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Plant Production for Sustainable Society as a Semi-closed Ecosystem

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Yoshiaki Kitaya
Organization for Research Promotion
Osaka Metropolitan University
Sakai, Osaka, Japan

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Chapter 1
General Introduction

Increasing global concern about a lack of food, depletion of natural resources such as fossil fuels and minerals, environmental issues related to human activities, etc. has led to a growing interest in sustainable food production in harmony with the environment. In recent years, in many industrial fields, an increasing number of companies have been working on so-called zero emissions, such as reducing the amount of waste generated and recycling the waste as much as possible to reduce the environmental load.

In agriculture, constructing a resource-recycling production system that suppresses waste emissions has become critical. Traditionally, in plant production in open areas such as paddy fields and vegetable fields, a wide range of circulating ecosystems incorporating organic matter such as undergrowth and fallen leaves of mountain forests and excrement of livestock and humans have been constructed over many years. However, in recent years, agricultural production systems have focused only on increasing productivity and have not focused on the increase in the burden on the environment surrounding plant production sites. As a result, for example, the eutrophication of rivers and lakes due to the outflow of excess fertilizer has become apparent.

As a result, for example, eutrophication of rivers and lakes due to the outflow of excess fertilizer, groundwater pollution due to underground infiltration of fertilizer, light pollution that affects the photoperiodism of surrounding animals and plants due to supplementary nighttime light in facility cultivation, depletion of groundwater due to excessive pumping of groundwater, soil salt accumulation due to inappropriate irrigation worldwide, overgrazing of livestock, and desertification due to improper management have become apparent.

To help solve these problems, especially in agriculture in urban areas, by increasing the efficiency of raw material and energy use or by recycling and reusing waste generated in the production process, it is becoming essential that the number of resources used and the amount of waste can be reduced as much as possible. However, there are many difficulties in introducing the material cycle type into the

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current open plant production system and increasing productivity. However, compared to conventional plant production systems in fields and paddy fields, facility-type plant production systems such as greenhouse cultivation of vegetables and flowers, factory-like plant and mushroom cultivation, or nursery plant production in facilities easily introduce the material cycle type in a facility-based plant production system that is a more closed environment, especially a semi-closed environment. The term “closed” here means that it is closed from the viewpoint of material circulation. Although it is not closed for energy, it is necessary to reduce the input from outside the system as much as possible for energy.

In Japan, environmental conservation agriculture has been promoted since the 1990s to solve the environmental, regional resource management, and regional socio-economic problems that have become apparent in agricultural areas, led by the Japanese Ministry of Agriculture, Forestry and Fisheries. In addition, Article 36 of the Food, Agriculture and Rural Area Basic Law, revised in 2015, describes the importance of promoting agriculture in and around cities and makes use of the characteristics close to the consumption areas, and the national policy came to promote agricultural production that meets the needs of urban residents. The role of urban agriculture includes supplying fresh and safe locally produced and locally consumed agricultural products, conserving the local environment, understanding agriculture through familiar agricultural experiences, supporting food education and environmental education, providing a place for community activities, and providing the amenity space as a green area and securing disaster prevention space. In the future, it is important to have a facility-based plant production system responsible for a wing of urban area agriculture to utilize these various significances in urban area agriculture effectively.

Compared with production in paddy fields and vegetable fields, in facility-based plant production systems that require more initial and maintenance costs, technology development that efficiently controls plant growth with low-cost management is an important issue. In addition, we consider the ecosystems, including human activities in urban areas, as closure. I propose introducing facility-based plant production systems with the central axis of the substance circulation in the material cycling system. While increasing the sustainability of facility-based plant production systems, for the basic idea of substances and energy-effective utilization to minimize the impact on the surrounding environment, as an example of application to the agricultural production system of resource circulation and energy conversion technology, we also propose technology for maximum use of methane fermentation using organic waste discharged from urban areas and farming areas.

In recent years, in Japan, large-scale natural disasters, global warming, production-based vulnerability, and regional community decline due to decreased growers, changes in production and consumption due to new coronavirus infections, etc. have occurred. Corresponding to these issues, the construction of a sustainable food system is urgently needed to provide a stable supply of food in the future and to respond to rapid movements in Japan and overseas corresponding to SDGs and global environmental problems. Therefore, in Japan’s Ministry of Agriculture, Forestry and Fisheries, the “Green Food System Strategy” was formulated in 2020, which implemented both the productivity improvement of the food and agriculture, forestry, and fisheries industry and the balance of sustainability in innovation. Among these circumstances, the importance of plant production for a sustainable society in their contribution to sustainable food system construction is further higher as a semi-closed ecosystem.

1.1 A Material Cycle System Centered on Agriculture in the Ecosystem, Including Human Activities in Urban and Suburban Areas

In the urban ecosystem in a steady state on average for a relatively long period (for example, several years), the amount of material and energy flowing into the ecosystem is almost equal to those flowing out. In the urban ecosystem where material/energy access and ideal circulation have been achieved in areas, including urban and suburban green areas (farmland and sato-yama) and coastal waters (sato-umi) based on material cycles, the amount of material and energy inputs and outputs into and from the system are reduced. We strongly require most plant functions to ensure environmental protection and food and material production to achieve such a material-cycling society.

In recent years, emission reduction, reuse, and recycling of large-scale food waste in urban areas have significantly increased. Consequently, developing efficient food production systems with low environmental impact is critical in semi-natural ecosystems involving anthropological activities and agroecosystems, particularly those involving facility-based plant production, to substantiate food production from an environmental standpoint. Plant production will play a critical role in the health and welfare of humans, particularly in urban areas. Thus, to produce food efficiently while protecting the environment, a semi-closed system and material-cycling farming are needed for a material-cycling-oriented society.

For such a sound material-cycling society, the urban area is regarded as a semi-closed system, and the plant functions of the suburban green spaces and urban green spaces, as well as the agricultural functions that can guarantee environmental conservation as well as food production, are fully utilized as well as conservation of natural ecosystems.

1.2 Overview of This Book

To solve issues such as shortages of food, biomaterials, and energy and damage to the environment, plants play an important role by providing materials for food, biomaterials, energy sources, and environmental conservation.

In this book, the following items are regarded as semi-closed systems:

1. Mangrove forests as semi-closed systems in coastal ecosystems
2. Environmental control in facility-based plant production systems as semi-closed systems
3. Control of the gaseous environment in the root zone as a semi-closed system
4. Controlled ecological life support systems as completely closed ecosystems in space
5. A sustainable balance of human activities and environmental conservation in urban ecosystems

The concept of items (1)–(4) can be extended to item (5), which concerns urban ecosystems incorporated with agriculture. It is necessary to use plant functions in urban ecosystems best to achieve a material-cycle society. To achieve a sustainable balance of human activities and environmental protection, I focused on the material cycle within each system mentioned above.

Chapter 2
Mangrove Forests as Semi-closed Systems in Coastal Ecosystems

Abstract Tropical coastal zones with mangrove forests as semi-closed ecosystems have recently been damaged by human pressures. Therefore, reforestation of mangroves and restoration of coastal areas have recently become urgent issues. To carry out mangrove plantation operations efficiently, it is essential to understand how the growth characteristics of young plants are affected by environmental elements at plantation sites. Young seedlings of some mangrove species have well-developed hypocotyls. The hypocotyls of the seedlings play an essential role in their growth at early stages. The early development of mangrove seedlings at different elevations differed. Species with a greater ability to generate O_2 in hypocotyls showed greater tolerance to high tidal levels and greater survival ratios at low elevations.

Keywords Afforestation · Estuaries · Hypocotyls · Mangroves · Mudflats · Reforestation · Salt tolerance

Tropical coastal zones have recently been damaged by the pressures of increasing population, food production, and industrial and urban development in many parts of the world. Especially in mangrove swamps near human living areas, which are considered coastal woodland areas near villages called "Sato-yama and Sato-umi landscapes" (e.g., Watanabe et al. 2012), excess cutting of trees for fuel and construction materials and conversion of forests to agricultural land and aquaculture ponds for commercial production have caused environmental problems. Therefore, reforestation of mangroves and restoration of coastal areas have recently become urgent issues.

2.1 Roles of Swamp Ecosystems

The role of swamps is important because they control environmental systems in basins and provide coastline protection, microclimate control, water purification, soil formation, wildlife habitat, and human use.

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Large tracts of swamps and wetlands can be found in the tropical zone. Vast swamp areas, including mangroves, can be found in Southeast Asia with humid weather conditions. Historically, most of these swamps were exploited after the 1970s' increase in land development. Agricultural development first occurred some decades ago in some areas, but most of them were abandoned. Currently, they have become tropical savannas that do not support plant cultivation and thus present a significant social problem in many tropical and subtropical countries.

2.2 Roles of Mangrove Forests in Coastal Ecosystems

Extensive mangrove forests, as shown in Fig. 2.1, are an important component of tropical and subtropical swamps. Swamp ecosystems, including mangrove forests, play an essential role in conserving tropical coastal zones. The values of the mangrove ecosystem are not only the production of goods such as timber and charcoal derived directly from the mangroves themselves and fish, shrimp, and other aquatic resources indirectly supported by inputs from the mangroves but also from a series of less tangible services that mangroves provide, such as shoreline protection and sediment and nutrient trapping. Recently, the function of below-ground carbon

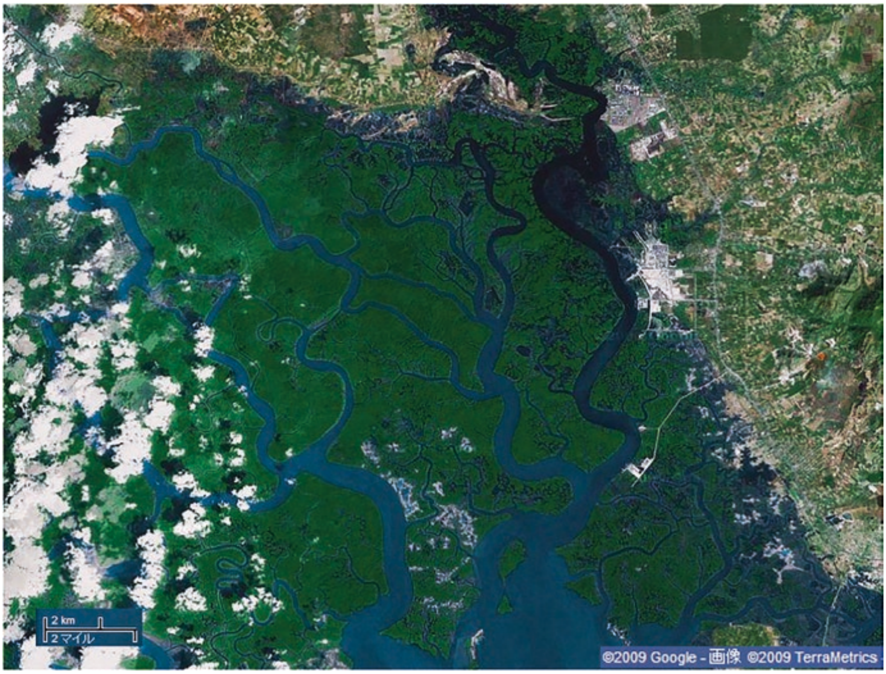

Fig. 2.1 Mangrove forests are extending in tropical and subtropical swamps

sequestration by mangrove peat accumulation has also been identified, emphasizing its role in mitigating atmospheric carbon dioxide accumulation.

In other words, mangroves have both sato-yama and sato-umi functions and various benefits for not only natural ecosystems but also human society as ecosystem services, including food production, atmosphere and water purification, soil erosion prevention, flood control, and cultural issues such as spiritual well-being and ecotourism.

Despite their importance, mangrove forests and ecosystems in Southeast Asia have been disturbed and destroyed by urbanization, timber cutting, shrimp farming, etc. In addition, the mangrove ecosystem faces severe threats from global environmental change and exceptionally rapid sea-level rise. They have recently been damaged by the pressures of increasing population, food production, and industrial and urban development in many parts of the world. Especially in mangrove swamps, the excess cutting of trees for fuel and construction materials and the conversion of forests to agricultural land and aquaculture ponds for commercial food production have caused environmental problems. Therefore, reforestation of mangroves and restoration of coastal zones have recently become urgent in many countries. Developing a comprehensive awareness of ecosystem functions and improving ecosystem restoration skills are helpful for local people and solutions to some global environmental problems.

2.3 Geo-Ecological and Environmental Characteristics of Mangrove Ecosystems

"Mangrove" is a general term for a group of tree plants with strong salt tolerance that grow in the intertidal zone affected by the ebb and flow of seawater in the estuary delta region of the tropical to the subtropical coastal area, as shown in Fig. 2.2. Typical mangroves (true mangroves in the narrow sense) are 50–60 species belonging to *Rhizophora* sp., *Sonneratia* sp., *Avicennia* sp., *Xylocarpus* sp., *Lumnitzera* sp., and *Aegiceras* sp. Approximately 100 species, including mangrove associates (mangroves in a broad sense), are distributed worldwide (Fig. 2.3). Due to the large number of species distributed along the coast of Southeast Asia, it is believed that mangroves originated in this region and spread throughout the world.

Each tree species in the mangrove forest is distributed corresponding to the ground height of the microtopography (McKee 1995). The growing tree species may differ even with a ground height difference of approximately 0.1 m. In natural vegetation in simple and gentle terrain, species peculiar to a specific place form a band-like community along the contour lines from the seaside (Fig. 2.4), which is greatly affected by the tide level, to the land side, which is less affected by the tide level. Such distribution characteristics are due to the water retention time, which varies depending on the ground height, soil characteristics such as pH and salinity, and the degree of salt tolerance, which varies depending on the tree species.

Fig. 2.2 Mangroves growing in the intertidal zone affected by the ebb and flow of seawater in the estuary delta

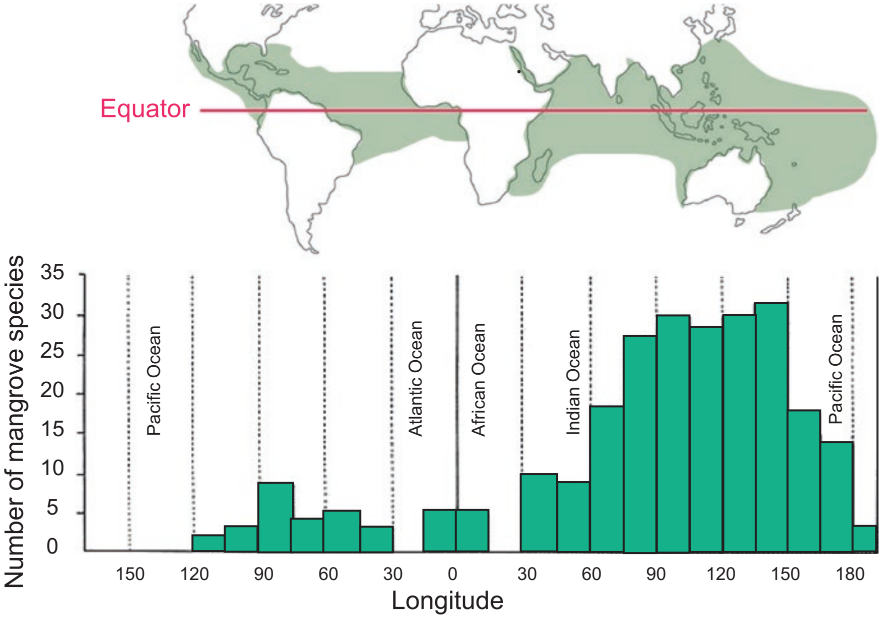

Fig. 2.3 Distribution of mangrove species in the world (from Spalding et al., 1997)

Fig. 2.4 Each mangrove species growing on the slope corresponding to the specific topography

In addition to the high salinity, the soil in which the mangrove grows is muddy and has extremely poor air permeability. However, the maximum transpiration rate of mangrove trees is equivalent to that of tropical trees (Larcher 1995), the CO_2 absorption flux of mangrove forests is up to 30 μmol $CO_2/m^2/s$, and photosynthesis is actively performed (Monji et al. 1996; Kitaya et al. 2001a). The mangrove ecosystem is a site of active CO_2 exchange (Figs. 2.5 and 2.6), during which a large amount of carbon accumulates in plants, especially roots (Fig. 2.7). Mangrove forests are also active for water exchange between forests and the atmosphere (Fig. 2.5).

To thrive in the intertidal zone, which is difficult for ordinary land plants to grow, mangroves must have an anaerobic resistance function corresponding to the anaerobic root zone environment in addition to salt tolerance. Since water is absorbed from soil containing salt water with low water potential, mangroves, like other halophytes, accumulate organic substances such as polyol compounds and amino acids in the body to lower the penetration potential, and the water potential of plants is lower than that of soil water (Larcher 1995). However, high concentrations of salt water in the root zone reduce mangrove stomatal conductance and suppress transpiration (e.g., Ball 1996), so mangrove growth where freshwater underground or seawater diluted with rainfall or river water is available has often been reported to be promoted (e.g., Sternberg and Swart 1987). In addition, from the viewpoint of cell physiology, similar to other halophytes, osmotic pressure regulation and metabolic system protection by salt-induced and produced proteins, suppression of sodium ion

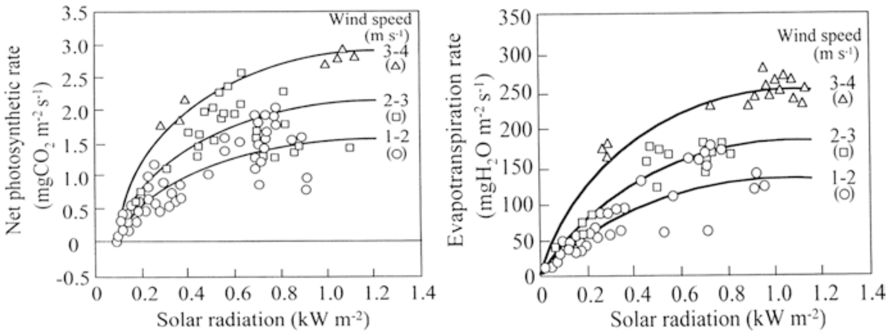

Fig. 2.5 Effects of solar radiation (irradiance) on the net photosynthetic and evapo-transpiration rates of a mangrove forest as affected by wind speeds above the canopy (from Kitaya et al., 2001a)

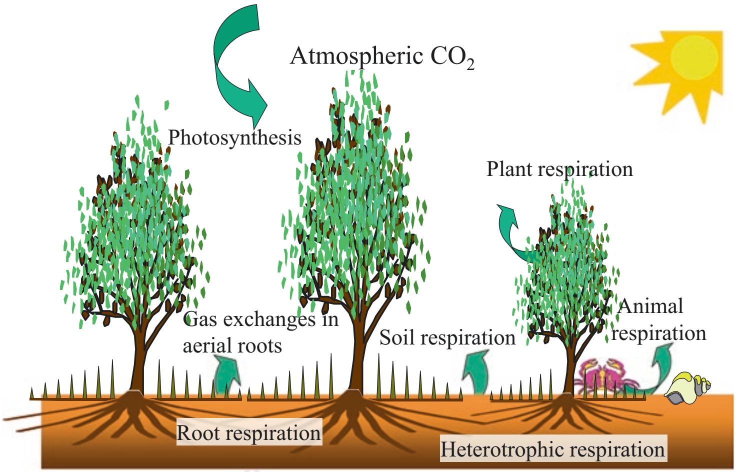

Fig. 2.6 CO_2 emission and absorption in the mangrove ecosystem

influx into cells, accumulation in vacuoles, etc. contribute to salt tolerance. In some mangroves, salt is excreted from the body by shedding aging leaves that have accumulated salt.

One of the functions for salt tolerance is a tree species (such as *Avicennia marina* and *Ardisia japonica*) with an organ called a salt gland for excreting excessively absorbed salt from the leaves. The salt gland has a multicellular structure and is connected to intracellular cells by plasmodesma. It removes NaCl from intracellular cells and excretes it to the leaf surface.