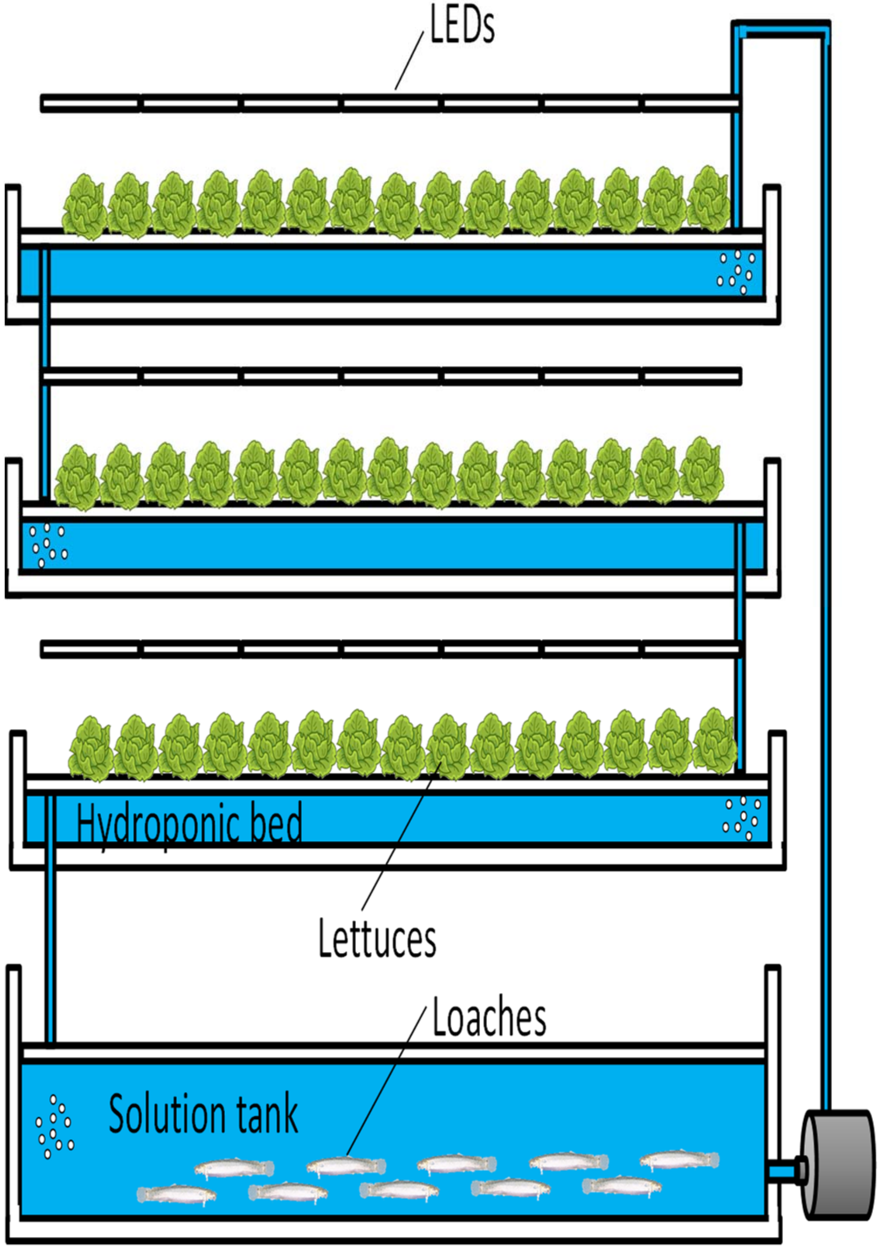


With plants (Aquaponics)

Without plants (Aquaculture)

0.05 Daily mass gain (g d^{-1}) 0.03

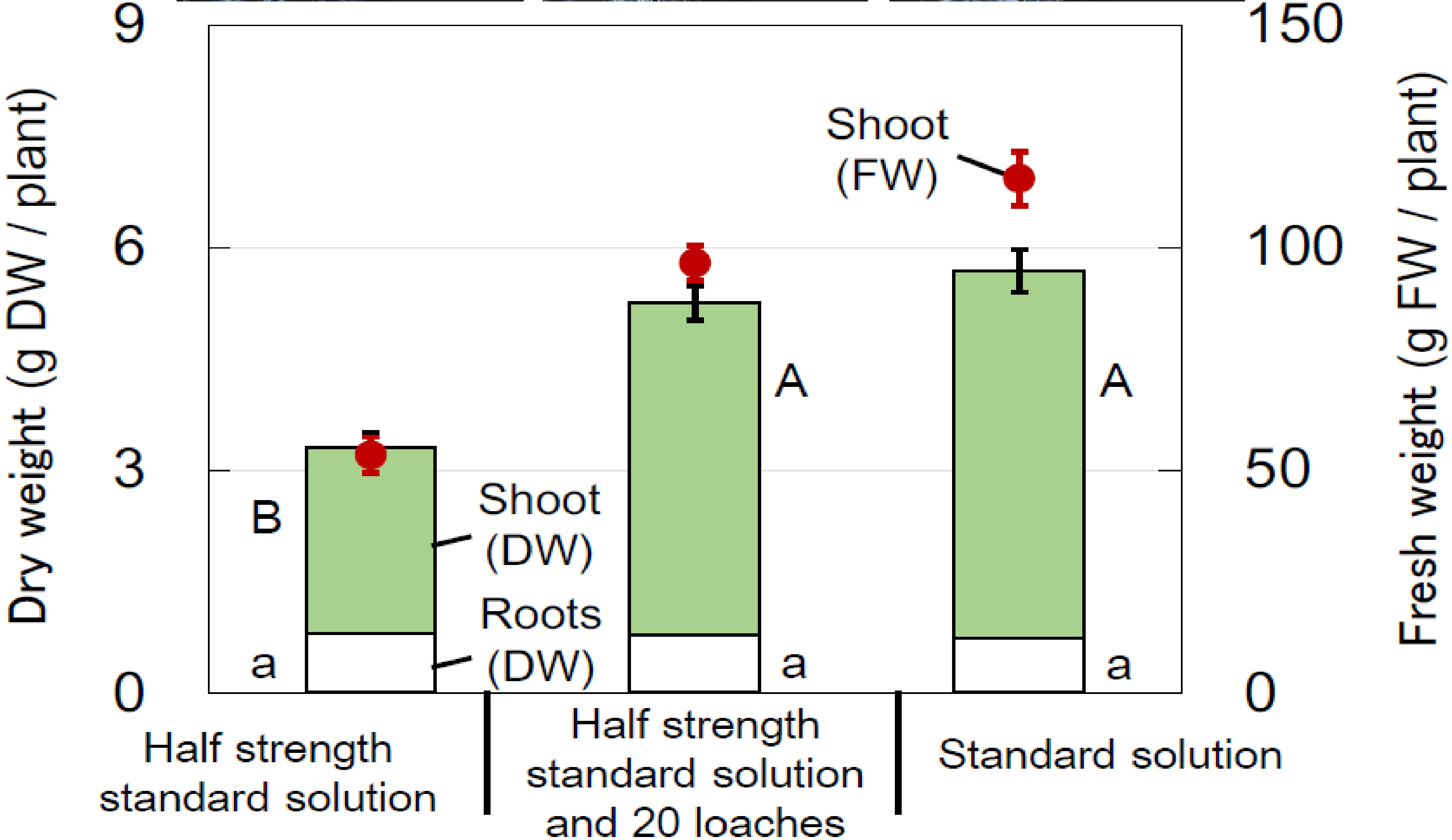
Aquaponics with lettuce plants and loach fish



Cooking examples of loach fish

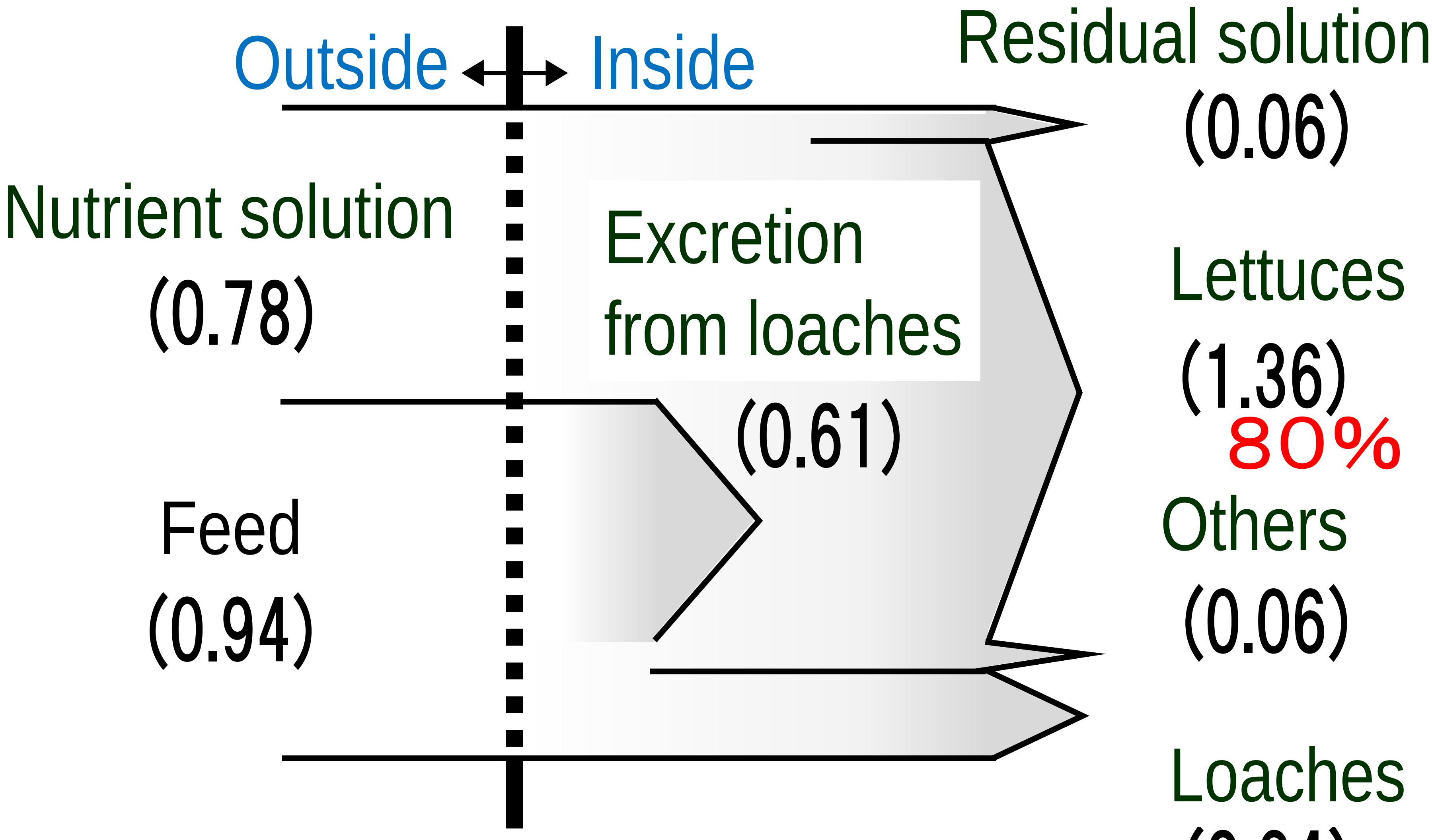
https://hitosara.com/dish/32dojou.html

(Shimakawa et al., 2019).



Growth of lettuce plants in 3 treatments at day 21

N (g) dynamics in aquaponics with 6 lettuces and 20 loaches



80% of input N was accumulated in lettuce plants and 20% in loach fish

(Shimakawa et al., 2019)

Effect of fish density on biological production combining lettuce hydroponics and loach aquaculture

(Kitaya et al., 2021)

In this study

The effect of fish density on biological production and nitrogen recovery in aquaponics by combining lettuce hydroponics and loach aquaculture was investigated.

We controlled fish density which is proportional to the number of fish and the amount of total feed in the system.

Experimenta duration：21 days each
Basic nutrient：Half strength OAT-A
EC: 1.2 dS m^{-1}

Environmental conditions:
Temp.：25/20 ℃ (Day/Night)
Light source：LED
PPFD：200 μmol m^{-2} s^{-1}
Day length：16 h d^{-1}
Relative humidity：70％
CO_2 level：700 μmol mol^{-1}

Results

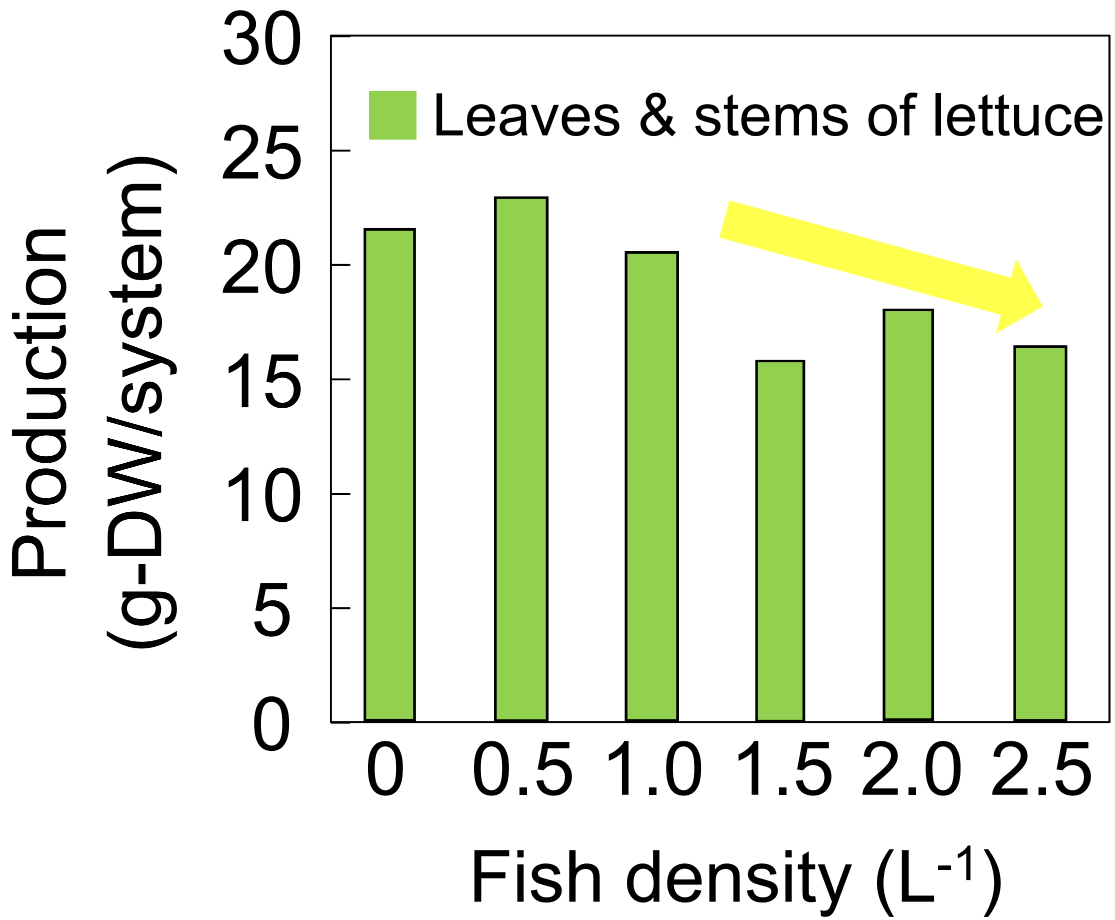
0.5 1.0 1.5 2.0 2.5

Fish density (L^{-1})

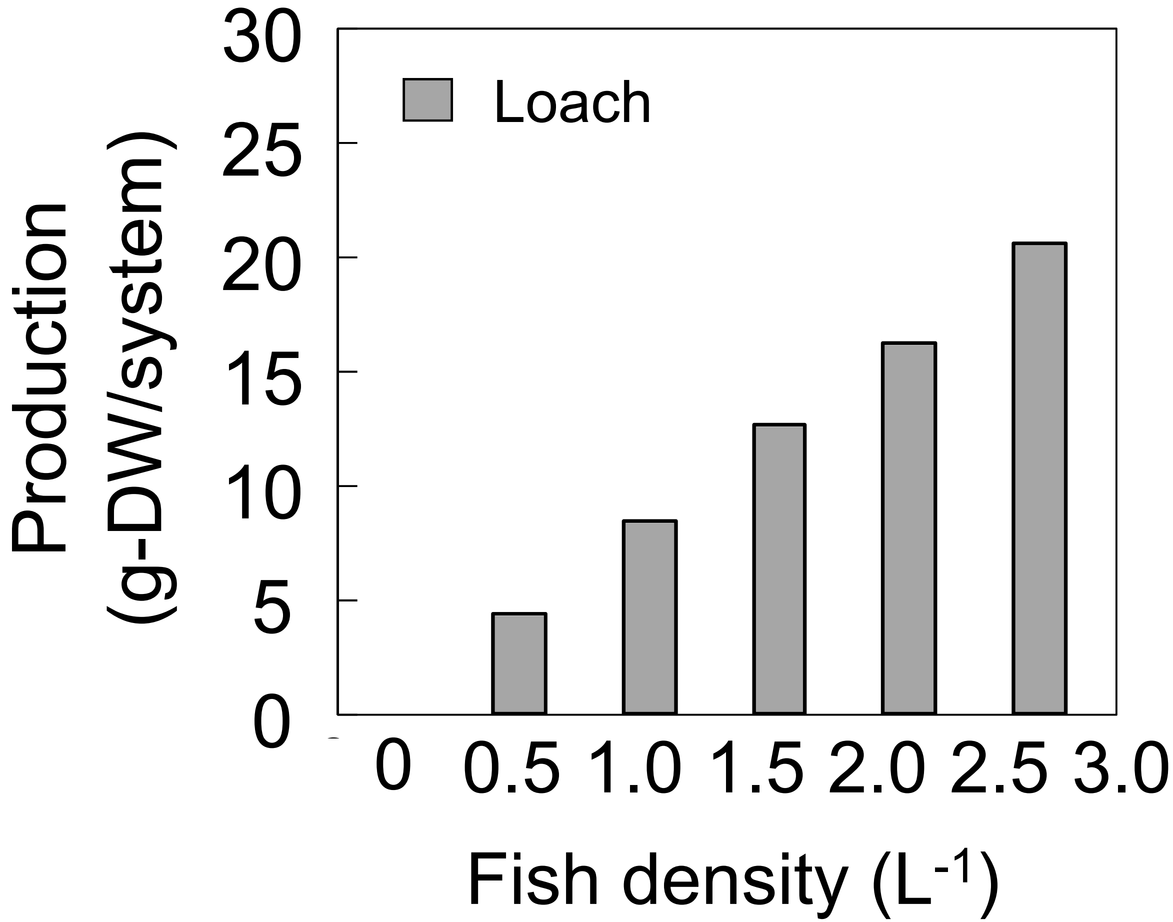
10 cm

Nomal hydroponics

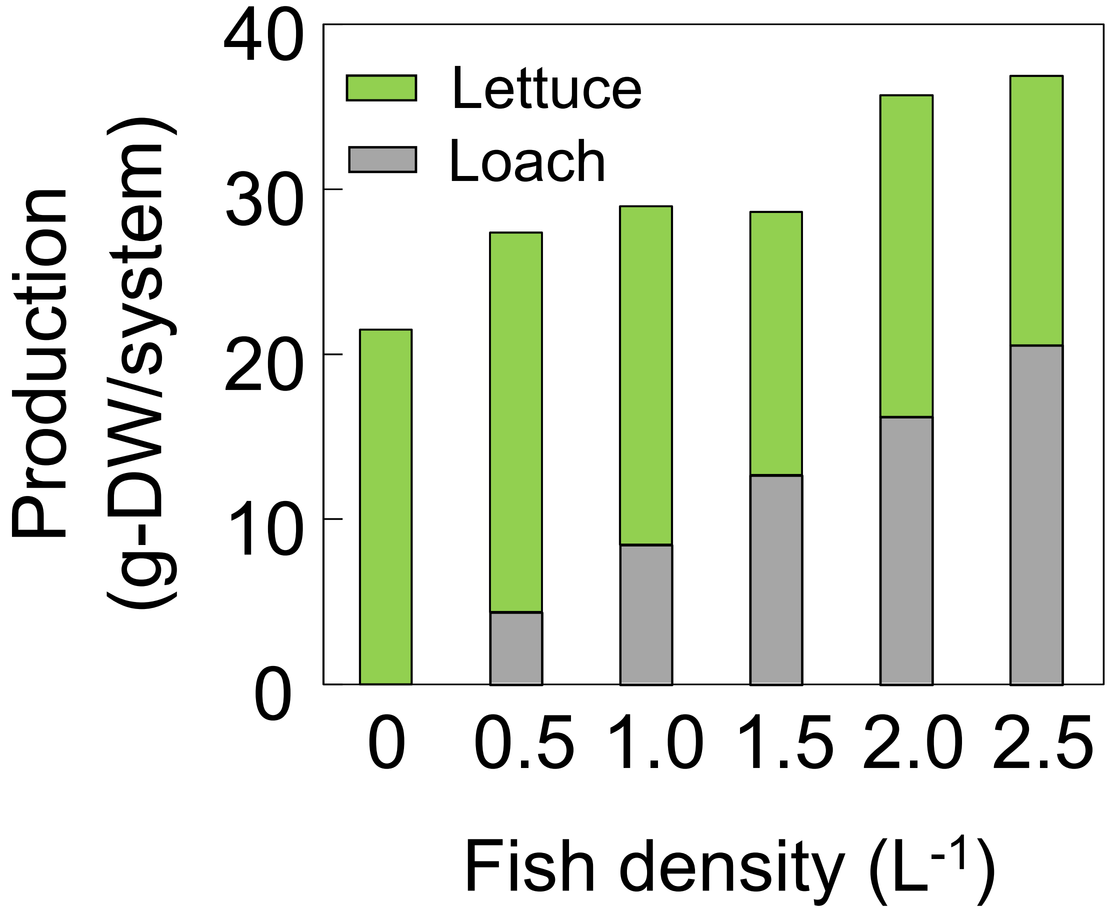
There was no apparent difference in plant size.



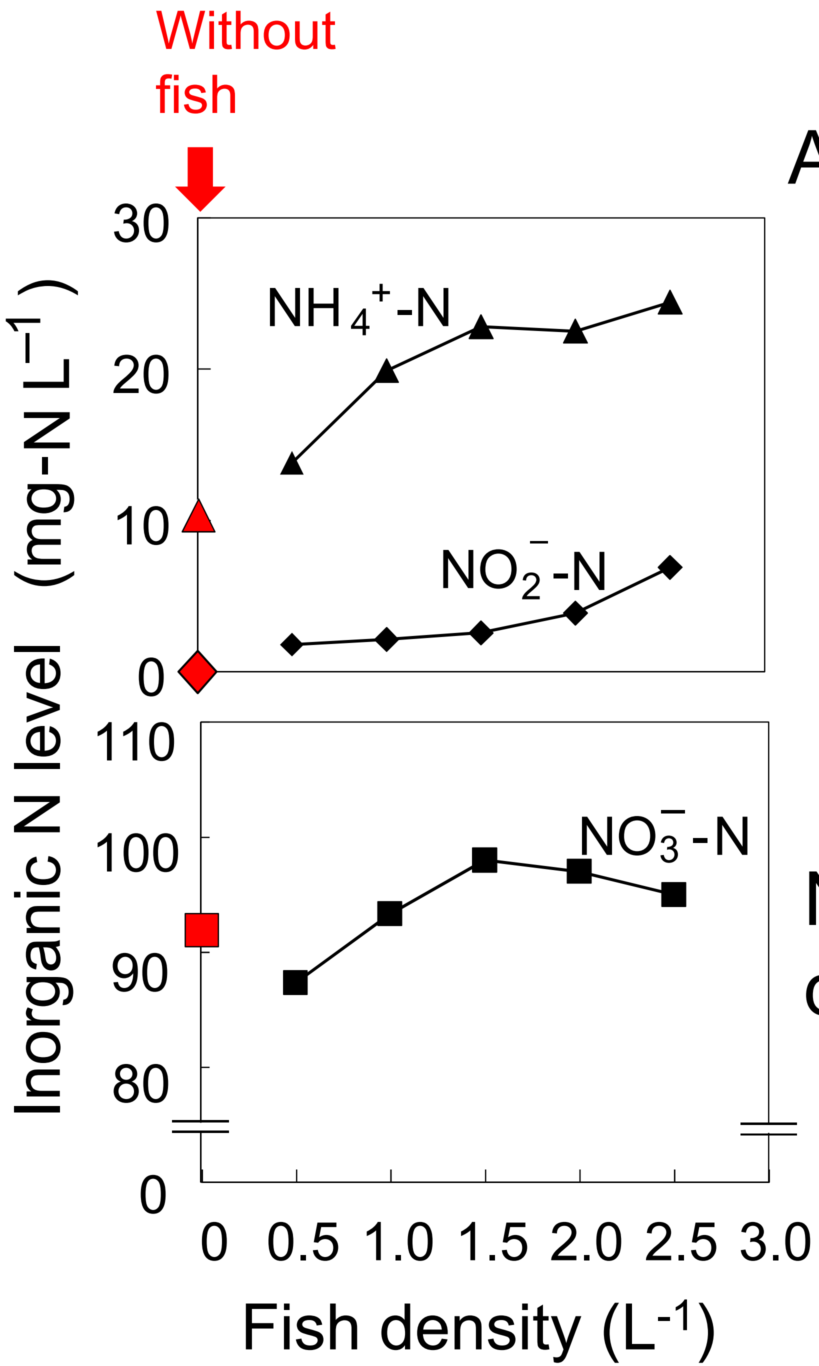
Lettuce production was not significantly related to fish densities but tended to decrease at high fish densities.



Loach production increased with increasing fish densities.



Total production of lettuce and loaches increased with increasing fish densities.



As the fish density increased,

and the amount of nitrogen input from feed increased,

NH_4^+-N increased,

NO_2^--N increased,

NO_3^--N increased until the fish density exceeded 1.5 fish L^{-1}.

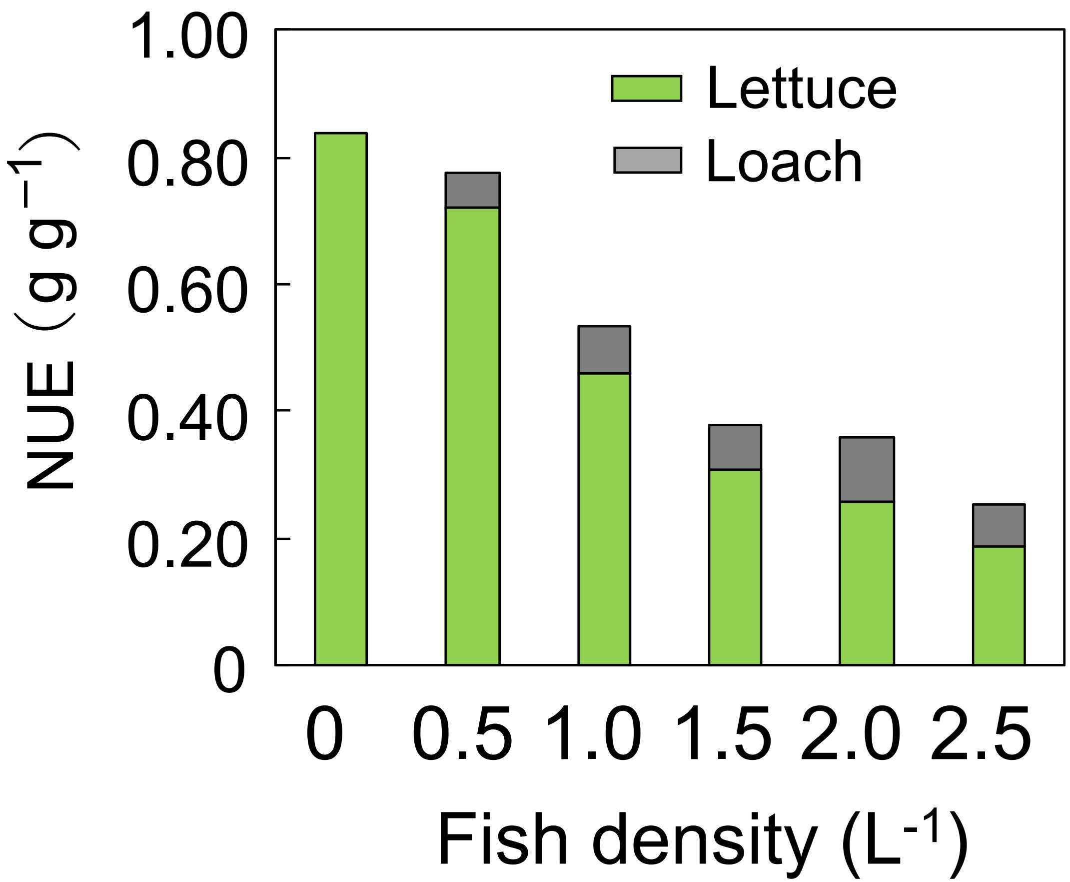
Nitrogen Utilization Rate (NUE)

$$NUE = \frac{N_{plant} + N_{fish}}{N_{input}}$$

N_{plant}: N content in lettuce plants

N_{fish}: N content in loach fish

N_{input}: N content in feed and initial nutrient solution



NUE of loaches was not significantly related to fish densities.

NUE of lettuce decreased with increasing fish densities.
It is considered that the lettuce growth rate was constant and nitrogen accumulation in the lettuce did not change.

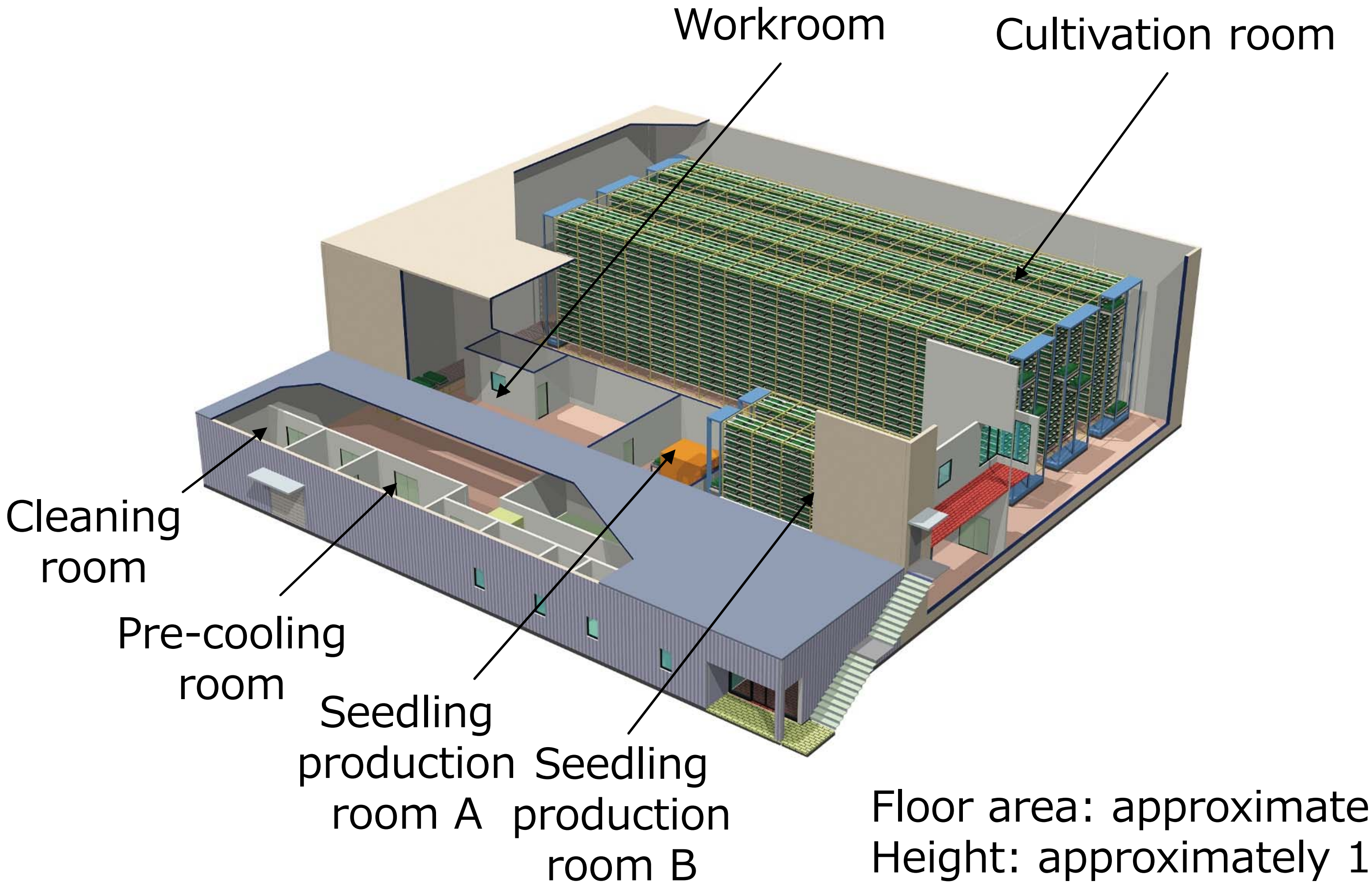
NUE of total production decreased with increasing fish densities.

The biological production rate can be increased by increasing the density of loaches and lettuce plants.

From the viewpoint of resource recycling, it is necessary to consider an appropriate balance between lettuce and loaches.

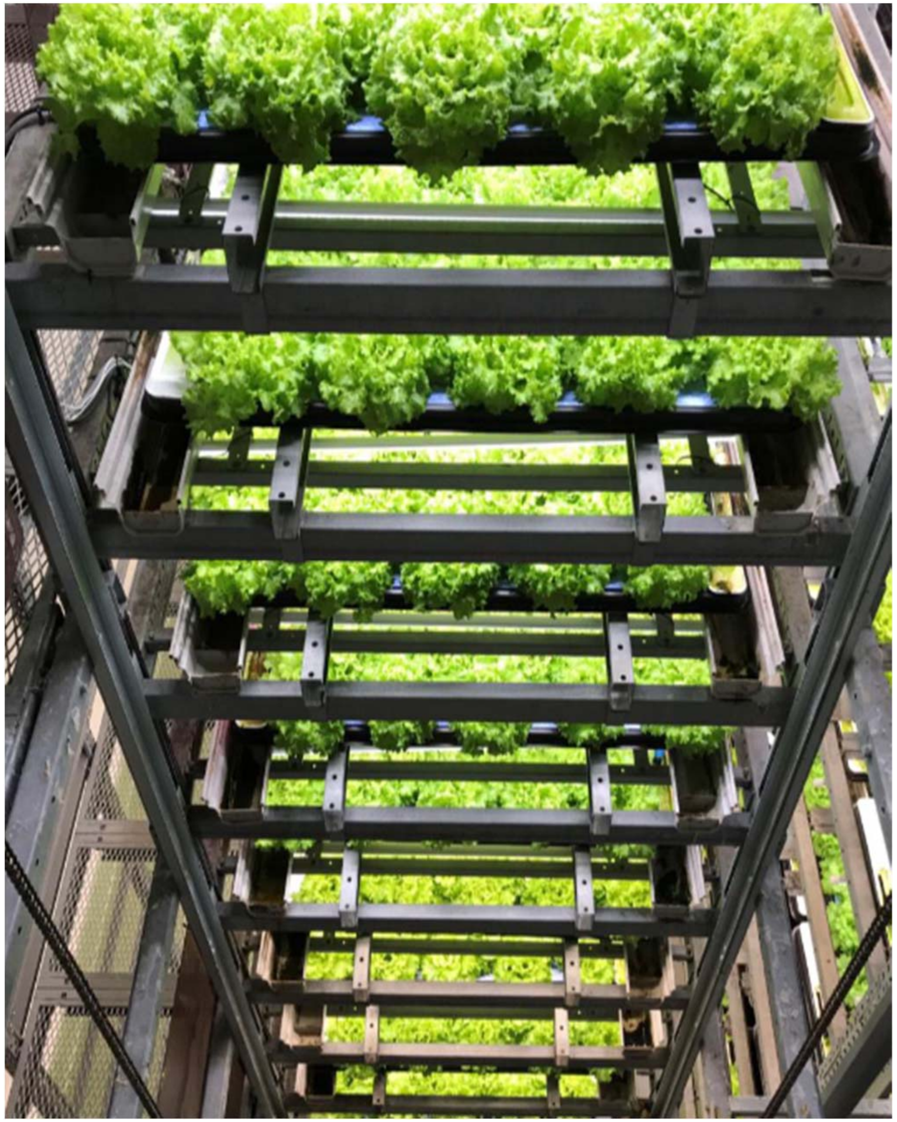
To increase nitrogen recovery in aquaponics with a high fish density, the effect of plant density will be important.

Vertical farm at Osaka Metropolitan University



Floor area: approximately 1300 m^2
Height: approximately 10 m
Full capacity: 6656 plants day^{-1}

Internal view of the vertical farm

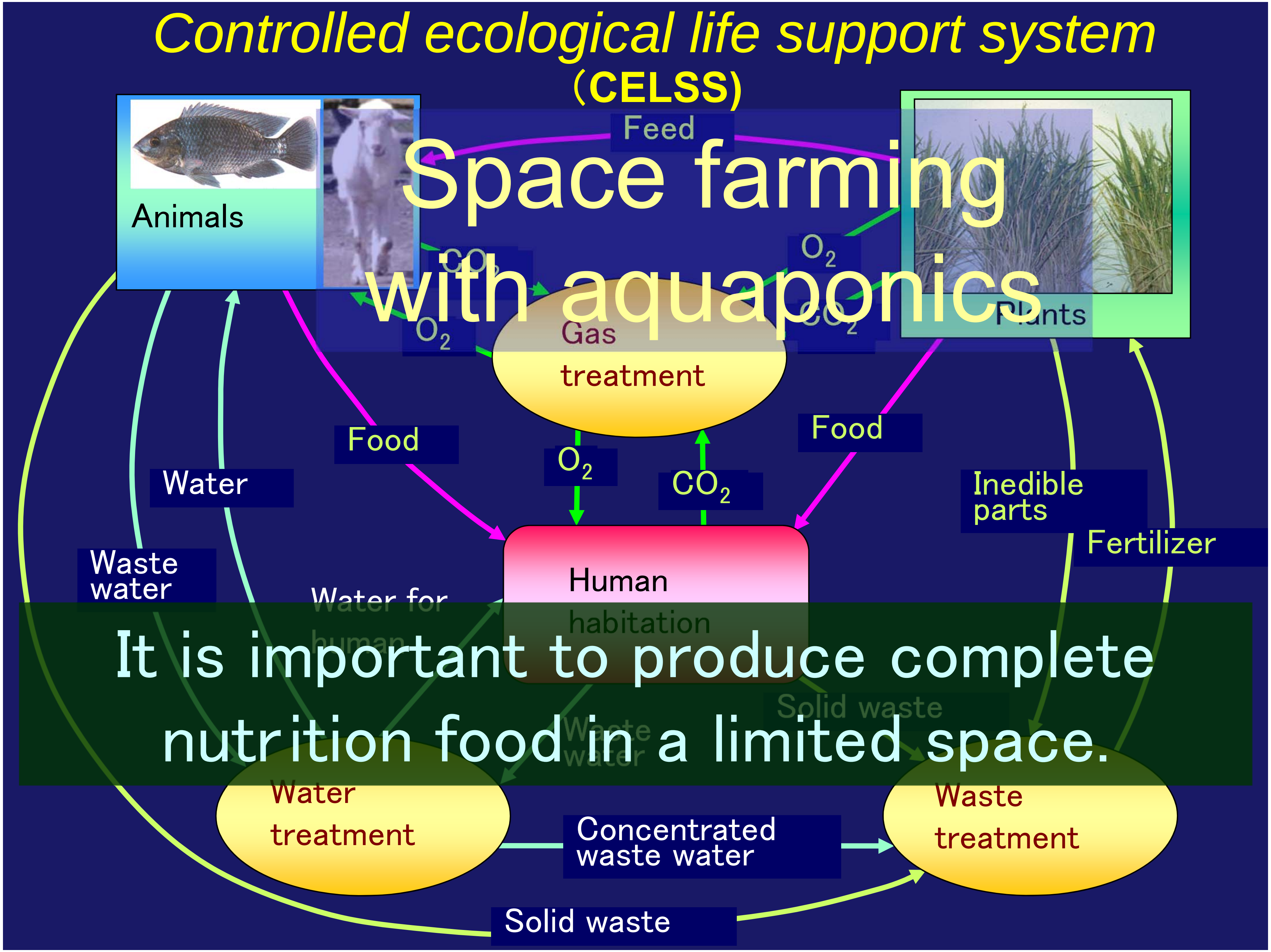


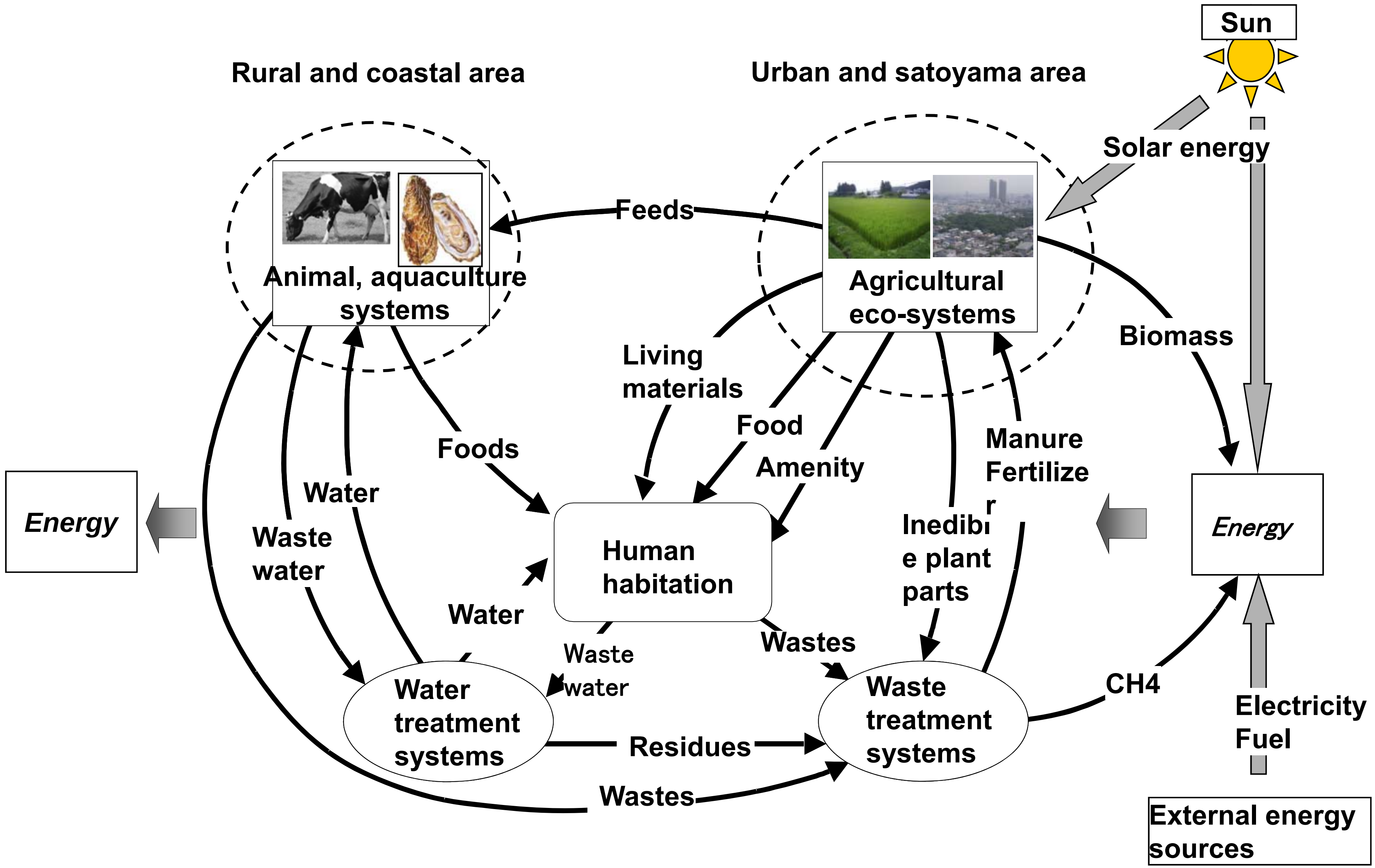
Vertical farm with aquaponics

We are developing human- and environment-friendly vegetable production systems with companies, which reduce the use of chemical fertilizers.




Aquaponics in artificial light plant factories and natural light greenhouses


Controlled ecological life support system
(CELSS)
Space farming
with aquaponics
Feed
Animals
Plants
CO_2
O_2
O_2
CO_2
Gas
treatment
Food
Food
O_2
CO_2
Water
Inedible
parts
Fertilizer
Waste
water
Water for
human
Human
habitation
It is important to produce complete
nutrition food in a limited space.
Solid waste
Waste
water
Water
treatment
Concentrated
waste water
Waste
treatment
Solid waste



Application of the CELSS to eco-systems especially in urban areas