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IN THE TROPICS AND SUBTROPICS

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Master Thesis

Agroecology

Ecological Engineering

B.Sc. Martina Hammer

Future Potentials for Food Production & Wastewater Treatment in Havana's Urban Vegetable Production

This work was financially supported by the Eiselen Foundation Ulm

MSC 11 Delivery: 30.04.2004

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MASTER THESIS

Future Potentials for Food Production & Wastewater Treatment in Havana's Urban Vegetable Production

For Martina Hammer

1. Introduction

The „Special Period" starting in 1989/90 when Cuba lost its support of the Soviet Union forced Cuba to change its agriculture into organic as well as to extend urban agriculture to maintain food supply. This included the promotion of urban vegetable gardens to improve the supply of the urban population with fresh food products.

2. Problems and possible solutions.

A shortage of organic and inorganic fertilizer exists in the gardens as well as water supply often is not guaranteed. An additional problem is the contamination of Havana Bay and its rivers through wastewater. A possible solution is reuse of wastewater in urban vegetable gardens. The wastewater is treated before its application in decentralized systems with help of ecological sanitation techniques as greywater wetlands.

3. Research methodology

The production system of the urban vegetable gardens as well as the analysis of production constraints are assessed by onsite interviews in the gardens. Additional information on urban vegetable production and wastewater treatment is collected from other stakeholders such as government officials, NGO representatives, and scientists. Water and organic matter supply are analyzed by onsite measurements and discussion with the gardeners while nutrient supply is addresses through an experimental comparison of the nutrient uptake of lettuce plants grown in the gardens with a control group.

4. Working plan

- Literature review of urban vegetable production in Cuba and application techniques of wastewater in general
- Conduction of onsite interviews
- Assessment of organic matter and water supply
- Realization of the experiment on nutrient supply
- Collection of specific Cuban data and information for the application of wastewater and development of a greywater wetland design

The results must be presented according to the standards of Universität Hohenheim, Institut für Agrartechnik in den Tropen und Subtropen (495) for Master Thesis and the requirements of Prüfungsamt der Universität Hohenheim.

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DECLARATION

I assure that I conducted this Master thesis without help of a third party. All published and unpublished references, direct and indirect ones, as well as other aids are marked as such.

Also, I declare that this thesis is not used or submitted to graduate in another program.

Ås, April 30th, 2004.

Martina Hammer

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1 NOMENCLATURE

1.1 Abbreviations

CO	Carbon oxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
EHM	Empresa Hortícola Metropolitana (The Urban Horticulture Company)
FAO	Food and Agricultural Organization of the United Nations
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
HNO_3	Nitric acid
H_2O	Water
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectrometry
INIFAT	Instituto Nacional de Investigaciones en Agricultura Tropical (National Institute for Research in Tropical Agriculture)
IIRD	Instituto de Investigaciones de Riego y Drenaje (Institute for Research in Irrigation and Drainage)
K	Potassium
MINAG	Ministerio de Agricultura (Ministry for Agriculture)
MINTUR	Ministerio de Turismo (Ministry for Tourism)
N	Nitrogen
No	Number
N_2	Nitrogen gas
N_2O	Nitrous oxide
NGO	Non-governmental organization
NLH	Norges Landbrukshøgskole (Norwegian University for Agriculture)
ONE	Oficina Nacional de Estadísticas (National Statistics Office)
P	Phosphorus
PVC	Polyvinyl chloride

1.2 Symbols

A	area	m^2
d_{10}	grain parameters effective size	mm
h	depth in the inlet	m
i	slope	%
K	hydraulic conductivity	m/d
K_{Dim}	hydraulic conductivity * 0.3	m/d
l	length	m
n_e	porosity of the effluent	%
Q	hydraulic conductivity	l or m^3/d
q	specific daily discharge	m/d
t	retention time	d
w	width	m
α	angle of the steep area	°

1.3 Units

CP	Cuban pesos (1 US$ = 27 CP (Sept. 2003), although officially used: 1 US$ = 1 CP respectively : 1.2267 € = 1 CP (12.03.04 – Banco Central de Cuba))
d	day
g	gram
h	hour
ha	hectare
kg	kilogram
km	kilometer
km^2	square kilometer
l	liter
ml	millimeter
m^2	square meter
m^3	cubic meter
pers	person
y	year
%	percent
°C	degree Celsius

1.4 Technical terminology

Agroecosystem	natural ecosystems modified by humans that build the foundation of agriculture (Olson and Francis, 1995)
Blackwater	wastewater from toilets
Brownwater	wastewater containing faeces only
Cachaza	filter cake mud, by-product of the sugar industry
Ecology	the study of organisms in relation to their surroundings (Chapman and Reiss, 1992)
Greywater	water coming from sink, showers, and washing machines; all household wastewater excluding toilets
Yellowwater	wastewater containing urine only

ABSTRACT

The objectives of this study were to describe Havana's urban vegetable production, to analyze production constraints, and to explore the potential of ecological sanitation techniques (primarily greywater wetlands) for providing water, organic matter and nutrients. On-site interviews were conducted at 10 gardens. The gardens were selected to include different forms of ownership, localities, and management practices. Additional information was collected from other stakeholders such as government officials, NGO representatives, and university researchers. Onsite measurements and discussions with stakeholders provided data on the supply of water and organic matter. Supply of nitrogen, phosphorous, and potassium was addressed through an experimental comparison of the nutrient uptake of lettuce plants grown in the gardens with a control group of plants provided with sufficient nutrients. Results showed that water supply was adequate in 7 of the 10 gardens, but there was a deficiency of nutrients and organic matter in all gardens. The average total nitrogen concentration of lettuce plants grown in the gardens was 2.0-2.3% compared to a target value of about 5.0% as determined in the control group of plants and from literature. Potassium and phosphorous deficiencies were less severe. This was due to a shortage of organic and inorganic fertilizers in the market and limited recycling through, for example, locally composted organic waste. Greywater wetlands would not relieve the deficiency of nutrients and organic matter. It is recommended to examine other ecological sanitation techniques, for example, blackwater utilization and improved composting of organic household waste. Further research and development involving gardeners and other stakeholders are needed particularly regarding blackwater utilization.

RESUMEN

Los objetivos de este estudio fueron describir la producción urbana de vegetales en la Ciudad de la Habana, analizar las limitaciones en la producción y explorar el potencial de las técnicas de saneamiento ecológico (principalmente humedales con aguas grises) para proporcionar agua, materia orgánica y nutrientes. Se realizaron entrevistas en 10 huertos. Los huertos fueron seleccionados tomando en cuenta, las diversas formas de propiedad, localidades y prácticas de manejo. La información adicional fue obtenida mediante consultas a diferentes actores, tales como autoridades locales, representantes de ONG e investigadores de la universidad. Las mediciones tomadas in situ y las charlas con expertos en el área, proporcionaron datos sobre el suministro de agua y materia orgánica. El contenido de nitrógeno, fósforo y potasio suministrado a las plantas, fue obtenido a través de una comparación experimental. En el citado experimento, se midió la concentración de nutrientes tomados por plantas de lechuga que crecieron en los huertos (bajo condiciones normales de Cuba) y un grupo de plantas de control, a las cuales se les proporcionó las cantidades de nutrientes necesarios. Los resultados demostraron que el abastecimiento de agua era el adecuado en 7 de los 10 huertos, pero había una deficiencia de nutrientes y de materia orgánica. La concentración total media de nitrógeno en las plantas de lechuga que crecieron en los huertos fue de 2.0-2.3%, comparada con un valor de referencia de cerca de 5.0% según lo determinado en el grupo de control de plantas y en la literatura. El potasio y las deficiencias de fósforo eran menos severas. Esto se debió a una escasez de fertilizantes orgánicos e inorgánicos en el mercado y a la falta de reciclaje, entre otros, de basura orgánica para compostaje. Los humedales para tratar aguas grises no suplen la deficiencia de nutrientes y de materia orgánica. Se recomienda examinar otras técnicas de saneamiento ecológico, por ejemplo, la reutilización de aguas negras y fomentar el compostaje de basura orgánica. Se hace necesario investigaciones adicionales y otros desarrollos con énfasis en la utilización de aguas negras, donde se implique la participación de productores y de otros actores.

2 INTRODUCTION

Through the end of the trade relations with the Soviet Bloc in 1989/90, and the tightening of the US embargo, Cuba suffered an economic crisis. The Cuban government under Fidel Castro declared the “Special Period in Peacetime” in 1991, which basically put the country on a wartime economy-style austerity program (Rosset and Bourque, 2002). The “Special Period” had major impacts on the agricultural sector. Before, Cuba had an import dependent agricultural system. After 1989/90 imports of grains, fuel and other energy sources dropped by more than 50%, and imported fertilizers and pesticide decreased by 70% (Rosset and Benjamin, 1994). Cuba’s agriculture sector, similar in its intensity to California’s, faced the problems by changing to an organic production system, i.e. without artificial fertilizers and pesticides. A nearly closed, self-reliant system developed reclaiming its traditional techniques while it was simultaneously incorporating its already theoretically existing knowledge of biopesticides and biofertilizers as substitutes. Pests and nutrient deficiencies were seen as the main reason for low productivity (Altieri et al., 1999). In the process of transition, people working in the Cuban agricultural sector gained the understanding to see limiting factors in the production as symptoms of a much deeper problem in the agroecosystem, caused by the imbalances inherent in large-scale monoculture and high-input regimes, and detected diversification as key strategy. Diversified cropping systems optimize nutrient cycling and organic matter accumulation, close energy flow, conserve resources, exhibit immunity to pests, and sustain levels of productivity (Altieri et al., 1999).

Aside from the “Special Period”, Cuba, especially Havana, is facing another problem: ongoing urbanization and extension of its cities (ONE, 2002). This results in problems of wastewater treatment and supply of fresh food products in particular. On one side, experience and successes in the implementation of organic agriculture, well-working agroecosystems in the countryside, and people’s own initiative in setting up small gardens inside the cities, Cuban started to encourage urban agriculture. Raul Castro, the successor as political leader of Cuba created its future vision: to guarantee and even extend the success of urban agriculture he plans to use all free areas in Havana for the establishment of agriculture until the year 2006. The hope is to minimize and even close Havana’s lack in food supply. This goal is difficult to realize because water needs for gardens often compete with the need of citizens. Also, gardens experience a one-way flow in their nutrient management. Nutrients are leaving gardens in form of food products; they are not recycled to guarantee nutrient supply for gardens. On the other side, wastewater management and sanitation systems lack capacity and are in urgent need of rehabilitation (Werner et al., 2003). Drinking water and sanitation systems of Havana are summarized as having an old, insufficient infrastructure and a large deficiency of treatment equipment; hence, most of the water is released untreated into the sea (Hernández et al., 1998).

Recently, the idea was born to use the one for the benefit of the other. Wastewater provides water, nutrients, and organic matter to urban agriculture while urban agriculture provides its treatment. Through this linkage, it becomes possible to optimize nutrient cycling and organic matter accumulation, to close the energy flow, to reuse resources, and to sustain urban agriculture as well as wastewater treatment in combination with secure food production and higher supplies for the urban population. Some cases of wastewater use in urban agriculture already exist. Reasons are unavailability of other water sources in the outskirts of Havana, scientific interests, knowledge of the positive sides of wastewater, and interests in an improvement of Havana's wastewater treatment problem. But until now, only untreated wastewater is used in fruit and flower production.

2.1 Research objectives & questions

The research objectives of this paper are to

- describe the agroecosystems of Havana's vegetable gardens.
- analyze production constraints of water, nutrients and organic matter
- suggest improvements by exploring the potential of ecological sanitation techniques (preliminary greywater wetlands).

The objectives are addressed with help of the following research questions:

- What is Havana's state of the art in urban vegetable production, wastewater treatment, and interactions between them?
- What kind of bottlenecks exists in urban vegetable production and how do they influence the gardens?
- What are possibilities for the implementation of ecological sanitation in vegetable gardens and can this approach be sustained in urban agroecosystems?

3 MATERIAL AND METHOD

3.1 Location

3.1.1 Cuba

Cuba is the biggest island of the Greater Antilles with a surface area of ca. 110 000 km^2. It holds a strategic important position as the island is located in the entrance to the Golf of Mexico and is surrounded by the Atlantic Ocean and the Caribbean Sea (MINTUR, 2000). The country has a subtropical climate with an average humidity of 78% and annual temperature average of 25.5°C (ONE, 2002). The population is 11 million people (MINTUR, 2000). The island is one of the last communist countries in the world and is led by Fidel Castro.

Today, Cuba's high intensive urban vegetable production covers an area around 900 ha, 70 ha in Havana. But in total between 9000 and 15000 ha are under cultivation in Havana (Campanioni et al., 2001; Cruz and Sánchez, 2001; Altieri et al., 1999). These gardens altogether cover 6.8% of the Cuban diet (FAO, 2001). The national goal of vegetable supply for the Cuban inhabitants is 300 g daily per capita oriented at the FAO standard of 109 kg annually per capita (= 298.6g daily per capita). Cuba reaches this goal, but there exist problems in Havana with a planned supply of 264 g daily per capita in 2003 (MINAG, 2003).

3.1.2 Havana

Havana is Cuba's capital and biggest city. With its 2.2 million inhabitants it covers an area of 5731 km^2 with 124.2 pers/km^2 and the rate of expansion is 5.4%. Havana has to face a positive migration rate while most provinces show negative ones (ONE, 2002). This is due to its importance as the centre of Cuba in political, economical, and cultural aspects.

Havana has a subtropical climate. The total annual precipitation is about 1200 mm, spread over 113 days of rainfall (ONE, 2002). The season with the most rainfalls is between May and October (see Figure 1). The months from November till April are characterised as the dry season. The medium temperature lays between 22°C and 29°C (ibid), but can go up to

35°C on some days during the summer months, especially in August, and down to 6°C during winter. Lowest temperatures are normally measured in January. The daily average sunshine length is 7.6 h (Hernández et al., 1998). Also special for its climate is the appearance of hurricanes during the summer months. From 1800 till 2001, a total of 105 were registered in Cuba, 19 of them showed high intensity with a speed of more then 200 km/h (ONE, 2002).

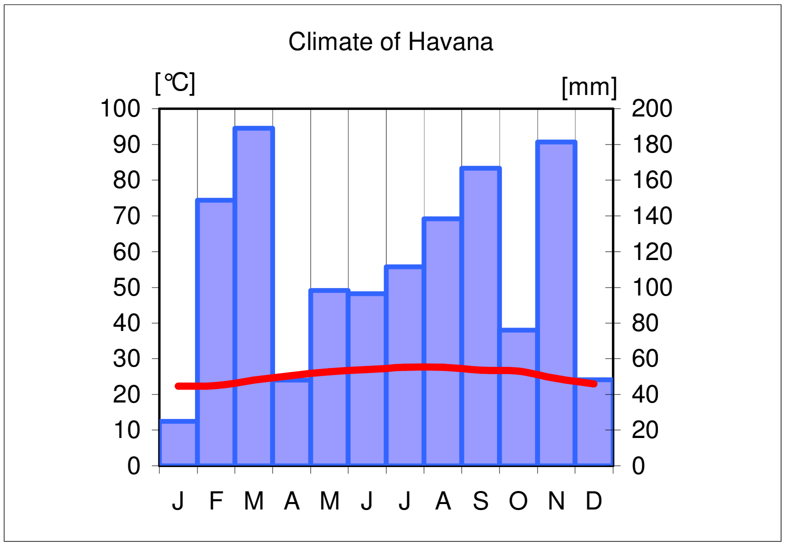

Figure 1 : Climate of Havana for 2002 measured in Casablanca. (Centro de Clima, 2003) Red line = temperature.

3.1.3 Gardens involved

Eleven gardens were selected to represent the variety of size (144-8000 m^2), purpose (i.e., crop production versus research and demonstration gardens), ownership (private versus public), and management practices. Table 1 shows the properties of each garden. The gardens ranged from 144 m^2 to more than 8000 m^2. The smallest were private while the larger ones were owned by national research organisations active in the area of urban agriculture or by EHM, the urban horticulture company that owns most of the gardens in Havana.

Table 1: Gardens' characteristics.

Garden	Area under cultivation (m^2)	Owner	Purpose
1	8064	EHM	Production
2	4800	Cooperation	Production
3	4800	EHM	Production
4	2044	National/ Cooperation	Research/production
5	1968	EHM	Production
6	1400	EHM	Production
7	1120	EHM	Production
8	900	Private	Production
9	322	Private	Production/education
10	144	Private	Production/education
11	-	National	Research

All gardens (beside No. 11) were participating in the onsite interview, described below. Not all gardens could participate in the more detailed analysis of water, nutrient, and organic matter supply (see 7.2), so they could not provide the data or in the case of the measurement of nutrient supply (see 3.4) the plants died.

3.2 Onsite interviews

Two different interviews were conducted to address the groups working with urban vegetable production. The reason was to receive a balanced overview from stakeholders working in the gardens and active in the scientific research and administration.

1. Gardeners/administrators of ten gardens were found willing to participate in the survey (see 3.1.3 and 7.2). They were asked to answer a pre-prepared interview schedule (see 7.4) first. Onsite observation took place to gain additional information and for a better understanding of the situation of the garden. Later on, several

visits were added to ask for further details, reassurance, and to talk to other people working in the gardens. With this strategy it was possible for the gardeners to gain a better knowledge about the interviewer and her interests and they could add valuable information.

2. Members of non-governmental organizations, governmental institutions, and scientific experts were interviewed with the help of specific case-designed interview schedules.

The data collected were of qualitative and quantitative character. Data about production management was used qualitatively to present and explain the management system. Results on water, nutrient, and organic matter supply of the 10 gardens are shown in numbers.

3.3 Measurement of water supply

Water was assumed to be a limiting factor for urban vegetable production. Therefore, this aspect was addressed by measurements of the amounts of water ($l/m^{2*}d$) available for the gardens. Three different methods were used dependent on the specific garden's situation. In three cases (garden No. 8-10) the amounts of water were conducted by measuring the volume used daily out of the storage tank. In three cases (garden No. 1, 4 and 5) the administrator knew the specific amounts applied. In two gardens (No. 2 and 3) water supply was calculated with the help of information given by the gardeners and by water meters installed onsite. In the last two sites (No. 6 and 7) the water was determined by volumetric-flow measurements (Yoo and Boyd, 1994): specifically, the outlet of one micro sprinkler was put into a 1-liter-bottle and the needed time to fill it was measured. Afterwards, the amount per m^2 and day was calculated due to information collected about bed sizes and irrigated area.

3.4 Measurement of nutrient supply

Seedlings of the lettuce variety *Black Seeded Simpson* were planted in several vegetable gardens to gain information about the nutrient status/supply of the vegetables (for details see 7.3). For control, four samples were planted in pots with fertile compost and an additional supply of artificial fertilizer to assure a secure supply of nutrients. In seven gardens the lettuce plants died after transplanting due to high solar radiation, the stress of transplanting, and insects. A replanting took place but was not successful.

The plants grew for five weeks. Then they were cut above surface, washed and dried in a cabinet drier first at 60°C to bring them to their constant weight and afterwards at 105°C to secure a complete drying. Later, they were analysed for the macronutrients nitrogen, phosphorus, and potassium by the laboratory of the Section Soil Science and Plant Nutrition (Department of Plant and Environmental Sciences, NLH, Norway). The total Nitrogen was determined by the Dumas method (see Bremner, 1965) and phosphorus and potassium were disaggregated after the *Inductively Coupled Plasma Spectroscopic Method* according to 985.01(c) (Helrich, 1990) (see 7.3).

3.5 Measurement of organic matter supply

While analyzing the findings of the first data collected, with the help of the interview schedules on nutrient supply (see 3.2 and 7.4), it became clear that not only the nutrient supply and its quality were a constraint for the urban vegetable production but also quantities of organic matter. Therefore, measurement of organic matter supply was added.

The method used depended on what type of organic matter was addressed. In the case of compost, compost piles were measured and the amounts calculated by the times applied per year and m^2. When the organic matter was bought, the gardeners mostly could give information on how often and how much (per m^2) they applied. In two gardens (No. 1 and 6) this was not possible and the amount had to be estimated: truck loads per year and average bulk density of compost (average moisture of 1 m^3 = 600 kg/m^3 (Esser, 2004)). When both compost and bought material were used, the two amounts calculated were added.

4 RESULTS AND DISCUSSION

4.1 Urban vegetable production

Urban vegetable production can be categorized in garden types according to legal or production characteristics. In reality, often mixtures and combinations of the types exist and can be seen as “extremely heterogeneous in size, crop mixes, and management levels” (Altieri et al., 1999), also varying with time, as the structure of urban agriculture itself (Cruz, 2003). A good example is the raising of the beds that was found in nearly all gardens. This was a typical characteristic of the organoponics according to Altieri et al. (1999). But this is seen as a helpful tool to avoid poor topsoil and to have a good nutrient supply for plants, so the technique was applied in all gardens visited what does not mean that these gardens were all of the type “organoponic”.

To provide a better overview what urban vegetable production means, the vegetable gardens are presented in their production system (see Figure 2). The different subsystems as cultivation system, seeds & planting, pest management, commercialisation and gardens’ economy, and social aspects are pointed out to present the system and to show the imports in and exports out of it. The garden system’s boundary is defined according to the spatial dimensions of the gardens. For example, everything leaving the garden’s area is declared as export. The subsystems, i.e., water, nutrient, and organic matter supply, are discussed more in detail later (see 4.2).

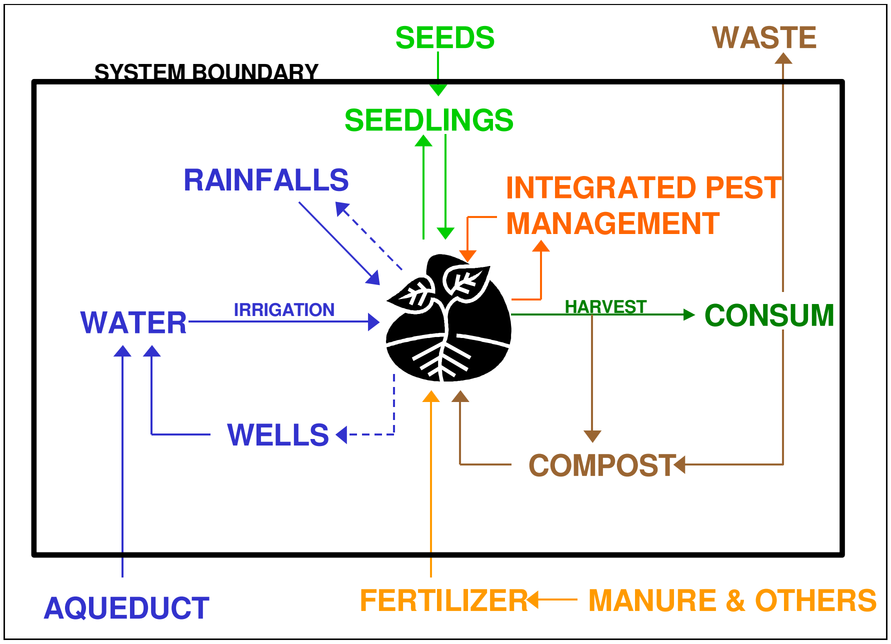

Figure 2 : System of the urban gardens.

Cultivation system

The cultivation system is mainly influenced by seasonal variations. During winter a variety of 30 to 40 crops are planted. In summertime the number of species cultivated is reduced to ca. 15 species (Companioni and Quintero, 2003). A lot of species cannot be planted because of increasing pest/weed pressure during summer in combination with heavy rainfalls and high temperatures.

Two different types of crops are cultivated according to time aspects (ibid):

- Crops with short cultivation period around six weeks, e.g., lettuce and spinach.
- Crops that require longer cultivation, e.g. carrots, tomato plants, and herbs.

Intercropping and crop rotation are two important tools. They help to provide pest control, optimal usage of space, optimal surface coverage (to avoid evaporation, growth of weeds, and soil erosion,) and stabilisation of soil fertility and structure.

Seeds & planting

Two management practices are observed. Big organoponics and intensive gardens mostly use plant nurseries with highly professional technique. Large gardens often receive their seeds from seed production companies according to the needs of the gardens. The nursery is often located inside greenhouses and irrigation systems are applied.

The smaller farms often prefer to maintain their own seeds by ripening of plants. They use normal beds as plant nursery. Here, seedlings are not protected very well especially during summertime and quality and quantity decreases. Shading is often missing which is mentioned as one of the main important factors for a productive plant nursery (INIFAT, 2002).

Pest management

Pests are controlled with the help of integrated pest management. This includes two main principles, A) maintaining garden health and B) preventing and controlling pest outbreak. Garden health includes location of the plot, plant varieties, planting itself, soil maintenance, and treatment of the equipment. Pest control focuses on soil treatment, protective plants (e.g. basil, repellent fungi, natural enemies, entomopathogenic microorganisms, traps, and sprays of herbal consistence.

The two major problems for the organic urban agriculture consist of (Vázquez, 2003):

- Soil fungi. This can be banished with help of Tricoderma spray. By application, repellent fungi is spread which eliminates the pest.
- Nematodes. Nematodes represent the bigger problem, as there exists no tool to eliminate them in organic acceptable ways. They can be controlled indirectly by cultivation time of a crop stays, planted varieties, and crop rotation.

In the beginning of urban agriculture the pest pressure was high due to the lack of knowledge and tools available to deal with it. Currently, techniques are being developed and spread so farmers gain experience and improve integrated pest management (Vázquez, 2003).

Another problem are weeds, especially, in the humid summer when they grow fast and intensive labour is needed to control them. The gardeners reported that weed seeds survive the composting procedure and emerge after application of compost.

Commercialisation and gardens' economy

The harvested products are cleaned and then used for self-consumption or sale. Concerning the different forms of urban gardens there exist several ways for commercialisation, which are linked to the legal categorisation of the garden (Cruz, 2003). Produce is sold in several ways: on the plot in booths, in booths in the city called "punto de venta", at farmers' markets, by EHM, or through fixed contracts with social institutions. Most farmers sell on their own plots. The advantage is, they do not have to pay sales tax of 5% (Cruz, 2003, and Cruz and Sanchez, 2001).

The economic situation of the gardens varies and depends on design and layout. Also, the administrator has a major impact. But in general, larger gardens provide a higher monthly wage (see 7.5). In general, people working in urban vegetable production receive higher wages then the average Cuban worker with an income of 250 CP. Interesting is that wages in the 10 gardens stayed below the amounts the gardeners announced to earn when asked. Also, experts of INIFAT and others estimated wages of 600 CP. Only one out of ten gardens reached this amount.

Social aspects

There are two categories of people working in the gardens. In the larger ones normally administrators/engineers are employed to take care of the organizational aspect and normal workers who do the labor work in the garden. The administrator/engineers are mostly younger and higher educated than the workers, some of whom are even retired but still want to work. They often enjoy doing something useful and gain an extra income beside their pension. Most employees are living in the area. The smaller gardens are often run completely by old men. In the 10 gardens women employed were working the gardens in the administration, as engineers, secretaries, or in the sales booth, none in the fields. Also, people working in the gardens were mostly living in the neighborhood, so the gardens provide mainly local jobs for people in the area while these persons of the neighborhood represent also the majority of the customers. Regarding this, the gardens are very sustainable at the local scale.

4.2 Subsystems

4.2.1 Water supply

Water for the gardens comes from wells installed on the site or the urban drinking water network supplies the gardens. The priority use of drinking water is for domestic purposes. Usage in agriculture is accepted nowadays but official approvals by the state are planned for the near future. In three cases (No. 8-10) the drinking water supply net was. To avoid this conflict several gardens (No. 1, 4, and 5) had wells or plan to install one (No. 3). Here water supply is steady and they are not dependent on anybody in times and amounts they irrigate. Since pumps for water conveyance run by electricity, there exist no problems for their energy supply then if they had pumps running on gas as gardeners said. The only drawback to well water is its salt content in the costal zone. Rainwater collection as alternative does not exist in the gardens at all, even though some small projects are taking place to gain experience in this like in the centre of Fundación Antonio Núñez Jiménez de la Naturaleza y el Hombre (Cruz, 2003).

Overall, the technical equipment for irrigation purposes is good. Mainly, micro-sprinkler systems are used run by electrical pumps. Gardeners expressed satisfaction when being asked about their systems. Although literature states micro-sprinklers are not common, this study showed otherwise. Only one garden (No. 10) was found without a micro-sprinkler system and this was likely due to it being a new business. Beside this, the usage of hoses and watering cans is common. The applied amount per day is suggested to be between 4-6 l/m^2 (Puig, 2003). Handbooks for farmers, e.g. "Manual Técnico de Organopónicos y Huertos Intensivos", calculate an irrigation schedule based upon soil type, amounts of water, times of application, crop, age of the crop, and plot size (MINAG, 2000).

Table 2: Water supply in the gardens

Place*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Area under cultivation (m^2)	8060	4800	4800	2040	1970	1120	1400	900	320	140
Amount of water (l/m^2*d)	6	2.1-3.1	6.8-10.2	9.7-14.3	5.0-5.2	4.3	3.9-4.3	3.5-4.2	6.4	0.28

* Numbering see 7.1.

Table 2 shows that there exists a wide range (from 0.28 till 14.3 l/m^2) in the actual water supply between the different gardens. Only three gardens (No. 2, 8, and 10) are below the lower value of 4 l/m^2*d. In contrary, two gardens (No. 3 and 4) show very high daily amounts that it has to be doubted if they are really true.

Overall, water supply is not a problem although there is a slight difference between larger and smaller gardens. Gardens supported by EHM (No. 1, 3, 5-6) all show adequate supplies. A reason is also the support they get by EHM and the people employed. Often they have several staff members with a higher education/university degree who work in the administration and take care of specific issues such as water supply. So, one can assume that good water supply depends more on the administration of each garden and the administrators/gardeners agility and cleverness than the size and legal/production type. The gardens below the mark of 4 l/m^2 support this result: one is small, one is medium, and one is large. Another influencing factor is that the survey was conducted from June till September – the rainy season in Cuba (see Figure 1). So, people might have more problems, especially if they get their supply from the official drinking water net, in winter when the precipitation is lower and this is the main factor the official net relies on (Vasquéz and Cordero, 2003).

The major advantage of greywater wetlands is to reuse the water (see 7.6.1). The water supply for the gardens in Havana is not the constraint as it was assumed to be. This finding is shown in the ten cases, where seven of them have a secure water supply, and other stakeholders reported the same. Only in Old Havana large problems were mentioned, and all stakeholders were looking for alternative solutions including greywater wetlands. In general, if gardeners want to change their system, they prefer to dig a well for an assured and independent water supply, rather than a dependent greywater wetland. Additionally, they do not have to worry about health hazards, maintenance, and monitoring. Another strong argument against greywater wetlands is the low costs for water and water conveyance/irrigation systems. The equipment is cheap and can be bought in CP. If they pay for water, expenses will be very low (between 3-20 CP/month); only No. 3 reported high costs. Gardens pay for a fixed volume, so most do not have water meters, or in case they have, they have a fixed cost for a certain volume and extra charges for use over the limit. The situation might change in the near future. Experts anticipate changes in water regulations for the use of urban agriculture. Then, greywater wetlands become an approaching alternative.

4.2.2 Nutrient supply

The nutrient supply is mainly covered by the input of organic matter as compost, humus, cachaza (see 1.4), manure, and biofertilizers and stimulators. The biofertilizers contain free-living, nitrogen-fixing bacteria, phosphorus-soluzibilizing bacteria and others to enhance the nutrient uptake of plants while the main stimulator based on aminoacids and pectin is used to stimulate the roots (Treto et al. 2001).

Table 3: Nutrient balance of cachaza, manure, and humus (Companioni and Quintero, 2003)

Organic Matter	Doses (kg/m^2)	Portion (g/m^2)			Needed average g/m^2/y	Nutrient balance		
		N	P	K		N	P	K
Cachaza	1 5 10	15 75 150	13 65 130	8 40 80	N=79	-64 -4 +71	-8 +44 +109	-89 -57 -17
Manure	1 5 10	7 35 70	2 10 20	3 15 30	P=21	-72 -44 -9	-19 -11 -1	-94 -82 -67
Humus	1 5 10	18 90 180	7 35 70	6 30 60	K=97	-61 +11 +101	-14 +14 +49	-91 -67 -37

Nutrients contained in humus, cachaza, and manure are shown in Table 3. The nutrient balance is never adequate for nitrogen, potassium, and phosphorus and for potassium even negative at application rates of 10 kg/ m^2*y at all three types of organic matter. This is also stated by the gardeners who say their plants are smaller in stature then in former times and have a lighter colour, an indicator for nitrogen deficiency.

Therefore, another nutrient supplying tool was developed, earthworm humus (*humo de lombriz*). Research on this matter started in the 1990s (Rosset and Benjamin, 1994) but its implementation is relatively new. This material is rich in nutrients but its production volume is still low. Reasons might be that the worms have to be fed with manure, which is hard to acquire and is in demand for direct use in the fields.

Table 4: Nutrient values of the lettuce plants samples

Garden type*	Total Phosphorus in g/kg	Total Potassium in g/kg	Total Nitrogen in %
Control	7.1	71.4	5.2
State institutions	5.8	64.1	2.3
Normal gardens	4.6	42.2	2.0
Bergmann, 1993	4.5-7.0	42.0-60.0	4.0-5.5

* Definition of garden type see 7.3.

Table 4 shows lacks of N, for both state institutions and normal gardens. Also the amounts of P and K are at the lower end of the scale in case of the normal gardens. As expected, the highest amounts were found in the nutrient-supplemented control plants. The plants raised in research beds of state institutions had more nutrients than in the normal gardens. An explanation is a better supply of water and organic matter in national research organisations as well as having technical support (scientists) on site. Although normal gardens show the lowest results, no differences can be made depending on gardens' size, because the number of samples is limited. Beside this, a lot of plant samples did not survive in the field due to problems like insect attacks, high solar radiation, heavy rainfalls, and indisposition of the gardens' owners. In general, it became clear that the supply of nutrients for plants is very closely linked to the supply with organic matter, and if this supply is insufficient the nutrients' contribution will not reach an acceptable level.

Greywater wetlands do not provide a lot of nutrients (see 7.6.1). Especially, nitrogen contents are low. Although this deficiency can be improved by abandoning the septic tank (to raise the amount of organic matter in the water) it also increases the amount of greases coming into the wetland and therefore might disturb the treatment process as well as increase health risks.

4.2.3 Organic matter supply

The organic matter supply was discovered to be very important because the majority of nutrient input is accomplished through it. Gardeners also reported the importance of supply due to high losses through intensive and short cultivation times, settling of the soil, and erosion (see also 3.5). Also, the topsoil is of poor quality (Companioni et al., 1997). Topsoil is often mixed with building foundation material from ruins, which contain high amounts of sand and does not support the vegetable production. Four main types of organic matter are manure, cachaza, humus (see Table 3), and compost. While compost is mainly produced in the gardens, the others are imported. The situation gets even more complicated because the availability of city-based organic matter is low. Moreover, importing organic matter requires administration, organization, and affordable and dependable transportation. As a result, importing organic matter is the highest expense after salaries, 50-60 CP/m^3.

Due to these problems, all gardens visited had established composting, but the intensity was quite low. Composting often includes only garden waste, leftovers that cannot be sold, and weeds. This effect causes a nutrient flow out of the agroecosystem. Composting household waste does not take place for the following reasons: A) Most households do not separate waste. B) In most cases it is only seen as an additional supply. C) Several gardeners mentioned that they prefer to sell their own compost of poor quality (see 4.1) and buy better for their own needs.

Table 5: Organic matter supply in the gardens

Place*	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Area under cultivation (m^2)	8060	4800	2040	1970	1400	1120	900	320	140
Amount of OM (m^3/ha*y)	200	300-500	391	563-792	167	11	24	7	0

Numbering see 7.1. No. 2 did not provide this data.

Official sources mention that an application rate of 33-167 m^3/ha*y is needed (Grupo Nacional de Agricultura Urbana, 2000). The higher amount is suggested for intensive gardening. All persons interviewed claimed their organic matter as insufficient. Gardeners report they needed 2000-3000 m^3/ha*y. Only the gardens supported by EHM (No. 1, 3, 5, and 6) and research institutions (No. 4) have a sufficient organic matter supply according to the official sources stated above. An explanation can be that the recommended amount of 33-167 m^3/ha*y might cover the nutrient supply of plants (see Table 3) but not the requirements stated by the gardeners who expressed them in a volumetric way. This also explains the variation between the amounts expressed to be necessary.

Supply of organic matter varies considerably amongst gardens. Gardens No. 1-6 are large, practice intensive gardening, and show organic matter supply at or above the guidelines, while No. 7-10, which are less intensive production systems, do not even reach the lower amount of 33 m^3/ha*y as advised. So, regarding organic matter there exists a relation between garden size/production system and supply. Unlike water provision that is more dependent on the administrator then on garden' size (see 4.2.1), organic matter supply is strongly linked to production intensity and size.

An improvement regarding organic matter supply is strongly needed in the urban vegetable production. Greywater wetlands filter most organic matter, which might be used by wetland plants but not substantially benefit vegetable production. Also, wetlands require considerable space that can be used more effectively, for example, an improved composting system that will provide desperately needed organic matter.

4.3 Greywater wetlands: General observations and recommendations

To make the agroecosystem of urban vegetable production more sustainable supply of nutrients and organic matter has to be improved and solutions inside the system's boundaries need to be found to decrease the imports. Regarding water supply, this is difficult to achieve with an ecological sanitation approach. In fact, water supply is adequate: however, legal access can become a problem in the near future. In few cases of discontent, it is planed to dig wells. This measure guarantees safe, secure, and independent water sources without using a lot of space, maintenance and monitoring; moreover, gardeners clearly prefere wells to a greywater wetland. Nevertheless, in Old Havana, where wells are out of question due to closeness to Havana Bay people are highly interested in greywater wetlands.

Nutrient and organic matter supply problems are more severe. Greywater wetlands can provide limited nutrient requirements, but this issue is not their main target (see 7.6.1). Reed beds with a vertical flow, or improved composting by adding blackwater, appear more suitable than wetlands. Even an improvment of the actual composting techniques without using blackwater would be helpful. Gardeners reported bad quality of their compost and problems with emerging weed seeds after application (see 4.1), a sign of too low temperatures during the composting process. Advancing the technique and additional collection of organic household waste of the surrounding houses would be helpful at a very local scale and is a very sustainable approach.

Normal greywater wetlands use a horizontal flow and need to settle out solids in the septic tank (see 7.6.1). Red beeds with a vertical flow elminate the septic tank. Greases and organic matter build up above the filtering media and can be used for organic matter in the gardens. The constraints are possible health hazards, large areas are required, and there is no practical experience in Cuba. Another alternative is the utilization of urine. In research after this field investigation, the application of urine was considered and demonstrated in plot trials and the feedback from farmers was positive (Avendaño, 2004). In general, it is hard to propose one specific solution, the situation between gardens varies widely. Which is clearly shown in this study. Although greywater wetlands cannot be recommended as general solution, it would provide relief for Old Havana where serious problems in water supply exist. The situation of the specific garden has to be analysed carefully and an appropriate design chosen.

Beside the technical side of choosing the right system and design, social and cultural obstacles have to be considered. Through any kind of ecological sanitation improvement, labour force will increase and new jobs will be created. This will cause higher costs and a burden for the gardens in the beginning, but in the long run enhances cost-effective sustainability by self-supplying nutrients and organic matter. More critical is the cultural reluctance of the Cuban society against wastewater use for food production. Although gardeners using wastewater in other areas of urban agriculture were aware of its benefits like nutrient supply, they still would have prefered to use other sources if possible. There existed no case in which wastewater was used for vegetable production. Several connections exist between wastewater and urban agriculture (see 2) but before a wider approach can be considered more technical data and information regarding Cuba and development including gardeners as well as tests on health hazards, maintenance, monitoring, etc. are needed and strongly recommended.

5 CONCLUSION

The future of the urban vegetable production in Havana is uncertain. The city is growing, and the area might be needed soon for building constructions. Moreover, the role of urban agriculture hinges, in part, on the uncertainty of the US embargo. What might happen if food imports increase again and fertilizer and pesticides become available, is unsure. Cuban agriculture did not become organic for ideological reasons only, but in part also of necessity. The present investigation showed:

- Today's main problems are not water but nutrient and organic matter supply.
- Nutrients and organic matter are strongly linked, and supply depends on external sources.
- Locally produced compost is often limited and has poor quality. Development of the composting techniques is needed.
- Utilization of blackwater is potentially a more effective solution than greywater wetlands to the observed nutrient and organic matter deficiencies.
- Safe blackwater treatment alternatives should be explored.
- The situation of each specific garden has to be considered when designing and implementing improvements.
- The return on investments in recycling solutions has to be secured by integrating them in the long-term city planning.

The implementation of ecological sanitation techniques into urban vegetable gardens is a seminal concept. Right now, however, there is no urgent need for more water. Experts anticipate changes in water regulations in the near future. Then greywater wetlands become a good opportunity to secure supply. In the meantime, focus should be on techniques improving organic matter and nutrient supply.

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7 APPENDIX

7.1 Gardens of the survey

Explanation for numbering of the gardens:

1. No. 1 represent the garden with the largest cultivation area, No. 2 the second largest, and so on.
2. Names of the gardens are not used in this paper, as the gardeners participated in the study provided that their and their gardens' names were not published.
3. No. 11 was not included in the survey. It was just added to the nutrient supply measurement (see Table 6) so it was a state research area with vegetable fields for the possibility of onsite research but not relevant in the other aspects of the survey.

7.2 Gardens' participation in survey

The gardens participated in different parts of the survey due to their abilities, facilities, and personal wishes. In Table 6 the gardens are presented and each ones' participation shown to ease the transparency of the data presented.

Table 6: Gardens and their personal participation

Garden	Water supply	Nutrient supply	Organic matter supply
1	X	(X)	X
2	X	-	-
3	X	-	X
4	X	(X)	X
5	X	X	X
6	X	(X)	X
7	X	(X)	X
8	X	(X)	X

Garden	Water supply	Nutrient supply	Organic matter supply
9	X	(X)	X
10	X	(X)	X
11	-	X	-

The (X) in the column of nutrient supply indicates that the gardens participated but plants died before harvest time (see 4.2.2).

7.3 Details of plant analysis

The analysis was accomplished by the laboratory of the Institutt for Jord- og Vannfag which is part of the Institutt for Plante- og Miljøvitenskap. It was accomplished with two methods one for nitrogen and one for phosphorus and potassium determination.

Total nitrogen was determined by the *Dumas* method. The samples were heated with copper oxide above 600°C in a stream of purified CO_2. Then the gases were led over hot copper to reduce nitrogen oxides, mainly N_2O, to N_2, and then over copper oxide to convert CO to CO_2 (Bremner, 1965). In the nitrometer, Leco CHN 1000, which contains concentrated alkali to bind the CO_2 and measures the amount of nitrogen gas with help of its thermical conductivity the nitrogen carbon dioxide gas mixture was collected. The results of the analysis had to be corrected for their dry matter content (Dahl, 2003).

Phosphorus and potassium were disaggregated after the *Inductively Coupled Plasma Spectroscopic Method* according to 985.01(c) (Helrich, 1990). 1 g was weighed, dried and ground. It was ashed for 2 h at 500 ºC and cooled down again. The ash was moistened with 10 drops of H_2O and 3-4 ml of HNO_3. The sample was set on a hot plate at 100-120 ºC to excess the evaporating HNO_3 then it was ashed for an additional 1 h at 500 ºC. Afterwards the ash was transferred quantitatively to a 50 ml volumetric flask and was diluted to volume with H_2O. The amount of total P and total K in the samples was determined with the help of the Thermo Jarrell Ash Poyscan 61E ICP-AES instrument made by Thermo Jarrell Ash Corporation a subsidiary of Thermo Instrument Systems, Inc.

Table 7: Detailed results of the analysis of lettuce samples

Code	Total Phosphorus in g/kg	Total Potassium in g/kg	Total Nitrogen in %
I	4.5	36.5	1.85
II	3.2	41.2	1.78
III	4.1	54.9	2.26
IV	6.3	77.6	5.80
V	5.4	77.9	5.60
VI	4.9	75.9	5.26
VII	4.3	40.1	2.20
VIII	5.6	38.0	1.89
IX	5.6	42.5	1.95
X	7.1	75.8	5.32
XI	7.6	70.3	4.94
XII	6.8	71.8	5.20
XIII	7.0	67.7	5.34
XIV	5.5	61.6	2.05
XV	6.5	58.6	2.08
XVI	5.5	72.0	2.62

Code decryption and comments

I – III: No. 5

IV – VI: No. 6, other breed therefore less relevant

VII – IX: No. 7, older plants

X: Control without additional fertilizer

XI – XIII: Control with additional fertilizer

XIV + XV: No. 4

XVI: No. 11

In Table 7 *control* includes No. X-XIII, which shows the plants grown in pots with a guaranteed nutrient supply; *normal gardens* No. I-III + VII-IX which were gardens with vegetable production in Havana; *state institutions* gardens run by state institutions here No. XIV-XVI. The values represent the average of nitrogen, phosphorus, and potassium of each group.

7.4 Interview schedule

Research parameter	**Interview question**
Social background	• What is your profession? • What are you working/doing/occupation? • What is you daily working time? • Who is your employer?
Conditions of ownership **Ownership relations**	• To whom belongs the garden? If personal property • Since when do you have this garden? • Did you buy it? • How much did it cost? • What was the reason for buying it? • What was the purpose of the garden before? If it is rented • Since when do you have this garden? • Who is the owner? • How much is the rent? • What was the reason for renting it? • How is the relationship with the owner? • For how long have you a renting contract?
Who works	• Who is working in the garden? • How many hours a week? • How often per week? • Who has the main responsibility? • Who is helping? • Who is doing/helping with which job?
Distance home-garden	• Do you have more than one garden? What are the reasons therefore?

	• How far is it to your garden? • How often do you go there? • How do you get there? • Do you have problems with transportation issues (home-garden)? • How do you manage the transportation of goods?
Garden's dimension **Area in cultivation**	• How big is/are your garden/the different gardens? • How many beds do you have? • Size of the beds? • Are all beds planted all the time?
Form of cultivation	• What type of cultivation do you have? • Do you have different types, beds? • What are the reasons therefore? • Did you have others in the past? • Why did you change?
Crop rotation **Types of vegetables, fruits, animals…** **Possibilities for year round production**	• What types of vegetables do you have? • Do you have different vegetables in different seasons? • Do you have the same vegetables each year? • Do you have a certain system planting them? A specific rotation cycle? • Do you grow vegetables all year round or do you have a break? • Do you change different vegetables in various beds? Or do you have one type all the time in one bed? • Do you plant them mixed or do you separate them strictly? • What is the criteria to plant them together or separated? • Do you also have fruits? Which types? • What about animals?
Harvest times **Growing time/sequences**	• Do you have special harvest times in the year? • How often do you harvest each vegetable per year? • What are the different reasons for a harvest? • When do you decide to harvest? • How long need … (specific vegetable) from planting/seeding until harvest? • Are there different time spans depending of the seasons? • What are the main factors the time span and possible variations depend on?

Production of vegetables	• What amounts of vegetables do you harvest per harvest? • Can you give numbers or weights of different vegetables? • Where do you have the highest production? • In which time of the year do you have the highest production? • Are there different times for different vegetables?
Usage of vegetables **Value of vegetables**	• What do you do with the vegetables harvested? • Do you use them for yourself and your family? All? Which percentage? • Do you store them? Where, how long… • Do you give vegetables away to neighbours, the wider family? • Do you have always enough? • Do you sell them? Which percentage? • All vegetables or just specific types? • Where do you sell them? • Do you sell them regularly or just in times of overproduction? • Do you sell directly to the customers or to a trader? • What are the benefits of this? • What do you earn by selling? (price per amount) • Is the price steady over the year? • What are the variations? • When is it good to sell, when is it not profitable?
Seeds **Seedlings**	• Under which conditions do you plant the vegetables? • Do you use seeds or seedlings? • Where do you get the seeds/seedlings? • Is there a risk that the needed seeds/seedlings are not available? • What do you do in this case? • How much do the seeds/seedlings cost? • What is cheaper for you: seeds or seedlings? • What is easier to handle? • Do you have preferences concerning the different plants? • What are the various steps/treatments the seeds/seedlings need? • Do you have a separated nursery? • Do you to take special care with the seeds/seedlings? • What about shading, watering…?

	• Is there the danger that they are eaten by insects/snails? • Are there other threats for them?
Fertilizer **Nutrient status of the plants**	• What types of fertilizer do you use? • Where do you get the fertilizer? • Do you have fertilizer made by yourself? What kind of? • Do you produce compost? Why/why not? • Do you have fertilizer available all year round? • What are the costs for fertilizer? (Price per amount) • Where do you buy it? • How do you apply it? • When (season, growing state) and where? • Do you fertilize all vegetables? • If not, which do you, which don't you and why? • Do you have sufficient fertilizer for the plants' needs in your opinion? • What nutrients do they lack in your opinion? • In which time of the year do they lack most? • How do you notice it? Is it visible? How does it look like? • In which period of the growing do they need most? • In which period of the growing do they lack most? • Do you give them extra doses then? What? • Do you have other ideas for receiving additional fertilizer?
Illnesses **Pesticides**	• What illnesses do your plants have? (Insects, fungi, herbs) • Are there typical illnesses for typical plants/times/growing states? • How does it look like? • Do the plants die or do you just have a depression in the yields? • How often do you have problems with illnesses? • When did you have the last case? How big was the damage? • Does the illness normally affect only your garden or all gardens? • What do/can you do to prevent illnesses? • What do you do to fight an illness? • What possibilities do you have? Are you satisfied with them? • What else would be possible? Why don't you do it? • How much time do you use for fighting illnesses?

	• Which costs appear?
Water **Irrigation**	• Do you irrigate? • What do you irrigate? • When do you irrigate? How often? • What are the factors irrigation depends on? (Season, water availability) • Is enough water available all year round? • When do you have shortages? • What are the reasons therefore? • Do you have a fixed/variable irrigation system? • How do you estimate the conditions of your irrigation system? • What are the problems you face? • What do you do against them? • What are the costs of irrigation? • Do you have to pay for water? • Where do you get water? • How is it transported to your garden? • Where do you get spare parts? What do they cost? • How often do you have to repair the irrigation system? • How is water quality? • Do you have to filter the water before you apply it? • Is it the same water you drink?
Production steps	• What are the different steps that occur during one growing period? • Does it depend on the vegetable type? How? • Can you describe the steps more detailed? • When does which one occur? What are the parameters it depends on? • Which one needs most of the time? • Which one is very difficult to do? Where have you got to be more careful?
Working time **Maintenance work** **Investments (daily/long term)**	• How much time do you spend in the garden each day, week? • What do you do each day? • What do you have to do in a weekly rhythm? • What only once a month or even once a year?

	• Who is doing which work? Who helps with what? • How much time do your helpers spend in the garden? When do they come? • When do you come here mostly in the day (morning, noon…)? • Do you spend additional time in the garden in the weekends? • Are there periods were you take time off of your normal work for the garden work? When and what are the reasons? • Do spend a lot of additional time in emergencies or for maintenance? • What type of emergencies/maintenances are these? • Is it difficult to do this work, to have the time for it? • What do you do in case you haven't got the time? • What are additional costs that occur? How high are they? • What are the highest? In which category? • What is the reason for their appearance in your opinion?
Gardening in the past	• Do you know how gardening was in the past? • Did it change from these times until today? • What changed? • What are the reasons for these changes? • Do you think these changes can all be valued as positive in your opinion? • Which one? What is a negative change?
Support through institutions	• Do you know institutions that support your gardening? • What kind of support do you receive? • Is it personal support or non-personal? • Do you think it is helpful for you? • Would you like further support? Would you like an adviser? • Would you like to receive lessons, the offer to do courses? • Do you think you need further knowledge for a more successful gardening?
Reasons for gardening	• Are you satisfied with your garden? • What are the advantages? What are the disadvantages? • What are the reasons for keeping the gardens? • What is your main reason? Why? • What are the reasons for giving up the garden?

	• Do you think that is a general opinion or your private one? • Do you want to keep the gardens in the future? • Do you see changes for the future? • What will change in your opinion? Why?

7.5 Gardens' economy

An agroecosystem also includes an economic side (Olson and Francis, 1995). This aspect was included in the fieldwork also it was not closely related with the main research questions (see 2.1) to gain a better picture of the urban vegetable production one's. The data was collected with the help of the interview schedule and additional data was added during later visits in the gardens. Incomes and costs that split up into fixed and variable costs were recorded. Then the gardens' monthly profit and its productivity in relation to the workers/employees were calculated. An average monthly income was only calculated for garden No. 1-8, so No. 9 and 10 were working without profit interests and the output was used only for self-supply in the own family, for friends and neighbours.

Table 8: Average monthly income of a worker.

Place*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Monthly wage (CP)	530	1340-1440	490-550	400	390-450	530-570	250	270-340

* Numbering see 7.1.

The income of the workers consisted of two parts: a fixed monthly income of 200-250 CP and stimulations. Fifty percent of the monthly profit was paid to the workers in this flexible form of income. The monthly income (see Table 8) is varying between 250 CP (No. 7) and 1440 CP (No. 2). No. 7 and 8 show the lowest salaries. No. 2 has the highest, an outstanding one with 1440 CP compared with the other gardens of the survey. A clear statement regarding the gardens' size and wages cannot be made, but the tendency is that larger gardens offer higher wages. This result is supported by the fact that No. 9 and 10 the two smallest could even not be analysed from the economical viewpoint so there exists no income through sales. Additionally, the example of No. 2 shows that by side activities as ornamental plant, seedling, seed, and organic matter production and onside industry they reach higher wages. No. 2 is the only one participating in the study including such kind of activities.

Figure 3 : Comparison of productivity between all employees and workers only in the field

This tendency is also observed in Figure 3 while looking at the productivity reached by all employees in comparison with just workers occupied with real vegetable production in the fields. No. 2 is the only garden that has a higher productivity by all its employees compared to the employees working in the field. This effect shows that vegetable production is one source of income but there are others at the side. Besides, productivity is always lower when calculated with all employees although variations exist. Reasons are the numbers of people employed in administration and sales in comparison to employees working in the field, the ideology of the garden which range from highest productivity achievable to the provision of as much jobs as possible, personal interests/motivations of people employed, and management quality to organize the work due to its importance. Interesting to see is the difference between these salaries calculated during the survey and the oral information provided about them (see 4.1).

7.6 Greywater wetlands

7.6.1 General information

The systems to clean and reuse greywater are not new but used in the water and wastewater industry for decades (DelPorto and Steinfeld, 2000). Size and type of the individual system depends on (ibid):

- Flow rate
- Geological conditions
- Characteristics and constituents of greywater
- Plumbing specifics of the house
- Others as climate, budget, and regulations.

Therefore, greywater wetlands are first described generally and later on (see 7.6.2) the specific Cuban design developed during this study is presented.

Greywater is water coming from sinks, showers, and washing machines - households' wastewater beside that of the toilet. Greywater contains around 3% of the nitrogen, 10% of the phosphorus, 34% of the potassium, and 41% of the COD contained in wastewater (Otterpohl, 2002). The treatment process is as follows (see Figure 4): greywater is stored in a septic tank to settle out solids which either flow at the top or sink down, then led into the wetland and evenly distributed in the wetland by permeable PVC pipes in the inlet zone. Its flow goes horizontally through the wetland and in the outlet zone the same type of pipes recollects it. Important is, that the inlet pipe lays a little bit lower then the outlet pipe to avoid shortcuts in the waterflow.

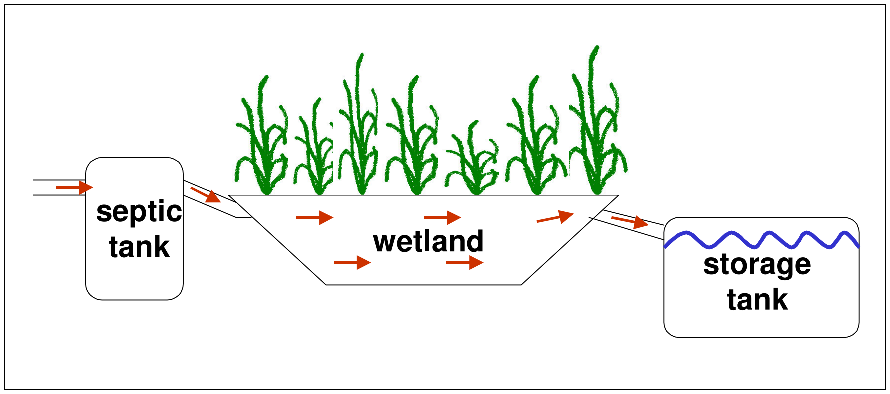

Figure 4 : Treatment process for the greywater

An important issue is the wetland design (see Figure 5) According to Kane (1998) usual measures are for the height h = 0.6m, the slope i = 0.01-0.5%, and the slant with an angle α = 60º. Length l and width w are calculated due to hydraulic capacity Q, hydraulic conductivity K_{Dim} (= K*0.3, the reduction factor due to roots etc. which decrease the overall porosity), retention time t, effective porosity of the material n_e, and specific daily discharge q by:

$$W = \frac{Q}{K_{\dim} \times D \times i} \quad \text{and} \quad L = t \times \frac{q}{n_e}$$

Important is the longer the wetland, the more extends the retention time of the greywater in it and the better the treatment will be.

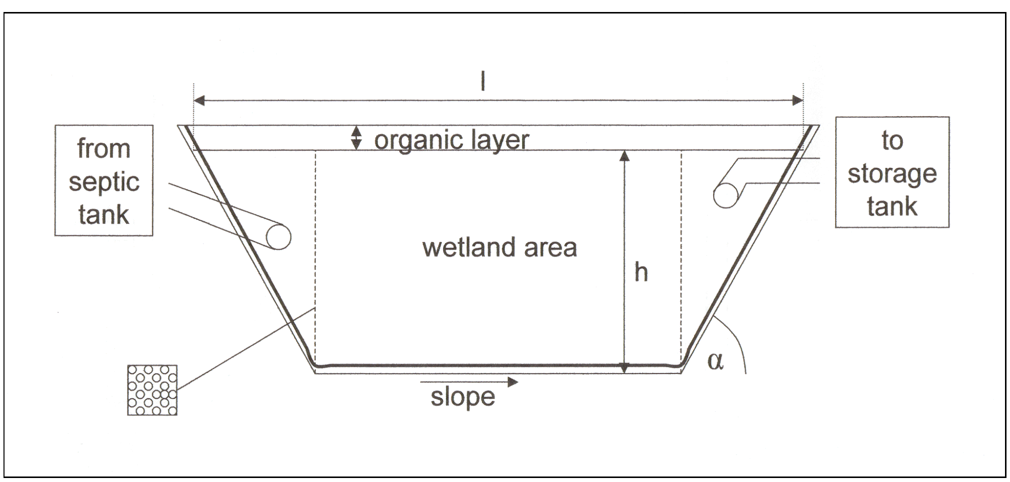

Figure 5 : Sketch of the greywater wetland from the side.

The media in the wetland is gravel. Two aspect have to be considered when choosing the type of gravel: A) to have a porosity n_e which guarantees the undisturbed flow of the liquid. B) The finer the media the higher is the surface area per m^3 material (Jenssen et al., 1991). The media in the inlet and outlet section is coarser to guarantee a quick infiltration of the water. These sections are separated by a permeable partition made of metal plate or brick stones for a better spreading of the water over the wetland's cross section area. Additionally, an impermeable layer of plastic foil has to be put into the wetland before filling it with gravel to avoid leaching at the bottom of the wetland what would cause contamination. The media is covered with an organic layer of 10 cm preferably soil which functions as an odour filter to avoid smell. Where greywater does not include excrement solids, a possibility is to take out the septic tank and simply filter the greywater to reduce its solids (DelPorto and Steinfeld, 2000). But then it is important to test the water for pathogens and other health hazards before application takes place.

7.6.2 Cuban design

Theoretical calculation for a constructed greywater wetland is reached with help of the following steps:

- Calculation of the overall area of the garden
- Calculation of the area under irrigation: overall area without non-irrigated parts like paths
- Amount of water needed daily:
- Needed is: 4-6 l/m^2 (Puig, 2003)
- Losses in tubes: 20% (Rodriguez, 2003)
- Losses through evaporation in the wetland: 10% (Rodriguez, 2003)
- Amount of greywater (Vasquéz and Cordero, 2003)
- Amount of water used daily by 5 persons: 400 l
- Percentage of wastewater is about 80% → 320 l
- Greywater: wastewater – blackwater (3*6 l/pers = 90 l): 230 l
- Number of flats and persons
- Amount of water divided by 230 l = Number of flats
- Number of flats times 5 = Number of persons

Table 9: Basic numbers for the calculation of the wetland's design (after Kane, 1998; Rodriguez, 2003)

h = depth (m)	0.6
Material in the wetland: medium gravel	
d_{10} (mm)	32
n_e = porosity of the effluent	0.4
K = hydraulic conductivity (m/d)	10000
Q = hydraulic capacity (m^3/d)	
t = retention time (d)	1.5
α =angel of the steep area (°)	60

- Calculation

The calculation is conducted due to the basic numbers shown in Table 9.

When the hydraulic conductivity is as high as here, the volume of the wetland is calculated over the porosity of the gravel (Jenssen, 2003):

$$n_e = 0.4 \Leftrightarrow 400\text{l/m}^3$$

So, the volume is:

$$V = \frac{Q}{n_e}$$

The dimensions of the wetland are calculated according to Kane (1998) (see 7.6.1). Final dimensions at the surface (due to α = 60°):

$$L = l + 0.6$$

w stays the same. So:

$$A = L \times w$$

- Above the gravel comes a layer of soil to avoid smell. The layer is 10 cm thick.
- Amount of mariposa plants, the Cuban national flower which shows the characteristics of a „wetland plant“:

4 plants /m^2

The full treatment process (see Figure 4) includes the collection of greywater in a septic tank of 2 m^3. Then, the water runs through the wetland, were it stays around 2 days and is collected afterwards in a storage tank until usage. The tank has a bypass to the local sewerage to avoid overflow problems.

The wetlands calculated theoretically for the three locations in Old Havana show quite similar sizing, based on the design described above.

Table 10 : Sizing of the wetlands

Name	Total area (m^2)	Irrigated area (m^2)	Q (m^3/d)	Wetland (m^2)	No. of households	No. of persons
Case 1	287	138	0.8-1.2	4-5.5	3-5	15-25
Case 2 / No. 9	410	321	1.8-2.7	8.3-12.3	8-12	40-60
Case 3 / No. 10	164	112	0.6-0.9	3.3-4.6	3-4	15-20

Table 10 shows the differences of the gardens and their need for irrigation. So, case 1 which needs a lot of its total area for administration, compost production, etc. irrigates just 48% of its total area, while the other cases (No. 9 and 10) with less additional requirements irrigate around 70% of their area. Also, the numbers vary due to the amount of water applied per m^2. In general, 280 cm^2 of wetland area are needed to irrigate 4 l/m^2 and 400 cm^2 if the amount of water goes up to 6 l/m^2. One person provides enough greywater for 5.5-8.2 m^2/d. It is important to be aware of the fact that the suggested numbers results from discussions with experts and are not yet proofed in practice. These basic numbers are likely to change when practical experience is gained. They are presented to provide an initial idea for design how a greywater wetland in Havana might look like according to data and estimations available in the present Cuban situation.

ACKNOWLEDGEMENT

The idea for this thesis was born in March 2003 by putting two Norwegian professors and an Agroecology student in a room trying to figure out how the latter can write a thesis in the area of Ecological engineering. It required time to create a researchable theme out of this first ideas. Also, it had to be figured out who was willing to give what kind of support and to convince all needed, that it is worth a field trip for exploration on the spot. Then, the goal, Havana, was reached and three months spent on studying lettuce and mariposa, vegetables and greywater, gardening and wastewater, urban agriculture and wastewater treatment. Finally, all needed to be transformed into black (letters) on white (paper). The reader of these lines knows that the author managed to reach this goal. But although there exists only one author, she never would have managed without support, encouragement, critic, questions, answers, distraction, focusing, advice, back-up, interruptions, and recommendations of others: scientists and professionals, family and friends, known and unknown. To all who happened to be in the right time at the right spot willing to give their contribution I want to say:

Thanks! Dank! Tusen takk! Gracias!

Special thanks go to my two Norwegian supervisors, Petter Jenssen and Tor Arvid Breland, for the idea and opportunity in the beginning, their advice and counseling during the whole time. Also, I would like to thank Karlheinz Köller for his and his institute's support in the realization, especially Wolfram Spreer for his assistance and encouragement. In addition, I would like to express my gratitude to the Eiselen Stiftung Ulm for the financial support provided and Christian Hülsebusch for his help to handle the required paperwork. Further, I want to thank William Warner, his help with the application for the scholarship as well as his critical reading and detailed comments concerning the final product.

For the support of their institutions as well as their personal one, I would like to express my thanks towards Heinz-Peter Mang, Gesellschaft Technischer Zusammenarbeit (GTZ), and my favorite Cuban professor Celia Rodriguez, Centro de Investigaciones Hidráulicas (CIH). I would have never managed to reach Cuba and do this fieldwork without them. Additional thanks in this context are expressed towards Alajandro Vázquez and Tatiana Cordero, Taller Barrio San Isidro, and towards María León and Omar Puig, Instituto de

Investigaciones del Riego y Drenaje (IIRD). Besides, my thanks go to Tania Salvador and her family, who nearly adopted me for the time of my stay in Cuba, and helped me, thanks Marlen and Rabdel! Also, I would like to mention all the gardeners, their patience and time they contributed to my work. And thanks to Viviana Avendaño for giving me the feeling that I am not alone but another student is struggling in the same field. Additional thanks go to Mette Aavatsmark and Dora Castillo who guaranteed me, unaware of Cuban conditions, that I went there well prepared, and Linda Aamodt that I returned safely as well.

In the final procedure, I want to thank Tore Krogstad, and his team for the plant analysis. Special thanks go to Irene Dahl for her patience in explaining me the whole procedure and Åsgeir Almås for his provision with additional information. Additional thanks go to the agroecology meeting group who listened to my thesis presentation in different steps and supported me with interesting ideas, helpful hints, and critical questions. Additional thanks go to Kjell Esser for his patience in helping me.

And last but not least, I want to thank my parents for escorting, supporting, and encouraging me through the whole time. My mum especially for all the fights she fought to save my data and my dad for coming to Cuba. Also, I want to thank Christine Stein, Uta Fesefeldt, Bernhard Bauer, and Traci Birge for answering all my stupid questions and providing me with their knowledge, Aylin Gimzal for all the 100s of coffee breaks to cheer me up, Ulrike Böcker, Annette Krauβ, and Axel Dippold who volunteered to read, and my classmates Kjartan Åsebø, Karme Petrutis, and Puspa Raj Tiwari for all the lunch break talks on thesis work.