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TECHNICAL REPORT

Urban horticulture: its significance to environmental conservation

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Abstract Urban horticulture, defined as plant production activities that are conducted in a city or suburb that produce horticultural plants that are wholly or partially edible, and which are economically viable, has the potential to reduce CO_2 emissions caused by the transportation of produce. Moreover, to increase productivity in limited areas and use limited resources effectively, closed or semi-closed systems (i.e., greenhouses) are considered more advantageous than open systems (i.e., fields) from which resources can easily escape into the surrounding environment. In this paper the significance of urban horticulture in reducing CO_2 emissions in the transportation process is discussed with reference to simple case studies. In the context of building or rebuilding greenhouses suitable for urban horticulture, the present situation regarding resource inputs and outputs in greenhouses is compared to that in open fields. The reduction of resource inputs and outputs in greenhouse production is also discussed.

Keywords Carbon dioxide · Greenhouse · Plant production · Resource · Transportation

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Introduction

Following plant production in agriculture and horticulture, the produce (e.g., vegetables, fruits, etc.) is transported to areas where it will be consumed. In the transportation process, fossil fuels (e.g., gasoline, light oil, liquefied natural gas, etc.) are consumed, resulting in the emission of CO_2 gas, which is a major cause of global warming.

In Japan, as elsewhere, there is increasing concern about global warming, particularly CO_2 gas emissions. There are two reasons for this. First, after the production sector, the transportation sector is currently Japan's second largest emitter of CO_2 gas. In 2005, it accounted for 19.3% of all CO_2 emissions in Japan (Greenhouse Gas Inventory Office 2007). Second, efforts to reduce CO_2 emissions have been lagging behind the need to do so.

Thus, in March 2006, the Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure and Transport jointly issued a publication entitled *Standards for Shippers to Use for Rationalizing the Use of Energy Related to Freight that They Have Transporters Carry*. Moreover, in April of that year, the law concerning the rational use of energy—the so-called "Energy Conservation Law"—was revised. As a result, freight carriers who own 200 vehicles or more, and shippers who, in conjunction with their business activities, transport, either themselves or through subcontractors, at least 30 million ton km of freight a year (hereafter referred to as "specified freight carriers") are required to report the annual volume of CO_2 emissions associated with their freight transport.

The agriculture and forestry industry, which includes horticulture, is categorized as a non-manufacturing industry within the production sector. The amount of CO_2 emitted by this industry's activities in 2005 was low, being 0.6% (8.6 Mt) of all the CO_2 emitted in Japan that year

(Greenhouse Gas Inventory Office 2007). The effect of this industry on global warming is therefore relatively minor. However, large amounts of CO_2 are emitted when transporting produce due to the long distances between production and consumption areas. In domestic and international transportation, the amount of emitted CO_2 was estimated at 9.0 and 16.9 Mt, respectively (Nakata 2007), which is comparable to or greater than the amount emitted during the plant production process. To reduce these emissions, two things are necessary: (1) a means of transporting produce with a lower CO_2 emission intensity rate (grams CO_2 emitted per ton km transported), in other words a so-called modal shift; and (2) reducing shipping distance by bringing production and consumption areas closer together, in other words “local production for local consumption.” Therefore, the importance of urban horticulture conducted in cities or suburbs that are also consumption areas, and the need to select and/or rebuild plant production systems suitable for urban horticulture, are both increasing. In addition, the current “local production for local consumption” movement is focused mainly on enhancing local economical activity, and rarely on environmental conservation.

We define urban horticulture as plant production activities that are conducted in a city or suburb that produce horticultural plants that are wholly or partially edible, and that are economically viable. In a broad sense, urban horticulture includes home vegetable gardens, community farms, rooftop and wall greening, park and city greening, and similar activities, each of which has significance. In this paper, however, we focus on urban horticulture in the narrower sense defined above. Parenthetically, we have not attempted to define “urban area” in this paper, viewing such a discussion as extraneous to our current objective.

In order to increase the sustainability of urban horticulture, it is necessary to consider both economic factors, such as maintaining or increasing productivity (e.g., produce yield), and environmental factors, such as reducing the amounts of energy, fertilizer, pesticide and other resource input into plant production systems, and alleviating adverse effects on the surrounding environment of such systems. The main plant production systems used in urban horticulture are greenhouses (closed or semi-closed plant production systems) and fields (open plant production systems). Currently, production systems are selected on the basis of profitability; environmental factors are only rarely taken into account. However, in view of the growing social demand for environmental sustainability, greater focus will come to be placed on environmental as well as economic factors in urban horticulture when selecting plant production systems.

In this paper we discuss the significance of urban horticulture in reducing the CO_2 emitted by transporting produce, basing our discussion on simple case studies. Plant production systems suitable for urban horticulture are also discussed.

Significance of urban horticulture from the perspective of CO_2 emissions in the produce transport process

In 2006, the Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure and Transport issued a publication entitled *Joint Guidelines for Methods of Calculating CO_2 Emissions in the Logistics Field, Ver. 2.0.* Using the CO_2 emission intensity rates given in that document for different transportation methods (see Table 1), we estimated the amount of CO_2 emitted when 1 ton of cabbage is transported to Tokyo from each of what were Japan’s top five cabbage-shipping areas in 2006 (Ministry of Agriculture, Forestry and Fisheries 2006, 2007a, b): Aichi Prefecture (230 kt), Gunma Prefecture (196 kt), Chiba Prefecture (119 kt), Kanagawa Prefecture (77 kt), and Ibaraki Prefecture (74 kt). In so doing, we made certain assumptions: (1) the distances between Tokyo and Aichi, Gunma, Chiba, Kanagawa and Ibaraki prefectures were assumed to be, respectively, 370, 110, 40, 30 and 120 km (roughly the distances between Tokyo and the capital of each prefecture); (2) we assumed a load capacity usage of 100%; (3) whereas, in the distribution process, produce is ordinarily carried by various transportation methods as it travels from the production area to the

Table 1 CO_2 emission intensity rate per ton km transported by each of various means of transport (Ministry of Economy, Trade and Industry and Ministry of Land, Infrastructure and Transport 2006)

Means of transport	CO_2 emission intensity rate (g-CO_2/ton km)[a]
Motor vehicles[b]	
Ordinary commercial trucks[c]	173
Small commercial trucks	808
Light commercial vehicles	1,951
Ordinary private vehicles	394
Small private cars	3,443
Railway	22
Coastal ships	39
Domestic aviation	1,490

[a] The figures in the table are standard emission rates according to the conventional ton km method. To calculate CO_2 emissions more precisely, the fuel method, fuel consumption method, improved ton km method, or inter-regional matrix method should be used

[b] Figures for motor vehicles are for 2002; those for railway, coastal ships and domestic aviation, for 2003

[c] Ordinary commercial trucks are vehicles with a load capacity of 3 tons or more

consumption area by way of wholesalers, we assumed for simplicity that produce was carried by only one transportation method, directly from the production area to the consumption area; (4) regarding transportation methods we focused on transport by ordinary commercial truck (hereafter "truck") and the railway network; and (5) for the CO_2 emission intensity rates of these transportation methods we used standard emission intensity rates determined according to the conventional ton km method, which are given in the aforementioned *Guidelines* and listed in Table 1. Incidentally, the figures in Table 1 are used to simply calculate the amount of CO_2 emitted with each transportation method. There are other methods of calculation, for example the fuel method, which calculates CO_2 emissions by multiplying a fuel's CO_2 emission intensity rate by the amount of fuel used; the fuel consumption method, which calculates CO_2 emissions based on fuel consumption and transport distance; the improved ton km method, which calculates CO_2 emissions by multiplying the ton km transported by the emission intensity rate appropriate to a particular load capacity usage rate (maximum loading capacity and rate); and the inter-regional matrix method, which calculates CO_2 emissions using the emission intensity rate for the transportation methods involved and for each sector of the transport route. However, for simplicity, we decided to use the conventional ton km method.

Because CO_2 emission intensity rates vary with transportation method, the amounts of CO_2 emissions from different means of transport will vary for the same distance. The transportation method with the lowest CO_2 emission rate is by rail. The emission rates of the other transportation methods are 1.8–157 times greater (Table 1). Accordingly, a modal shift can result in CO_2 emissions that are lower for rail transport over a long distance than CO_2 emissions from transport by other methods over a shorter distance. For example, CO_2 emissions from the rail transport of cabbage produced in Gunma/Ibaraki Prefectures are lower than those from truck transportation of cabbage produced in Chiba Prefecture (Fig. 1). However, for a single transportation method, CO_2 emissions are proportional to distance. For example, for truck transport from the top five cabbage-shipping prefectures in Japan to Tokyo (considered to be the consumption area in this model), the amount of CO_2 emissions will be lowest for transportation from Kanagawa Prefecture, the prefecture closest to the assumed consumption area. Similar results were obtained in case studies of sweetpotato and lettuce transportation processes (Fig. 2).

A report issued by the National Institute for Agro-Environmental Sciences (2003) stated that the amount of CO_2 emissions during cabbage production (by the traditional plowing method of cultivation of "early ball" cabbage) is 1.5 ton-CO_2 ha^{-1} (0.67 ton-CO_2 ha^{-1} from fuel, 0.62 ton-CO_2 ha^{-1} from fertilizer, and 0.21 ton-CO_2 ha^{-1} from pesticide). By dividing that figure by the average national yield per hectare in 2006, 41.5 ton ha^{-1} (Ministry of Agriculture, Forestry and Fisheries 2006, 2007a, b), we were able to estimate the amount of CO_2 emitted from producing 1 ton of cabbage: 36.1 kg-CO_2 (1.5 ton-CO_2 ha^{-1}/41.5 ton ha^{-1}). Comparing this value with those in Fig. 1, we found that when the production area and consumption area are far apart, CO_2 emissions from the transport process are sometimes greater than those from the production process. For example, the CO_2 emission from transporting cabbage produced in Aichi Prefecture to Tokyo is 1.8 times greater than the CO_2 emission from the cabbage production process. This means that, irrespective of efforts made to reduce CO_2 emissions in the production process, the benefit of such efforts will be negated if produce has to be transported over long distances from production areas before reaching consumption areas and consumers.

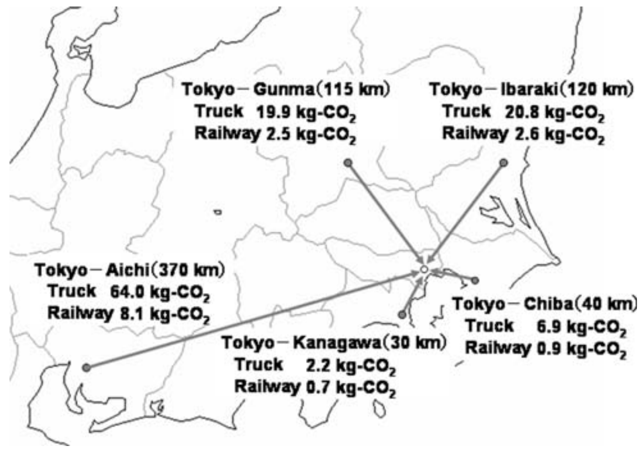

Fig. 1 Amounts of CO_2 emitted when 1 ton of cabbage is transported from production areas (Nagano, Ibaraki, Gunma, Shizuoka, and Chiba Prefectures) to the consumption area (Tokyo) by truck or railway. Based on a report issued by the National Institute for Agro-Environmental Sciences (2003) and on data from the Statistics Department of the Ministry of Agriculture, Forestry and Fisheries (2006, 2007a, b), we also estimated the amount of CO_2 emitted in producing 1 ton of cabbage: 36.1 kg-CO_2 (see text for assumptions used in estimating CO_2 emitted in the transportation process)

With urban horticulture, the production and consumption areas are close to each other. Urban horticulture can thus be expected to reduce the amount of CO_2 emissions caused by the transportation of produce, and hence is environmentally friendly.

Consumers tend to select produce according to freshness and price but to combat global warming they should be given information on the volume of CO_2 emissions in the production and transport processes as another factor on which to base their choice. To create a tool for providing such information, we started two projects related to the distribution of fresh horticultural produce in Japan:

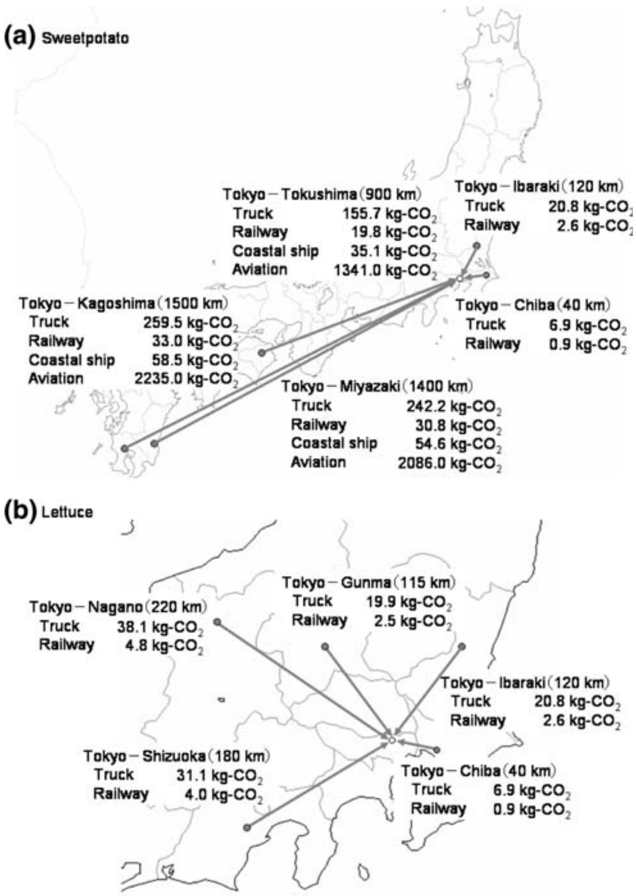

Fig. 2 Amount of CO_2 emitted when 1 ton of **a** sweet potato or **b** lettuce is transported from the top five production areas to the consumption area by domestic aviation, coastal ship, truck or railway (see text for assumptions used in estimating the amounts of CO_2 emitted in the transportation process)

(1) developing simple software for estimating the volume of CO_2 emissions produced by transportation, based on a thorough survey of distribution processes; and (2) conducting a survey of how consumers react when presented with information about products that are identical in price and quality but differ in the amounts of CO_2 emitted during the transportation process.

Traffic jams caused by transporting produce may be alleviated by reducing the conventional transportation of produce between production and consumption areas. On the other hand, promoting urban horticulture could actually cause traffic jams in urban areas due to heavy traffic in a concentrated area, causing an increase in CO_2 emissions during the transportation process. To avoid this, further studies of the transportation of produce in urban areas will be needed.

It has been reported (Nakata 2003) that the food mileage (total amount of transported food × transport distance) for food imported into Japan is three times greater than that of the United States and South Korea, five times greater than in Great Britain and Germany, and nine times greater than in France. As shown in Table 1, CO_2 emission intensity rates vary with the means of transport, so it is impossible to make simple comparisons, but the amount of CO_2 emitted in food transport is thought to be higher in Japan than in any other country. On the other hand, there are times when it is necessary to transport produce from production areas that are relatively far from the consumption area, either to supply necessary amounts of the produce or to obtain locally grown brands to sell at premium prices. However, following the revision of the Energy Conservation Law, specified freight carriers must now report their annual CO_2 emissions, as well as set goals for reducing those emissions by 1% or more in each of the next 5 years and submit an action plan for reducing CO_2 emissions. It has thus become necessary for those who transport products to pay even greater attention to transportation methods and distances. Moreover, urban horticulture, which is practiced within cities, suburbs or other places close to areas of consumption, may attract increased attention as a result of societal demands such as those mentioned above. Accordingly, it will become more important to select or rebuild plant production systems that are suitable for urban horticulture.

Characteristics of greenhouses as plant production systems suitable for urban horticulture

With urban horticulture, production areas are close to consumption areas (i.e., residential areas). Consequently, to ensure greater acceptance of urban horticulture, it will become increasingly important to consider nearby residents when applying pesticides or disposing of processing plant remains and/or waste liquids. In recent years, moreover, hypersensitivity to chemical substances has become a growing problem. In response, research has been initiated on alleviating chemical hypersensitivity; an example is the Chemiless Town, a group of homes built using materials that produce very low levels of chemical emissions, which was constructed by the Center for Environment, Health and Field Science, Chiba University (Mori 2006). As there may be people with such hypersensitivity in nearby residential areas, closed plant production systems such as greenhouses are preferable to open plant production systems such as fields, so as to control the drift of pesticides. In terms of raising productivity in limited areas and effectively using limited resources as well, greenhouses are often more advantageous than fields, from which resources can easily flow into the surrounding environment.

Next we consider the resource inputs and outputs related to greenhouses and fields (Fig. 3). Inputs common to both include the following: sunlight (radiation); chemicals such as pesticides and fertilizer; oil (heavy oil, light oil,

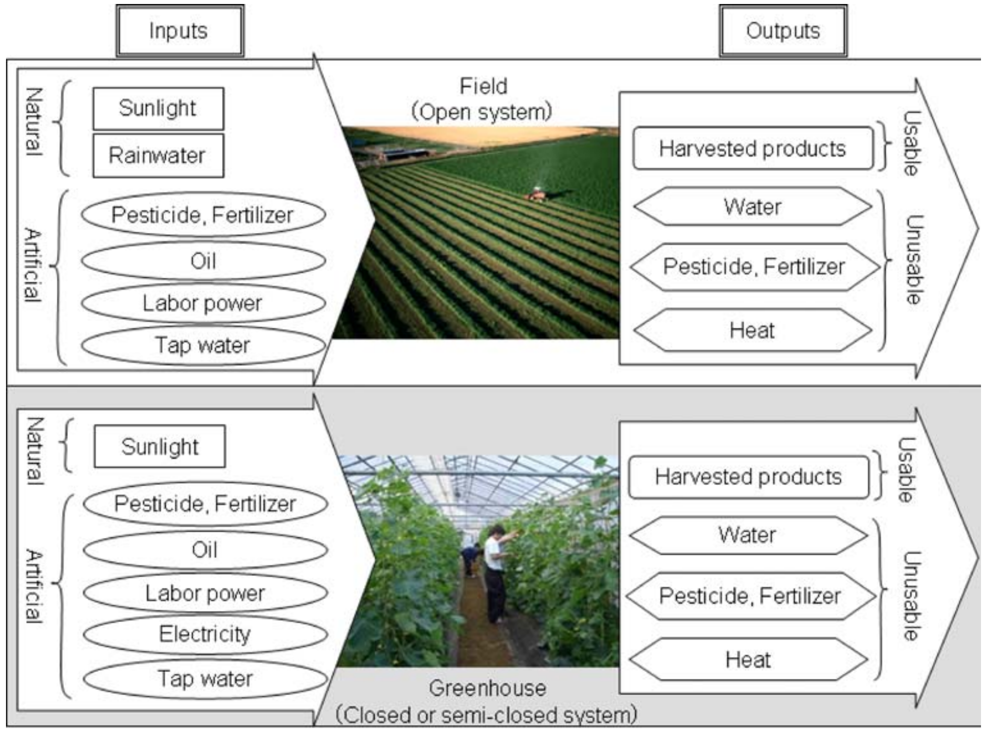

Fig. 3 Conceptual diagram of resource inputs and outputs in a greenhouse and a field

kerosene) used in agricultural equipment, etc.; labor; and supplied water (here we define this as tap water provided by the local government, water drawn from wells and rivers, and other types of water, the purification and transport of which consumes energy). Resource input exclusive to either greenhouses or fields is represented by electricity for the former and rainwater for the latter. On the other hand, outputs are the same for both systems. The sole output that is put to use is the produce itself. Outputs that are not used include the water (waste water), pesticides and fertilizer that end up not being absorbed in plant production and are instead transferred outside the systems, as well as the heat converted from sunlight and the heat generated by labor, plant respiration and the use of oil. Since greenhouses, unlike fields, are closed or semi-closed systems, fewer resources will be input for production, and the flow of unused production resources from the system into the surroundings will also be low, thus facilitating the efficient use of water, pesticides and fertilizer. Greenhouses also protect plants from severe weather (heavy rain, gusts of wind, etc.) and permit beneficial insects (for example, a pest's natural enemy) and microorganisms to be used without disturbing the surrounding ecosystem, factors that have the economic advantage of increasing yield (Kozai and Kubota 1997). However, while the amounts of electricity and supplied water input to greenhouses are generally greater than for fields, total resource inputs (the sum of natural and artificial resources) are considered lower for greenhouses; hence lifecycle CO_2 emissions may be smaller when using greenhouses than when using open fields. In order to draw a more precise conclusion, however, CO_2 emissions during the construction and management of greenhouses (from building materials, fertilizers, pesticides, etc.) should be compared with those of open fields. In addition, the economic viability of urban horticulture using greenhouses depends on the cultivar, so such factors also need to be evaluated in the near future.

In selecting a plant production system, it is necessary to consider economic as well as environmental factors. Electricity is the one input that generally applies to greenhouses only and not to fields. The main types of electricity-consuming equipment installed in greenhouses include: motors for opening and closing ceiling and wall windows; motors for opening and closing curtains; fans for circulating air; pumps if hydroponic equipment is employed; and controllers for each of these types of equipment. Compared to ordinary buildings, greenhouses use relatively few types and units of electricity-consuming equipment, and each type can be adjusted relatively easily. However, leveling the consumption rate of electrical energy has rarely been a consideration in greenhouse operation. For example, in some cases the controllers for various types of equipment operate independently of each other, so that multiple units of equipment may unnecessarily operate simultaneously, causing a temporary increase in electricity consumption. If the controllers were linked so that all equipment did not operate simultaneously, it would be possible to level the consumption rate of electrical energy and the capacity of the power supply, thus reducing initial costs and allowing greenhouses to operate using renewable energy technologies such as small solar cells. There have been cases where, by reducing the amount of electricity consumed by the equipment that opens and closes greenhouse wall windows, it has been possible to run that equipment on electricity generated by solar cells (Yano et al. 2005a, 2005b, 2007), but such operation has not been extended to the entire greenhouse. In future it will be necessary to clarify the operating conditions and power requirements of greenhouse equipment for use as basic information in greenhouse design.

Next we consider the water input into greenhouses, which is supplied water, i.e., an artificial resource. By contrast, in fields in regions that enjoy abundant rainfall, as Japan does (annual precipitation approximately 1,500 mm), rainwater, a natural resource, is typically used, except when watering new transplants or in periods of low rainfall. Supplied water, an artificial resource, is rarely used in fields, and even to the extent that it is, its proportion of all water used during the production period is small. This suggests that if rainwater could be employed in greenhouses, the input of supplied water could be reduced significantly and perhaps even eliminated altogether. Previously, Hojo (2002) suggested that the amount of water required for hydroponic cultivation could be supplied from rainwater in regions where there is at least 10 mm of rainfall in any given week and at least 100 mm of rainfall monthly. Rainwater is used for cultivation in commercial greenhouses in Holland and elsewhere, and also in regions where the supplied water is of poor quality (Hanan 1998), but in Japan it is not, with perhaps just a few exceptions. Moreover, there is very little scientific data concerning greenhouse plant production using rainwater.

In order to build greenhouses suitable for urban horticulture that are both economically and environmentally viable, it is necessary to reduce the artificial resources—electricity and supplied water—that are input into greenhouses and which are generally not required for fields. In general it is desirable to redesign greenhouses for urban horticulture based on a thorough understanding of resource inputs and outputs. Since urban horticulture demands an increase in productivity in a limited area while reducing resource inputs, we intend to study methods of modifying greenhouse environments to achieve this objective.

Conclusion

In this paper we have discussed the significance of urban horticulture in reducing CO_2 emissions from the process of transporting horticultural produce, referring to simple case studies. We reviewed resource inputs and outputs related to greenhouses, which are plant production systems considered suitable for urban horticulture, and described possible ways of making such systems even more suitable. With urban horticulture, production areas and consumption areas (residential areas) close to each other, shorter transportation distances reduce CO_2 emissions; urban horticulture is thus environmentally friendly. Moreover, if, when selecting a plant production system for use in urban horticulture, environmental factors such as using fewer resource inputs and limiting the effects of the production area on nearby residential neighborhoods are considered along with economic factors such as maintaining or increasing productivity, it should also be possible to improve sustainability (Fig. 4).

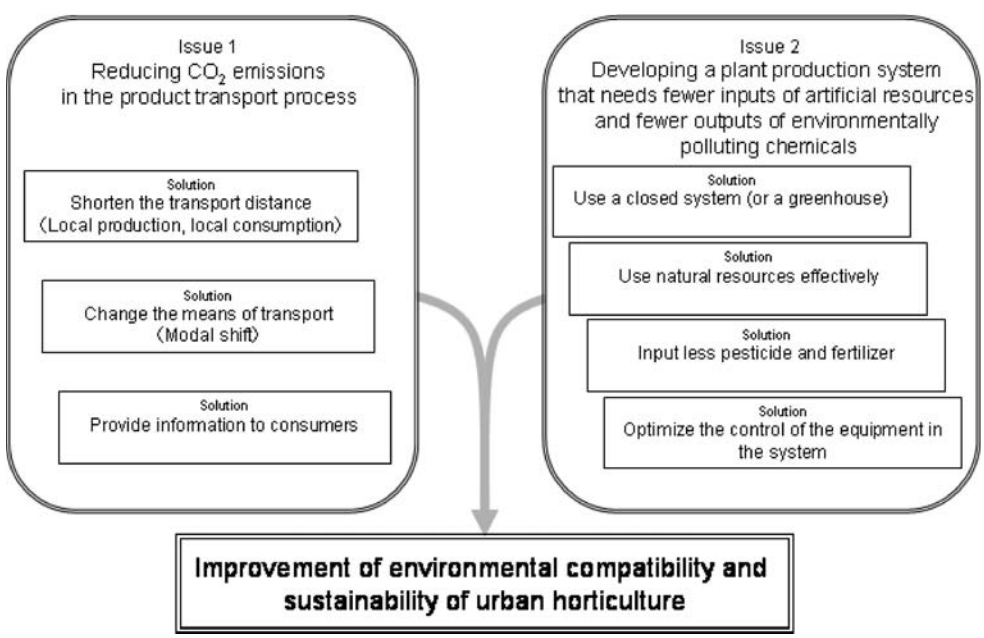

Fig. 4 Schematic diagram of issues and solutions for improving environmental compatibility and sustainability in the field of horticultural, a main theme of which is urban horticulture

Of course, replacing Japan's entire horticultural plant production with urban horticulture would be difficult, due to the limited area of urban land available and the weather requirements for certain kinds of plants. However, in terms of combating global warming by reducing CO_2 emissions, urban horticulture that uses plant production systems developed by redesigning existing systems, that uses fewer inputs of artificial resources, and that emits less environmental pollution, will become increasingly important. Finally, as this study is still at the conceptual stage, we will work with researchers from various fields at the Center for Environment, Health and Field Services to resolve the various issues discussed here.

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