RUAF Foundation
RESOURCE CENTRES ON URBAN AGRICULTURE & FOOD SECURITY

Rooftop Agriculture

- a climate change perspective-



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1 The concept

Rooftop agriculture is the production of fresh vegetables, herbs, fruits, edible flowers and possibly some small animals on rooftops for local consumption. Productive green roofs combine food production with ecological sustainability, such as reduced rainwater run-off, temperature benefits such as potential reduction of heating and cooling requirements (resulting in reduced emissions), biodiversity, improved aesthetic value and air quality. Most green roofs designed by architects however do not give attention to the productive potential of the roof tops, whereas green roofs developed by Community Based Organisations and Non-Governmental Organisations often take this as the starting point (production of fresh vegetables and herbs in containers, on “tables”, in popular hydroponic systems, etcetera).

Green rooftop (Durban-South Africa)

Three primary types of food producing green roofs can be distinguished (A. Quesnel, J. Foss, N. Danielsson, Sweden, 2011):

- Agricultural green roofs or direct producing green roofs on which crops are directly grown into (shallow) beds in a soil-based growing medium, that is possibly placed on top of a waterproof membrane or additional layers such as a root barrier, drainage layer and an irrigation system.

- Rooftop container gardens or modular green roofs that involve growing of vegetables, herbs, fruits and flowers in pots, buckets, containers, bottles or raised beds which contain a soil-based growing medium. This medium can be made up of mixtures of soil, compost or woodchips. Rooftop containers can range from simple pots to more elaborate systems. As much as possible locally available and recycled material could be used.

Examples of container roof gardens (Kesbewa-Sri Lanka; Bogota-Colombia) and a high-intensive hydroponic roof top system in Montreal-Canada

- Rooftop hydroponic systems which involve growing plants using water based nutrient solutions in place of soil. They require on-going fertiliser inputs. There are exposed hydroponic systems used in open-air settings, as well as hydroponic systems grown under cover (glass or plastic) to help increase yields and extend the growing seasons.

Rooftop gardens can be placed on individual homes, institutional and office buildings, roofs of restaurants and serve either home consumption, use of fresh produce in restaurants or institutional kitchens or commercial production.

2 Climate change impacts of rooftop agriculture

Cities concentrate impermeable surfaces like pavement and concrete, impeding storm water drainage as well as absorbing and converting solar radiation to heat; green roofs can offset these phenomena, depending on the type of production system and local climatic conditions, and make urban areas more sustainable and viable in the long-term. If well designed and maintained, green roofs may also extend the life time of the roof by 2-3 times. This results in reduced maintenance costs and decreases the amount of waste material that needs to be disposed of at a landfill site (Peck and Kuhn, n.d). The initial expense of a green roof may thus be earned back in energy and costs savings and avoided environmental damage.

Green roofs also offer an opportunity to promote inner-city biodiversity on underutilized, empty roofs and to address food security issues through the production of food.

Information on the impact of green roofs on climate change is provided by several researchers, though mainly from the global North. There are minimal surveys to date which deal with the combination of green and productive roofs. It is more difficult to get the same impacts with rooftop agriculture gardens as with green roofs. Contrary to green roofs without production of food, the coverage of rooftop agriculture is often not continuous, particularly with seasonal crops. For agricultural roofs there are also additional demands for safety and access, and inputs have to be supplied more regularly.

There are also differences among the different rooftop garden systems. For instance and in hydroponic systems, due to the lack of soil or an organic growing medium, water run-off is not reduced. Hydroponic systems also require a higher level of (initial) investment and maintenance, thus increasing related energy costs. However, hydroponic systems under permanent cover (greenhouses) will have a larger contribution to insulation. As agricultural yields can be high under these systems, contributions to food security will also increase, as well as the related impact on reducing GHG emissions related to transport from food grown outside the city.

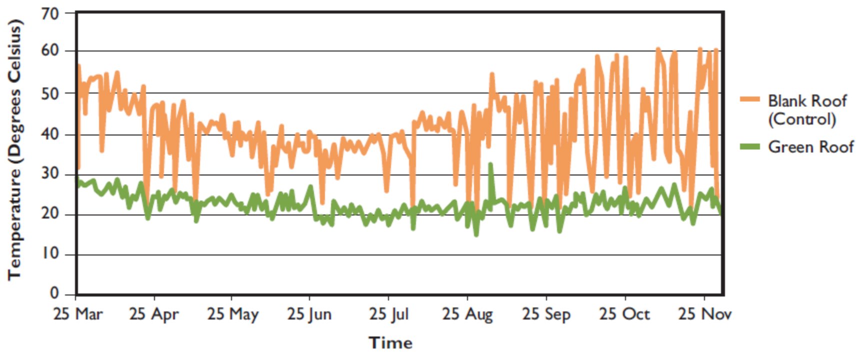
2.1.1 Potential climate change mitigation impacts

2.1.1.1 Reducing GHG emissions and energy use by reducing the Urban Heat Island Effect

An important problem in cities is the urban heat island effect, or the overheating of cities due to dense concentrations of asphalt that absorb solar radiation. The urban heat island effect results from dark surfaces such as rooftops and pavements which absorb solar radiation and re-radiate it as long wave radiation or heat. This situation is exacerbated in the city centre where there is a higher surface area of heat absorbing materials, such as concrete, asphalt, and steel, than the surrounding countryside. These materials act as a heat sink, resulting in higher temperatures than would otherwise be the case. On average, temperatures can be between 5°C and 15°C higher in urban areas than in rural areas.

The urban heat island effect contributes to pollution and increased energy consumption, costing the city money in cooling bills and deteriorated public health. Air conditioners and car exhaust further contribute to the heat island: the more temperatures increase, the more people rely on energy-intensive artificial cooling, providing temporary relief indoors but emitting greenhouse gases and fuelling a positive-feedback loop of rising temperatures and climate change.

Large scale roof planting can help reduce the “urban heat island effect” in the inner city through shading, absorption of heat in plant thermal mass and evaporational cooling. Green roofs reduce the air temperature above the rooftops as a result of solar reflection and evapotranspiration. Indeed, Durban studies showed that the air temperature above a blank roof (shown in orange) is higher than above a green roof (shown in green). The average ambient air temperature above the green roof and blank roof was 22°C and 41°C respectively from 24 March 2009 to 24 November 2009.

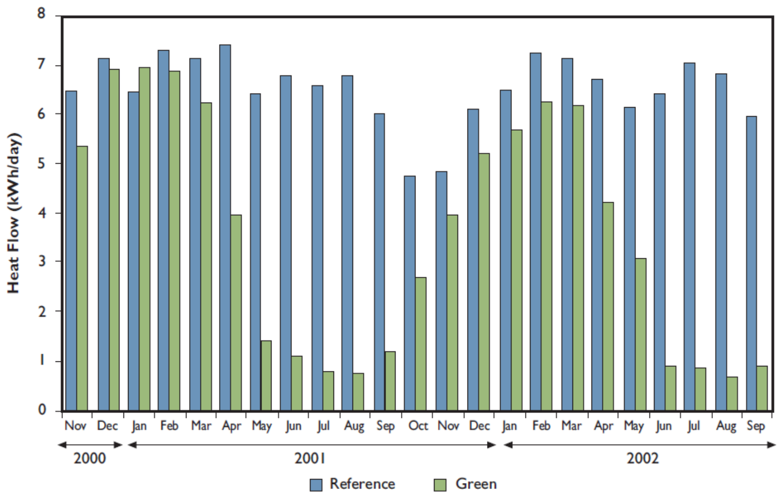


Average air temperature readings taken on blank and green roofs. Average temperature readings taken on blank and green roofs from 24 March 2009 to 24 November 2009. All temperature readings were taken at 13:00 (Van Niekerk et al 2011)

On average, there was an 18°C temperature difference between the green roof habitat and blank roof. It was also found that the green roof habitat reduced or moderated daily temperature fluctuations. On average, there was a 2.7°C fluctuation in ambient temperatures above the green roof habitat with a maximum difference in temperature between the lowest and highest reading of 17.6°C. In contrast, the average fluctuation in ambient temperatures above the blank roof was 9.8°C, with a maximum difference in temperature between the lowest and highest reading of 45.6°C. (Van Niekerk et al 2011).

According to the city's Department for the Environment, on summer days in Chicago, temperatures atop the green-roofed City Hall are typically 14 to 44°C cooler than the adjacent county office building, which has a black tar roof (Kisner, 2008).

During summer, green roofs can thus have an impact on cooling homes and buildings and reducing the heat flow through the roof by providing shade, insulation, and evaporative cooling. As a result the need for use of energy-intensive artificial cooling (air conditioners) inside buildings can decrease. Studies in Germany have shown that a green roof habitat can decrease the ambient temperature in underlying rooms by 3-4°C (Porsche and Köhler, 2003). Canadian researchers found that green roofs reduce the daily energy demand for cooling by 95% compared to a conventional roof from 19.3 kWh or 7,080 British Thermal Unit (BTU) per m2 for a building under a conventional roof to 0.9 kWh or 324 BTU per m2 for a building under a green roof habitat (Liu and Baskaran, 2003).



Average daily heat flow through roof systems (Liu and Baskaran, 2003)

During winter, green roofs may diminish the energy use for heating by absorbing solar radiation and diminish the heat loss through the roof by providing insulation. The Canadian study found that green roofs can reduce the heat loss from a building by approximately 26% during the winter months, reducing the energy demand for heating from 44.1 kWh or 16,200 BTU per m2 to 32.8 kWh or 12,120 BTU per m2 (Liu and Baskaran, 2003).

Insulation, shading and evapotranspirational cooling (cooling due to the evaporation of water from the surface of the green roof as well as evaporation of water from the aerial parts of the plants (transpiration) may thus contribute to reduced heating and cooling requirements, thus impacting energy use and related GHG emissions.

Also, most of the studies referred to have been done in temperate and northern climates. The question remains if similar effects will be observed in tropical climates. Only, the Durban study gives insight in the potential positive impacts of green rooftops in a city that experiences a sub-tropical climate with high temperatures and high levels of humidity, particularly in summer. Buildings in Durban are generally energy intensive, requiring high volumes of electricity for cooling. This is often the result of poor building design, that is, architectural design has not allowed for the free movement of air or ventilation through the building. Projections suggest that climate change will exacerbate the already high temperatures in Durban, increasing the need for and use of energy intensive cooling systems, such as air conditioning, hence contributing to increased GHG emissions (The majority of South Africa's electricity is generated by coal-powered fire stations which release large amounts of CO2 into the atmosphere. Reducing the use of electricity reduces the amount of electricity which must be generated and therefore the pollution of the atmosphere). Results of the studies done so far, demonstrate that there exists a significant opportunity to reduce the 'urban heat island effect' in Durban by creating green roof habitats on empty roof tops. This refers not only to empty roof tops in the city centre, but also densely developed suburban areas.

Reductions in energy savings and emissions will however be off-set against energy use and GHG emissions related to maintenance, production and transport of needed materials and inputs. Effects on heating and cooling will also depend on degree of (permanent) cover of the rooftop, local climatic conditions, building insulation, building types and heating and cooling behaviour of the owners(are homes or buildings cooled/heated using energy intensive equipment?). More research is needed to understand effects on urban temperature and the urban heat island for different types of agricultural green roofs in different localities.

Factors influencing the reduction of the Urban Heat Island Effect

In order to lower air temperature on the rooftop, best effects are found when a permanent green soil/vegetation coverage on the roof is maintained. Generally, more than 75% of the roof would have to be under soil/vegetation to have any measureable effects on the urban heat island/energy use and storm-water run-off. Plants with a high leaf surface area, perennial crops, self-seeding plants, and fast growing plants contribute to maintaining such permanent green cover.

2.1.1.2 Carbon storage[1] and sequestration[2]

Carbon storage

According a study in Michigan and Maryland (USA), 12 green roofs stored on average 1.62 metric tons of carbon per hectare (162 grams of Carbon per square meter) in aboveground biomass. These roofs, ranging from 1 to 6 years in age, were composed primarily of *Sedum* species (typically used for green roof habitat applications in the USA), and substrate depths ranged from 2.5 to 12.7 cm (Getter et al, 2009).

The potential for carbon storage is far lower (more than 30 times) than those of urban forestry systems, as a result of lower plant biomass. If the green coverage of an agricultural green roof is not maintained

[1] Carbon storage : the total current Carbon stock as a function of plant biomass (Zhao et al, 2010)

[2] Carbon sequestration: the assimilation of carbon by plants over one year as a function of net primary production. The net primary production is defined as the balance between the light energy fixed through photosynthesis (gross primary productivity) and the portion lost through respiration and mortality (Zhao et al, 2010)

during the whole year, the carbon storage will be lower than that of a non-agricultural green roof as plant biomass decreases after each harvest.

Carbon sequestration
An American study shows that an extensive green roof (i.e. shallow green roof) is able to sequester around 1.88 metric tons of carbon per hectare per year (375 grams of carbon per square meter) in above and belowground in the biomass and substrate organic matter. This green roof was composed of 20 plots with a substrate with a 6 cm depth, upon which a single species of Sedum (*S. acre, S. album, S. kamtshaticum, or S. spurium*) was grown. This species and substrate depth represent typical extensive green roofs in the United States (Getter et al, 2009).This carbon sequestration figure seems to be similar with that of urban forestry studies.

The potential of a green roof to sequester carbon is however dependent on a number of factors, such as climate, soils, condition, and plant species, and therefore varies widely. Harvesting vegetables on agricultural green roofs also influences radically the carbon sequestration potential, particularly the net primary production. A large part of the sequestered carbon by the vegetables is lost during the harvest. Therefore, the carbon sequestration potential of an agricultural green roof is certainly less than that of a non-agricultural green roof.

2.1.2 Potential climate change adaptation impacts

2.1.2.1 Reducing rainwater run-off

Cities generate a substantial amount of accelerated storm water run-off as a result of large areas of impervious surfaces, such as roof tops and roads. This is channelled into the city's storm water drainage system, from which it is discharged into rivers or the sea. In the case of heavy rainfall, this can result in the capacity of the city's storm water drainage systems being exceeded, resulting in the flooding of rivers and streams, and possible destruction. Projections suggest that climate change will exacerbate this situation by increasing the frequency and intensity of rainfall events. This can result in extensive flooding and possible damage to houses, businesses, and municipal infrastructure (Van Niekerk et al 2011).

Green and productive roof systems may contribute to storm water drainage by reducing the velocity and the amount of rainwater run-off, through the absorption of water by the soil media and plant roots. This reduces overall surface runoff as well as attenuating storm water runoff. The latter is beneficial from a storm water infrastructure perspective.

Impacts depend on the depth of soil or type of substrate used, and the extent and type of vegetation cover.

Factors influencing rainwater run-off

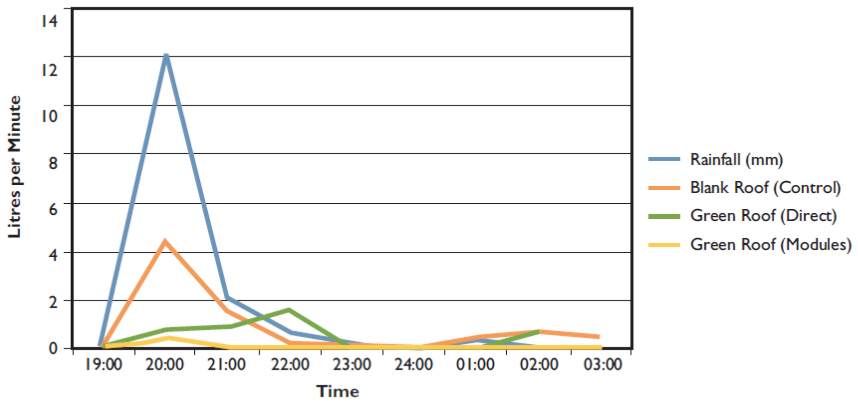
The efficiency to reduce rainwater run-off depends on three factors:

- soil depth: deeper soil retains more water
- the type of plants grown : plants with high leaf surface area intercept more rainwater, plants with a large roof mass absorb more water, seasonal crops are less efficient at times of the year when plants are absent or in the development stage (the leaf area is reduced).
- green roof surface area and cover: a greater surface area retains more rainwater; year-round coverage is more effective than seasonal coverage .

During rainstorms, the plants and soil on green roofs absorb the water that would otherwise run off and strain the sewer system. In addition to serving as a sponge, the bacteria and fungi on green roofs also function as a filter for contaminants, breaking down and detoxifying pollutants like nitrogen and phosphorus. These services, previously provided by open spaces and wild vegetation, could now be found with intentionally-planted green roofs.

Experiences in the USA have shown that green roofs may capture between 50-95% of summer rainfall, while peak runoff flows can be reduced with approximately 50% (EPA, 2009). Other research has shown that three to five inches (7,5 to 12,5 cm) of soil or growing medium can absorb 75% of rain showers that are one-half inch or less (Kisner, 2008).

According to eThekwini Municipality's Environmental Planning and Climate Protection Department studies on Durban, the amount of the storm water run-off from green roofs is eight times less as the amount from blank roofs. As shown in the below graph, the peak flow from a green roof habitat (green and yellow) is far lower than that of a blank roof (orange) during a rainfall event. This significantly decreases the amount of storm water that discharges into the storm water system, and therefore the rivers at any one time, reducing the risk of flooding, damage to property, and possible loss of life. It is important to note that the green roof habitat also substantially delays the peak run-off. It holds back the storm water and releases it slowly over a longer period of time. This reduces the pressure on storm water infrastructure during heavy rainfall events.



Comparison of rainfall run-off from a green roof and blank roof (Van Niekerk et al 2011)

Germany has started introducing tariffs for storm water run-off which accumulates on impervious surfaces, such as roof tops. German studies have shown that a green roof habitat with a soil depth of 10cm can reduce annual storm water run-off by as much as 50%, thereby effectively halving the amount of run-off, which would be subject to annual fees, from the roof (Van Niekerk et al, 2011).

2.1.2.2 Improving biodiversity

Green roofs can add to biodiversity. Compared to a blank roof, a hundred times more insects were identified on a Durban green roof system. They were (logically) also found in higher density (Van Niekerk et al, 2011). The insects on their turn attracted birds. A diverse choice of plants, depth and composition of the growing medium can attract a greater variety of insects and birds. Use of perennial plants, flowering at different times of the year, will be important to offer a permanent source of food and shelter for the insects.

An advantage of the container roof systems is that some small containers can be used as ponds. This creates small aquatic habitats which attract water-loving insects.

Use of perennial plants help attract insects throughout the year (Alternatives and the Rooftop Garden Project, 2008)

2.1.2.3 Reducing air pollution

Air pollution is generally concentrated in densely populated urban areas, particularly where there is heavy industry or large numbers of motor vehicles Poor air quality can result in a number of health effects, including difficulty in breathing, coughing, and aggravation of existing respiratory and cardiovascular conditions. Green rooftops contribute to improved air quality through the reduction of airborne particulate pollutants, heavy metals and volatile organic compounds as they are deposited on the soil, on the leaf surfaces of the plant layer, and onto the moist internal surfaces of the leaves. During the day, plants also absorb Green House Gasses (GHG) like CO2 and particulate matter, and release O2 through photosynthesis.

Canadian researchers estimate that each square metre of green roof habitat can remove ± 200g of Particulate Matter (PM) from the air each year. Based on this research, a green roof habitat of 6m2 can absorb roughly the amount of PM that one passenger vehicle will emit in a year (Liu and Baskaran, 2003). This estimate is based on a car that travels an average of 20,000km per year and emits on average 0.1g of particulate matter per km.

Similarly, a modelling exercise undertaken in Washington DC, examined the air quality benefits of establishing green roof habitats on 20% of the total roof surface of buildings with a roof surface of greater than 930m2. It was estimated that green roof habitats would cover about 2 million m2 and remove 6 tonnes of Ozone (O3) and almost 6 tonnes of PM annually. This is equivalent to what could be absorbed by about 25,000 to 33,000 street trees (Wong, 2008).

If the above findings were applied to Durban, the 550m2 green roof habitat would remove annually approximately 100kg of PM, which is roughly equivalent to that emitted by 92 passenger vehicles in a year and sequester approximately 209kg of carbon over a two year period. This is equivalent to the carbon that one passenger vehicle will emit in approximately four months (this estimate is based on a passenger car that travels an average of 20,000km per year or 1,666km per month, and emits on average 120g of CO2 or 33g of carbon per km) (Van Niekerk et al, 2011).

2.1.3 Potential developmental benefits

2.1.3.1 Reducing food insecurity

Agricultural productive green roofs contribute to food security by producing local fresh food. They provide an interesting opportunity to grow food in inner city and densely build-up areas, otherwise often lacking (open) space for food production.

Vegetables grown on a rooftop in Durban- South Africa (left), Kathmandu-Nepal (middle) and Montreal-Canada (right)

Durban studies calculated the amount of vegetables harvested (spinach, tomato, eggplant, spring onion, green pepper and chillies) from the 10m2 of rooftop planted with vegetables between June 2010 and January 2011, as well as, the approximate retail value. In total, approximately R564 (equivalent to around 50 Euro) worth of vegetables was harvested. This represents potential savings or a source of income for the household (van Niekerk et al, 2011).

If half of the Vancouver's usable rooftop space was used for urban agriculture, it could generate around 4% of the food requirements of 10.000 people. While combining this with hydroponic greenhouses, this figure could be increased to 60% (Holland Barrs Planning Group et al. 2002).

Systems	Surface area (ha)	Conservative Estimated Yields (kg/ha)	Produce requirements of 10.000 people (%)
Productive green roofs (without hydroponic system)	2.75 [1]	26 000	4.4
Productive green roofs and hydroponic greenhouses	4 [2]	346 000	59.5

Vancouver's estimates for food production of green roof systems (Holland Barrs Planning Group et al. 2002)

[1] *half of the Vancouver's usable rooftop space*

[2] *hydroponic greenhouses surface area: 1.25 ha*

For Toronto (Canada) to produce 10% of its fresh vegetable requirements within its' own boundaries, it was determined that Toronto required 2317 ha of food production area if all production was organic to fulfil other municipal environmental objectives. Of this, 1073.5 ha of land could be available from existing Census farms producing vegetables, lands currently zoned for food production, certain areas zoned for industrial uses and over 200 small plots (0.4-2 ha) dotted throughout the NE and NW of the City. 1243.5 ha of rooftop space would also be required (MacRae et al 2010).

In 2003, the City of Toronto owned approximately 1.700 buildings. Researchers proposed to convert 20% of all City-owned rooftops into agricultural green roofs over three to five years. Assuming a modest average food garden surface of 465 m², it would further make approximately 16 hectares available for food-production and for moisture absorption (Nasr et al, 2010).

Food grown on a rooftop, which is consumed by the household or in the neighbourhood, will also contribute to reducing GHG emissions related to transport, cooling, storage, processing, and packaging of food.

2.1.3.2 Improved living environment

Green roofs can improve the living environment in cities, by bringing back nature into often densely build-up spaces. Agricultural green roofs also offer opportunities for relaxation and physical exercise close to (in) the home.

Rooftops can also contribute to the creation of a network of green spaces (green mosaic), connecting to other green open areas in the city (e.g. Gardens, parks, public green spaces, water bodies etc).

Plants can also act as noise buffers, reflecting and absorbing part of the sound. For example, dense vegetation can reduce noise levels by up to 5 dB for every 30m of vegetation, up to a maximum reduction of 10 dB. Green roof habitats could therefore play an important role in absorbing and dampening the ambient noise levels in the city centre, as well as, in office complexes, dense housing developments, and industrial zones (van Niekerk et al, 2011). Noise reduction is dependent on the level of the thickness of the roof and the amount of (permanent) vegetation cover.

Summary of rooftop agriculture benefits

Effects category	Effects	Factors which influence effects	Direct agricultural systems/ shallow beds	Modular system/container gardens	Hydroponic system
Climate change mitigation impacts	Reducing the Urban Heat Island Effect	- Plant leaf area index - Green surface coverage	**XXX**	**XX** (less surface coverage)	**X to XX** (no roof cooling by evapotranspiration)
	Reducing Greenhouse gases emissions	- Green surface coverage (insulation) - Plant yield (volumes of food produced locally)	**XX**	**X -XX** (depending on surface coverage)	**X to XXX** (if greenhouse systems are used higher contributions to insulation, potentially high yield capacity; but production may be very energy intensive)
	Carbon storage and sequestration	-Soil coverage and depth , plant species used, degree of permanent cover and harvest	**X**	**X**	**-**
Climate change adaptation impacts	Reducing rainwater run-off	- Soil depth - Plant leaf area index - Green surface coverage	**XXX**	**XX** (less surface coverage)	**X** (no rainwater absorption through soil, if cover is used rainwater run-off will still be high, unless harvested)
	Biodiversity improvement	- Input of organic matter - Depth and composition of the soil -Variety of plant species and degree of permanent cover	**XXX**	**XXX** (less surface coverage)	**X** (no soil/organic growing medium, often high-intensive monoculture crops)
	Reducing air pollution	- Plant leaf area index -Degree of permanent cover	**XX**	**X to XX**	**X** (no soil/organic growing medium used; growing under cover does not allow PM absorption by soil and plant matter)
Developmental benefits	Reducing food insecurity	-Intensity of growing -Plant yield	**XX**	**XX**	**XXX** (potentially high yields)
	Improved living environment	-Degree of plant cover	**XX**	**XX**	**X**
	Community involvement, educational value, healthy fresh food, aesthetics and connection to nature, economic value, green job creation.				

Summary of rooftop agriculture benefits (adapted from Quesnel et al. 2011)

3 Technical aspects, design and management

3.1.1 Technical aspects for different green roof systems

As weight is a concern, rooftop growing is often taking place in shallow beds or containers. If the roof is quite limited in the weight it can bear, then some lightweight material should be mixed with the soil, or the beds made very shallow. If sufficient compost is not available, plants can be successfully grown in fresh organic matter of many kinds (such as woodchips). Such beds are fertilized and covered with at least a thin covering of compost or soil. Almost any vegetable can be grown in shallow beds. Once the beds or containers are established, they are like regular gardens except in their need for more frequent watering.

In the table below the different productive rooftop systems are compared in their various technical aspects.

Option	Direct agricultural systems/shallow beds	Modular system/container gardens	Hydroponic systems
Weight	Heavier system which may require structural supports. Depends on depth of beds and growing media used (see also below).	Lighter system depending on the type and number of containers used, which can be installed on an existing roof with sufficient structural capacity and on roofs with slopes up to 15 degrees	High variability
Installation	Need to protect the rooftop from direct contact with roots and the growing system (protective layers need be installed first)	Quick installation, containers may be moved	Installation generally requires higher investment and technical knowledge
Costs	Costs dependent on rooftop protection and structural supports needed	Costs depend on the number and quality containers. Consider using recycled materials.	Costs of growing containers and structural supports, as well as soluble fertilizers, generally high
Repair and Maintenance	Problems with the rooftop requires to lift layers and disturb vegetables	Containers can be moved easily	Maintenance requires a higher technical level
Alteration and additions	Alterations are difficult and a new installation takes a long time	Alterations and additions can be made easily	Alterations are difficult and a new installation takes a long time
Plants	Root growth limited by depth of the beds	Root growth limited by the container capacity. However containers may allow for planting even small trees.	Vegetables that grow in water

Comparison of direct/shallow beds, container, and hydroponic systems (adapted from Van Niekerk et al. 2011)

Weights are a function of the depth of the beds/containers, type of supports and growing media used. Two subcategories are sometimes distinguished:

- Intensive green and agricultural roofs that have a soil depth between 15cm and 1m.
- Extensive green and agricultural roofs that have a soil depth between 5 and 15cm.

The type of rooftop garden system to be installed depends on the structural capacity of the existing roof, the costs of installation and the types of plants that should be grown (see the table below).

Option	Extensive system	Intensive system
Weight	Lighter system owing to the shallower soil	More weight on the roof which requires a high structural capacity.
Building	Can be used on existing roofs, may require a few additional supports or not	Might call for new structural supports
Costs	Cheaper because of no or few additional load bearing supports	More expensive due to load bearing demands
Plants	Crop selection limited to species with more shallow roots (leafy greens and herbs)	Higher variety of species possible. More efficient plants growth and health because of larger soil depth

Comparison of extensive and intensive systems (own elaboration)

3.1.2 Suitable rooftop locations

It is important to determine whether the existing roof can bear the additional weight of a roof top garden, taking into account the weight of the growing media –in both dry and water-logged state-, crops, structural supports, (rain)water storage, and human presence. Weights may add up to 1000 kg/m2. As a general rule, heavy loads must be located near columns and beams located on the existing roof and construction.

Roof system	Weight range (kg/m²)
Extensive system	50 - 200
Intensive system	200 - 1000
Rooftop containers	50 - 1000
Hydroponic system	20 +

Weight of rooftop agriculture systems (Quesnel et al. 2011)

It is also important –before starting- to check the integrity of the roof- and repair holes or cracks to avoid water and root infiltration.

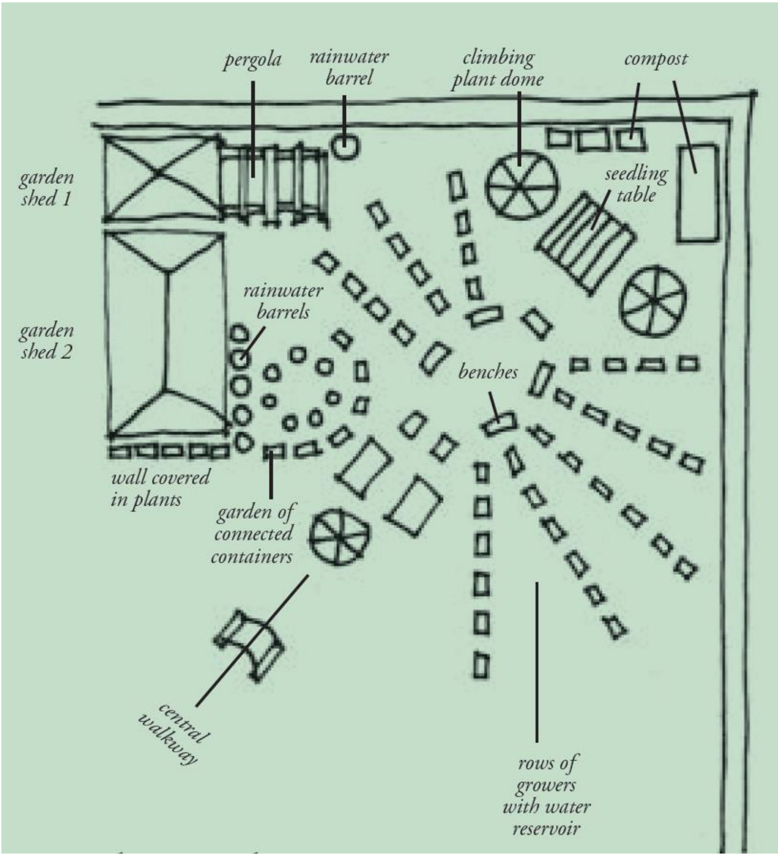
Generally, flat-roofed and concrete buildings are the most adapted buildings to install productive green roofs. Concrete buildings require less additional supports than wood frame or steel frame buildings (Holland Barrs Planning Group et al. 2002). Considering roof slope, Durban researchers advise a maximum slope of between 3° and 10°. Flat roofs and low slopes require an efficient drainage system to prevent pools, as to avoid roof rot and damage to the plants (Van Niekerk et al, 2011).

High rooftops are exposed to more winds. This may influence safety, access and water requirements (due to higher evapotranspiration). The higher the rooftop, the more energy needed for transporting soil, growing media, water and inputs to the roof.

The local climate, the exposure to sunlight (south or west / north or east), the wind velocity, and shading (by surrounding buildings for example) will all influence the design and the selection of plants. Depending on the orientation, may get less direct sunlight and will therefore be cooler and wetter, or will experience more direct sunlight and are therefore warmer and drier. Exposed and higher rooftops experience higher wind influence. Wind stresses plants by increasing evaporation off their leaves, and damaging foliage and branches. Some areas of the rooftop may be permanently or periodically shaded by surrounding buildings (Van Niekerk et al, 2011). Temperature and shading differences may also be observed in different times of the day and over the year.

Safe access and movement of people should also be taken into account. Fencing may be necessary.

When designing the garden, consider the basic features as well as possibilities for and constraints of the site: sun areas (full sun, partial sun, shade), access to water and electricity, interior and exterior access, circulation areas, railing, special features related to safety, etc. Consider all utilitarian and recreational uses that the garden should have: food production, relaxation and contemplation, gatherings, storage, rainwater recovery, area for doing manual labour, drying of cloths, composting, etc and determine the size of each area according to needs and priorities. The final design should be functional, and inspiring.



Snapshot of a rooftop garden design (Alternatives and the Rooftop Garden Project, 2008)

Before starting, also get information on regulations from the city. In addition to building codes that regulate materials and ensure conformity to the building code norms, zoning regulations may also determine use of space and maximum height of the building. Certain buildings may be classified as historical monuments or as being part of a historical sector, which also limits some types of possible actions. Height from the edge may also be regulated. Access may be regulated by fire codes (emergency exits). There may also be restrictions on flammable materials and on the height of structures like pergolas and pavilions (Alternatives and the Rooftop Garden Project, 2008).

3.1.3 Growing Medium

Great emphasis should be placed on developing lightweight systems for rooftop applications. If there were no weight considerations, a rooftop bed or container of 9-12 inches depth would be about ideal. That is more than sufficient to support even tall plants like sweet corn and to encourage plenty of root growth for even the most demanding of plants. For most rooftop applications, however, the bed or container will probably need to be shallower than this.

A bed half that deep would have the advantages of weighing half as much and requiring half as much material to be obtained and moved to the roof to make the bed, or be removed from the roof if plans change at a later date. The biggest disadvantage is that the maximum amount of water the bed can store is half as much as in the one twice that deep. This means that it will need to be watered twice as often.

When using shallow beds and containers, it is recommended to stay away from large vines that have such a large leaf area that they quickly deplete the water reserves of a shallow bed, such as tropical pumpkins, watermelon or sweet potatoes. However, with sufficient volume (with either a deeper bed or fewer plants in a bed) or more frequent watering, there should be no problem growing these larger leafed plants, letting them flow over a rooftop or down the side of the building. Root crops also require deeper beds.

The choice for composition of the growing medium depends on weight considerations and on the space and nutrients that different plants need for their growth. Both dry and saturated weight should be taken into account. To reduce weight, other growing media than soil could be considered (see also below), and soil depth kept to no more than three inches. Individual soil particles typically weigh approximately 2.75 times as much as an equal volume of water. There is space between the tiny soil particles, however, which can account for up to 50% of the volume of a good garden soil. If the weight after a drenching rain is considered and if it is assumed that all space is filled with water, such saturated soil weighs 1.9 times as much as an equal volume of water.

Individual particles of organic matter typically weigh slightly more than water (1.1 to 1.4 times) and the space between them are much more than 50% of volume. So in a totally flooded bed of fully decayed, compact organic matter, the weight would be at most 1.2 times that of water. In most cases, the weight will be almost the same as an equal volume of water.

In any case, the weight can still be considerable. The table below compares the weight of 3 inch (7.6 cm) and 8 inch (20.3 cm) deep beds that are 4 feet wide and 8 feet long (1.22 m x 2.44 m), one with soil and one with well decomposed organic matter, both fully saturated with water.

Depth	Weight	
	well-decomposed organic matter	good garden soil
3 inches	598 lbs (272 kg)	947 lbs (430 kg)
8 inches	1,595 lbs (725 kg)	2,552 lbs (1,147 kg)

Maximum weight of four rooftop gardens, each 4x8 feet (1.2x2.4 meters) (ECHO)

Consider using no sides to the garden beds in order to keep material cost to a minimum. If cement block sides are used, the weight and cost are considerably greater.

It is thus more efficient to choose a lighter medium in order to have a deeper soil depth and as a result a more efficient plant growth and health. Look for materials that are light weight and easily obtained at little or no cost. Several growing materials like vermiculite (worm compost), potting mix, Berea red sand, wood chips, grass clippings that have spent several weeks in a pile, household compost, corncobs, rice hulls, shredded coconut husks, sugar cane bagasse (what is left after the juice is squeezed from the cane), coffee pulp etc. and perlite can be used to make up the medium. Pulled weeds can be placed in the bed as long as they are covered with enough soil so that they will not germinate. Plants such as Napier grass (elephant grass) should be avoided because the stems readily sprout and grow. The growing medium should contains sufficient organic matter and allow the roots to aerate sufficiently. A good starting point for producing one's own substrate is to aim for a blend of inorganic materials with organic materials.

For example, a bed made from grass clippings and soda cans has light weights and offers some other special advantages. Such a bed can be several inches deep but still not too heavy, enabling larger vegetable plants to grow without special support. This bed is constructed using approximately 40% by volume of soda cans (with slits cut into the sides so roots can enter that well-aerated and hopefully humid interior). The other 60% could be made up of grass clippings mixed between and placed on top of the cans. Only using a grass clipping bed (without the cans) deep enough to support taller vegetables heat up too much for good plant growth due to the rapid decay process. Also due to rapid decay, the beds may shrink into a rather shallow bed that becomes so dense that the roots cannot get enough air. An alternative to soda cans might be pieces of coconut husk positioned so that as to create air spaces under each piece, or alternatively light volcanic rocks could be used.

A bed made from a 2-5 inch layer of weeds packed closely together and covered with perhaps a couple inches of grass clippings or (better) compost also works well. A benefit to placing weeds on the bottom (rather than grass clippings, for example) is that there is more space between the weeds, which is better for the roots.

The hydroponic rooftop system uses water as a growing medium. Weights depend on the amount and depth of containers used. Water containers are generally lighter than soil-based systems.

3.1.4 Construction and planting

In this section several methods of construction will be described. Principles for the selected practices include:

- They are oriented at home rooftop gardens (commercial rooftop gardens on institutional buildings are not described here)
- They should be low-cost
- Potential to make use of recycled and locally available materials and growing media. When use is made of materials and media that have to be transported over larger distances, their higher carbon footprint will offset reductions in carbon footprint resulting from increased local food production
- As much as possible, ecological production practices should be applied and use of chemical fertilizers, herbicides and pesticides avoided, both for health reasons and in order to reduce the carbon footprint related to use of external inputs.

Pollution factors should be minimised. When using (urban) soil, be careful to make sure that the soil is not polluted (especially heavy metals). When the garden is located near industrial areas, air pollution may be a factor of concern. Use of protective fences may reduce this risk. The produce can also be washed in a mixture of water and vinegar before consumption. When kitchen water is used for irrigation, care should be taken that no chemical detergents are present in the water.

3.1.4.1 Construction of direct agricultural rooftop gardens, using shallow beds

This method involves placing the growing medium directly onto the underlayment required for green roofs. The underlayment should be placed first on the roof surface, after which the garden is built on top of these protective layers. Plastic sheets can be used. For better protection an additional protection layer can be applied on top (usually a layer of geotextile bidum and a layer of 1000 micron plastic), followed by a drainage layer and another layer of geotextile fabric mesh. Use of these materials however is more costly.

Protective roof layer used in Durban green roofs (van Niekerk et al, 2011)

Roots might grow into any cracks that might be in the cement and eventually make them larger. Placing the garden directly onto a cement rooftop might cause minor discoloration. The plastic should eliminate both problems. If there are substantial cracks already in the cement roof, water might seep through to the ceiling below. If just plastic sheets are used, these will minimize but not eliminate this possibility. No doubt it will always be moist under the plastic, but that is less of a worry than a considerable supply of water and roots in direct contact with the roof. Using more protective roof layers will require higher investments. Another option to avoid direct roof contact is the use of tables, trays or heightened beds for growing.

Use of heightened beds, Dakar-Senegal

Depending on the growing material used, sides may not even be needed, especially if mulch is placed on top or at least on the edges of the bed. Sides are only necessary if the garden is placed on a platform or table of some sort where the garden extends right to the edge of the structure, or where appearance is important.

The shape of shallow beds can be of any length, but a break for a path every 8-12 feet is helpful. They should be just wide enough (4-5 feet) so that a person can reach to the middle of the bed from either side. Thought should also be given to maximum use of space. A path down the length of the rooftop with beds and aisles going off to either side might be the most efficient.

Soil or other growing media is placed to form the beds. A lightweight, well drained, high moisture retention soil growing media is compiled of vermiculite, perlite, organic materials and well composed growing medium or potting mix. The materials should be arranged to form the bed, than the bed should be thoroughly wetted. When using materials that will still decay (like weeds or grass clippings), the initial bed should be made deeper, to allow for shrinkage during the initial preparation and continuing as the bed decays. While adding water, walk over the bed to compress the material (when media other than soil are used) as the bed needs to be sufficiently dense to have ample moisture in the vicinity of the seed and roots.

Seedlings can be transplanted directly into these beds. Fertilisers should be added onto any system that is not based on organic matter, e.g. sand or gravel. A quick way of providing the needed micronutrients is to apply some manure or to water the garden with a manure tea made by soaking a bag of manure in a barrel of water for a few weeks.

Planting seeds or transplants into shallow bed gardens made of compost is done as in any other garden. Planting directly into beds of organic material that has not yet decomposed requires some special techniques. Larger seeds like peas or beans can usually be planted directly if the medium is made of a material that packs closely enough together to remain moist most of the day and make close contact with the seed to keep it wet. Seeds must be deep enough into the medium to remain moist but shallow enough to be able to grow to the surface after germination. The top inch of the beds tends to dry out, and watering needs to be done a few times each day until the seeds germinate. When using older, matted grass clippings are used, these may stay too wet.

Smaller seeds, like carrots, require compost or soil or something of very similar texture to get started. The entire bed can be covered with compost or soil in a 1-2 inch deep trench and seeds can be planted in this trench. A useful technique for germinating small seeds is to place a board on top of the row. This ensures that the top centimetre of the soil remains moist. Keep the board until the first seeds are germinating, and then remove it.

Transplanting likewise can demand special care if the medium is not similar in texture to soil. If the bed is made of un-decayed plant material that does not pack well, the top should be covered with 1-2 inches of soil/compost in which a small hole is made, the transplant is inserted, and filled in sand around with several handfuls of compost or soil.

At the first sign of nutrient deficiency, more fertilizer should be added. With high-nitrogen materials like grass clippings, this may only need to be done once or twice, or not at all. With low nitrogen materials like wood chips or straw it will be necessary to add fertilizer frequently. A small amount of solid fertilizer can be sprinkled around the plants, taking care not to get it in direct contact with leaves or stems. Wood chip gardens produce best if they are watered every other day with a solution of soluble fertilizer or manure tea. Manure tea should not be sprayed directly onto the plants because it may contain disease microorganisms.

The bed must be refurbished after harvest whenever it has shrunk to less than the desired depth or has become so dense that it holds too much water and too little air. Alternatively, the bed can be recycled: dismantled and the compost which has formed in it used as the top layer in constructing new beds. If the bed is still deep enough for another growing season, the only refurbishing needed is to apply fertilizer. Much of the bed, depending on its original composition, may by now have been converted to compost. The bed should not need as much fertilizer as it did when it was first constructed and planted and possibly may not need any addition of fertilizer, depending upon whether the now-decayed organic materials have turned into a good compost that provides all the nutrients needed for healthy plants. More fertilizer will be needed if there are heavy rains that leach away nutrients.

If the original organic material has completely turned to compost, then within one or two growing seasons the bed should be remade. Rather than layering new organic material, on top of the bed, it is best to remove the composted material, layer the new un-decayed material onto the place where the beds should be located, and then place the remains of the old bed back on top. First, the older material can become so dense that, if left at the bottom of the bed, aeration might be poor. This is not a problem when it is placed on top of the less compact fresh organic material. Second, it is much easier to plant into the composted material than it would be into the fresh material (http://www.echonet.org/content/urbanGardening/770)

3.1.4.2 Wick gardens

Wick gardens are a special form of shallow bed gardens. They enable people to have exceptionally shallow bed gardens without the need to water several times each day. Water is pulled up through a “wick”, through capillary action from a pool of liquid below, like an oil lamp that pulls oil through a fuse.

The wick garden consists of a piece of polyester or other synthetic cloth (the "wick") laid out on top of a plastic sheet on a flat area in the shape of the desired garden and a five-gallon watering bucket placed directly on the wick. The root balls (the roots and soil attached to plants in their starting containers) of transplants are placed directly on the wick. The beds are then filled in around the plants to a depth of three to six inches with lightweight material that will keep the sun and wind from the wick and will give some support to the plants. Examples would be pine needles, pieces of coconut husk, or even soda cans. It is important that this material be something that will not become waterlogged. A space is left on the cloth to hold the bucket. The wicking action of the cloth spreads water and nutrients to the roots, which grow above and below the surface of the cloth. Best results are achieved with short or trailing vegetables and herbs, such as tomatoes, onions, radishes, lettuce or mint.

The wick for the garden can be any kind of cloth. Pieces of old carpet make a good wick. For example the wick might be an old blanket, pieces cut from old clothing, a piece of carpet or a special fabric made for this purpose that is used in greenhouses to keep the soil in small pots moist until they are ready for sale.

Very thin pieces of cloth may not be able to deliver enough water to areas farther from the bucket, especially on a sunny and windy day or after the plants have developed a considerable leaf area. If the thickness of the wick seems to be a problem it can be doubled over to make it twice as thick with twice the water moving capacity or a thicker piece of cloth can be used.

Nutrients need to be added either directly onto the cloth wick or dissolved in the supplied water. To every gallon of water between 1-3 teaspoons of a soluble fertilizer with micronutrients should be added that has been manufactured for soil-less gardening.

Watering is done through the bucket that will slowly release water to the wick. Five-gallon buckets that have tightly fitting lids can be used (one bucket per 16 square feet is about right). A single 3/8-inch (0.95cm) hole is drilled in each lid. The hole should be located roughly an inch (2.5cm) from the side of the lid. The bucket is filled with water that contains about a tablespoon of soluble fertilizer, which is sold at garden centers, at farm supply stores for injection into irrigation systems, or at greenhouse supply houses for hydroponic vegetable production.

The buckets are placed in such a way that they are spread around on the bed to help ensure even distribution of water. A small barrier around the spot where the buckets are to sit can be constructed from wood or bamboo, but if the bed is made from materials that tend to stay in place, e.g. pine needles, this is not necessary.

The sun and wind must be kept from drying the cloth and damaging the roots. Roots that start to grow on top of the wick will likely be damaged by direct sunlight. Furthermore, a wick in full sun that is kept wet with water that contains all the nutrients necessary for plant growth will quickly become covered by a green growth of algae. This will be unattractive, use up a lot of the nutrients, and will take a lot more watering because the sun and wind evaporate the water so much more quickly. A final problem is that if there are salts in the water, for example if the water is hard, these will be left behind along with any unused fertilizer when the water evaporates. This can build up and become harmful to the plants. It is thus necessary to cover the wick, to keep the sun and wind off of the cloth and to keep the sun from damaging the roots that will emerge. Pine needles, gravel, woodchips, recycled soda cans, or corncobs can be used.

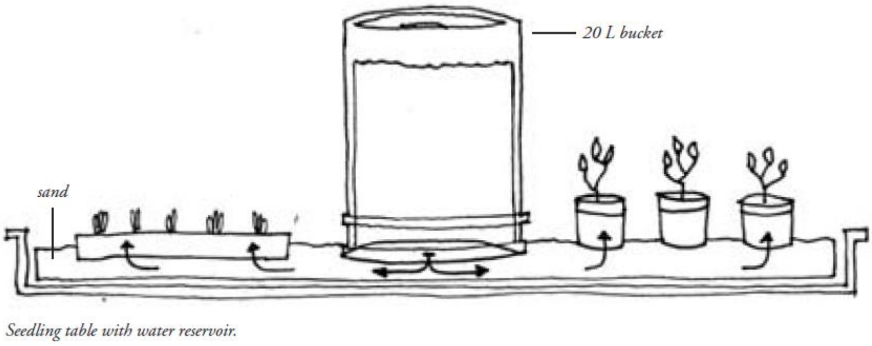
The system works best if plants are transplanted rather than directly seeded. The basic problem seems to be that a seed sitting on a wet piece of cloth may not have sufficient contact to absorb the water needed for good germination. Very small seeds, such as lettuce, would be more likely to germinate than large seeds, such as beans. The wick and whatever material is now covering the wick are to be thoroughly watered before transplanting onto it. The place where each plant is to grow must be determined and then the first plant removed from its container. At the spot where the first plant is to be placed the covering material is placed aside so that enough of the wet wick is exposed. The root ball must be placed in tight contact with the wick. Good root ball/wick contact is very important. Until new roots start to grow, the only water the root ball will receive is that pulled from the wick by capillary action. Covering material around can now be replaced on and a little above the root ball so that the sun and wind do not dry out either the wick or the root ball. This process is continued until the entire garden is planted.

After planting the wick garden, each of the five-gallon buckets can be filled with water that has 1-3 teaspoons of soluble fertilizer dissolved in each gallon. The lid, with the previously drilled 3/8 inch hole, can be placed tightly on the bucket, the bucket turned upside down and set on the wick. Water immediately begins to trickle from the hole and onto the wick. Wicking action (movement of water caused by capillary action) moves the water from under the bucket and continues to move it toward the edges of the garden. The cloth wick acts like an irrigation pipe, distributing water and nutrients over the entire area of the wick.

The wick only holds a very little amount of water. If the buckets run dry, the vegetables tend to wilt easily. So if conditions favor rapid loss of water through the leaves, the buckets need to be refilled soon after they empty and perhaps with a slightly less use of soluble fertilizer. If this is not possible, adding another bucket can be considered. Some plants may develop such a great leaf area, for example pumpkins, with vines several feet away from the bed, that watering becomes overwhelming. In such cases a wick garden is not a suitable system for growing those plants. When needed, the bucket irrigation system can be supplemented by sprinkling water directly over the bed at any time.

The wick garden works best during drier periods. An inch or so of rain can quickly wash away nearly all the dissolved nutrients when the garden is only a piece of cloth. So the wick method is best suited for gardening during seasons when rains are infrequent. Alternatively, the area can be covered with a plastic rain shield of some sort. At any time of the year, if it rains enough so that the nutrients may have washed away, they should be replaced. Some hydroponic fertilizer dissolved in a watering can and sprinkled over the wick is enough. This is even more important if it rains several days in a row. That is because the hydroponic solution in the bucket only drains out when the wick begins to dry up. If the wick does not dry out for several days, the bucket may not be of much help, leaving plant roots only with water and air but no nutrients (http://www.echonet.org/content/urbanGardening/771).

The wick garden principle also works for seedling tables (see Annex 1 for instruction on how to construct such a seeding table):



Seeding table with water reservoir (Alternatives and the Rooftop Garden Project, 2008)

3.1.4.3 Constructing container gardens

Different types of containers may be used, such as old tires, bags, pots, bottles, buckets etcetera. The size of the containers used, determines the species that can be grown. E.g. tomatoes require about 20 cm depth, while for lettuce 15 cm depth is sufficient. Melons , eggplant and squash may require up to 25 cm of soil depth. In larger containers even small fruit trees can be grown. The advantage of using portable growing containers is that they can be placed anywhere and moved if necessary. When using tires, the bottom that will hold the growing media in the container can be a piece of ordinary plastic, e.g. like painters use to keep paint from splattering on the floor or a thick garbage bag.

For tires: lay a tire flat on the ground. With a knife or machete or large-tooth saw, the top rim is cut-off. A piece of plastic is placed inside the tire on the bottom rim, large enough so that an inch or two of plastic extends up along the walls of the tire. After that the top rim is turned so that it can be cut off upside down and placed inside the tire where it will fit against the bottom rim, holding the plastic firmly in place. If the plastic is trimmed to near the bottom of the tire, the garden will essentially be a portable "shallow bed garden." Any suitable soil, compost or potting mix can be used to fill the tire. Based on is used for a planting medium and how plants are growing, fertiliser should be added. A PVC pipe can be added in the centre to see how much (if any) water is standing in the bottom and so judge when to water. As with the shallow beds described above, incorporating something with a lot of air space into the planting medium helps to reduce the weight of the tire garden.

A container garden can be moved if necessary as seasons change. A growing vegetable may need to be moved where there is more sun or less sun or where there is less wind. It can be placed on sticks or stones so that air can circulate underneath, keeping the roof surface dry. Also there is no contact of the roots with the rooftop itself. The advantage of container gardens- to shallow beds- is that there is less potential to damage the roof.

A tire garden in Kesbewa-Sri Lanka placed so that there is no direct contact with the roof

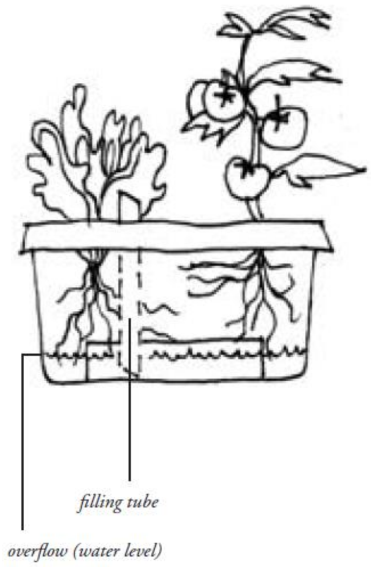
3.1.4.4 Container gardens using wicks

Container gardens can also be created using wicks and other waste materials, in order to reduce the frequency of watering. One model is the "the layered garden", which is constructed by selecting some containers with no drainage holes in the bottom. Drainage holes two or more inches up the sides are made. A piece of cloth is laid across the bottom extending up one or more sides. Cloth made from man-made fibers work much better in the long term because they do not decompose. Microorganisms will attack natural fabrics such as cotton or wool, causing them to rot and disappear within one or two growing seasons. Roughly an inch of for example Styrofoam packing "peanuts" are placed on the cloth, then the cloth left extending up the sides are folded over onto the "peanuts". It may cover all of the "peanuts" or just part of them. Then another piece of cloth is placed across the "peanuts" so that they are completely covered. In order to assure that all pieces of cloth are continuously wet, there should be a considerable area of contact between any piece of cloth and one or more of the other pieces. The close contact is important because water being wicked (drawn up) from the pool at the bottom must be transferred from one piece of cloth to another until it reaches the top.

When the container is about a third full, regular or organic fertilizer is sprinkled on top the cloth. Another inch or so of "peanuts" added and then sprinkled with more of the fertilizer. After filling to the top once again fertilizer is added. Now transplants can be placed directly onto the bed. The pieces of cloth and "peanuts" can be moved, holes cut in the cloth, or whatever needs to be done to get the root ball into the unusual "planting mix." Good initial contact between the root ball and the cloth is essential. Small pieces of cloth can be placed around the root ball if necessary to achieve this close contact. Mulch, for example wood chips, grass clippings or rice hulls, can be placed on top to keep the sun and wind from drying out the cloth and causing an accumulation of salts near the top (from salts in the irrigation water and from added nutrients).

The container should be well watered from the top with a solution of hydroponic (i.e. soluble) fertilizer or a manure tea. This is to be continued until enough water is added that it starts to drain from the holes on the side of the container. As the plants continue to grow water without nutrients can sometimes be added. As this is done some of the dissolved nutrients are washed towards the bottom of the container. As the roots pull water from the cloth the nutrients will start to move back up as capillary action pulls the water back to the top. If watering takes place every day, or if it rains every day, and the cloth never dried out, the nutrients do not get a chance to cycle back to the top. After a lot of rain, even though the reservoir may be full and the cloth is surely wet, enough water with soluble nutrients must be added to assure that the roots will be surrounded with everything they need for good growth. Ideally the container will alternate from having a full reservoir of water and nutrients to having the reservoir nearly empty (http://www.echonet.org/content/urbanGardening/773).

A second model is building a container garden with a water reservoir. A water container is placed in the growing container. A small portion of the growing medium should be in permanent contact with the water reservoir. A perforated tube filled with potting soil and placed between the two containers, will act as a wick that transports water from the reservoir to the roots. A simple overflow hole separates the water reservoir from the growing mix, ensuring adequate air to the roots at all times (Alternatives and the Rooftop garden Project, 2008. For instructions on its construction: see Annex 2).

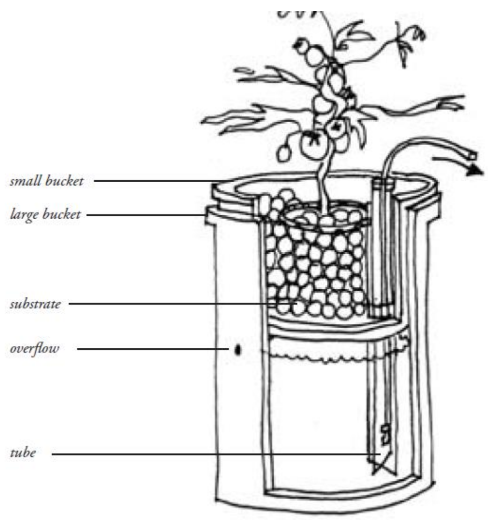


Container with water reservoir (Alternatives and the Rooftop Garden Project, 2008)

3.1.4.5 Constructing hydroponic gardens

In hydroponic agriculture, roots develop in a nutrient solution made from soluble elements that are directly available to the plant. These fertilisers are in general of synthetic origin, although some organic –but generally expansive- fertilisers are currently available. The potential of this technique is its high-yield potential and the fact that it optimised water. However it requires energy, specialised inputs and technical knowledge. Hydroponic gardening is generally done in a controlled environment: green house, cultivating room, shade structure. The Alternatives and Rooftop garden Project developed a popular "hydroponic grower" that can be built using recycled materials and uses an air pump rather than a more costly water pump.

The hydroponic grower container takes the form of a bucket with inert substrate suspended over a reservoir of nutrient solution. A small aquarium pump will force air into a tube that is submerged in the solution. When bubbles come up they will transport small nutrient solutions to the surface. The solution will percolate through the substrate, feeding the plant with water and nutrients before returning to the reservoir. Annex 3- copied from the Guide to setting up your own Edible Rooftop garden (Alternatives and the Rooftop garden Project, 2008; pages 36-37) gives a detailed description of how to construct such hydroponic growing container.



A hydroponic growing container (Alternatives and the Rooftop garden Project, 2008)

3.1.5 Choice of plants and (climate smart) production techniques

The selection of plants depends on the local climate, location of the roof, used rooftop agriculture system and growing medium, and household food demand. However there are some general principles that apply, especially if a climate change perspective is considered. Plants should be:

- drought resistant or tolerating low-water conditions, in order to limit use of water, limit energy use for getting water up the roof and adjusting to drier growing conditions (small beds),
- heat tolerant and wind resistant, to adapt to growing conditions on a roof,
- as indigenous and endemic as possible, as these are often best adapted to local climates, and help to attract local populations of insects and birds,
- attracting butterflies and other insects to improve biodiversity and fertilisation. This can be done by selecting plants that grow and flower in different times of the year and thus always provide food and habitat for the insects,
- as much as possible grown from seeds collected locally (i.e. within 50km radius of the green roof habitat site), as plants more suited to local conditions are likely to require less maintenance (watering, pest control etc.), and have a greater chance of survival. This also reduces the carbon footprint of the plants used, and maintains the genetic composition of the local species populations,
- attractive to the eye. This can be done by using a variety of plant mass, texture and colour and choose plants that grow and flower in various periods of the year,
- grown in a wide diversity– the greater the diversity of plants, the greater the variety of birds and insects attracted to the roof. Plant diversity also increases the chance of year round plant cover as some species may die off seasonally or under certain conditions, while others survive. Plant diversity also contributes to a healthy and varied diet (use of medicinal plants and herbs can be promoted as they are often very suitable for growing in shallow beds) and reduces risks of pests and diseases,
- chosen for their potential to maximise carbon sequestration and capturing of particulate matter. Very little is known about the carbon sequestration potential of different species, but growing small tree species and non-food plants that ensure permanent cover will increase this potential,
- grown intensively and providing as much as possible a permanent roof cover, in order to increase impacts on rainwater run-off and urban heat island (a minimum of 75% of the roof has to be covered with soil/vegetation to have any measurable impacts on UHI/energy sue and storm-water drainage), reduction of air pollution maximise food production and improved biodiversity, etc. Favour food plants with high yield that take up less space to optimise available resources (e.g. lettuce, tomatoes, herbs, peppers might be favoured over broccoli, cabbage, corn). Dwarf varieties of many plants and even fruit trees can be used (adapted from van Niekerk et al 2011).

Intensive use of rooftop space (Kesbewa- Sri Lanka)

Plant selection of course also depends on the type of roof top garden system chosen:

Shallow beds and container gardens systems	Less than 15cm of growing media	Drought tolerant herbs, strawberries, leafy greens
	15 - 30cm of growing media	Above mentioned plants + chives, lavender, sunflowers, time, cilantro, lemongrass, sage, tomatoes
	30cm + of growing media	Above mentioned plants + kale, carrots, potatoes, blueberry bushes, raspberries, gooseberries, boysenberry or even small fruit trees
Hydroponic systems	-	Cucumbers, tomatoes, eggplants, peppers, leafy greens

Examples of suitable plants for different rooftop garden systems (Quesnel et al, 2011)

As for plant choice, similar considerations can be drawn up for the choice and selection of production techniques. Application of the following "climate-smart", production techniques are recommended:

- use as much as possible locally available and waste materials , while taking into account the durability and origin of support structures and materials used. Use can be made of recycled materials for edging and containers. For edging wood is a light material, often locally available, low-cost, but needs to be replaced regularly. Aluminium or concrete are more expanse, have a larger carbon footprint, while concrete can be very heavy,
- practise mulching (protecting the soil by adding a layer of organic matter –dead leaves, cocoa shells, wood chips, straw or cardboard) and shading in order to reduce evapotranspiration and enhance moisture availability for the plants,
- reduce water loss by watering early in the morning or late afternoon,
- include water absorbing media, such as vermiculite in the growing medium to hold water longer,
- plant larger plants along the edges to act as wind break and reduce the drying effects of the wind,

Left: Use of shading in Amman-Jordan; Right: Optimising use of space in La Paz, Bolivia

- apply rainwater harvesting and use of kitchen water, in order to reduce use of and competition with drinking water. Combine different sources of water to have year-round supply. Water containing chemical detergents should not be used,

Rainwaterharvesting and use of kicthen water (Van Niekerk et al 2011)

- apply “low-space production techniques” and make optimal use of vertical space to increase plant production/m2

Use of low-space production technologies; optimum use of vertical growing space

- minimise use of external inputs and fertilisers: use compost made from household waste recycling, apply manure tea or other organic fertilizers, use organic pesticides (such as chilli or garlic) or use insect traps,

Manure or compost tea

"Manure tea" is made by soaking animal manure or compost in water (usually in a permeable bag or bucket) for several days. With the aid of microbial organisms, nutrients are released and dissolve the water. The dark, smelly liquid is used to fertilize the growing medium.

Composting: some tips

1. The compost site, bin or heap should be placed in a sunny area to ensure that there is always warmth.
2. The compost site or heap should be contained using a bin or cage made of wooden slats. There should be sufficient circulation of air.
3. Organic materials, such as kitchen scraps, left-over food, dry leaves, and weeds can be added to the compost heap.
4. It is important to ensure that there is sufficient water to keep contents moist (not wet).
5. The compost heap should be turned regularly to increase oxygen levels and to kill the seeds of weeds and fly larvae. In general, the heap should be turned when it gets cool inside (van Niekerk et al 2011).

- maximise both food production and the potential for income generation in order to reduce (household) vulnerability to food shortages/increased food prices and changes in income; to diversify income sources (and thus enhancing resilience of the producers) and in order to allow for making further investments (for example in rainwater harvesting technologies).

Sale of seedlings as in income generating activity

3.1.6 Investment and maintenance costs

Costs depend on structural adjustments needed to start the rooftop garden, type of support structures, containers and external inputs used; repairs and maintenance etcetera. Fertilisation and maintenance hydroponic systems require the highest investments and technical knowledge.

Costs have to be offset against possible reduced heating and cooling bills, savings made by growing ones' own food and income generated through eventual sales.

4 Policy measures and incentives

There are a wide variety of laws, bye/laws, ordinances and codes that may bear on green roofs and rooftop agriculture. Below an overview of relevant legislation is given for Durban, South Africa (Van Niekerk et al, 2011).

Legislation	Relevant Sections
Conservation of Agricultural Resources Act (43 of 1983)	• Classifies weeds and invader plants as either Category 1, 2 or 3 plants based on extent to which they colonise an area and displace indigenous plants. • Requires landowners to control Category 1, 2 and 3 plants.

Constitution of South Africa (108 of 1996)	• First legislation to introduce an "environmental right" into South African law.
	• Requires protection of the environment, for the benefit of present and future generations, through reasonable legislative and other measures that:
	  • Prevent pollution and ecological degradation.
	  • Promote conservation.
	  • Secure ecologically sustainable development and use of natural resources.

Environmental Conservation Act (73 of 1989)	• Regulates waste, noise, and activities which may have a detrimental impact on the environment. • However, the regulation of activities which may have a detrimental impact on the environment were repealed when the National Environmental Management Act (107 of 1998) came into effect.
eThekwini Municipality: Building Bylaws	• Regulates roof coverage, loading of buildings, and management of stormwater. • Most of these bylaws were repealed when the National Building Regulations and Buildings Standards Act (103 of 1977) came into effect.
eThekwini Municipality: Water Supply Bylaws.	• Regulates the installation of water systems, storage tanks, wasting of water, prevention of the pollution of water, and use of water from other sources other than the municipal supply.

Natal Nature Conservation Ordinance (15 of 1974)	• List plants which are specially protected and protected.
	• In terms of the Ordinance:
	  • It is an offence, punishable with a fine and/or imprisonment, to gather, export, import, purchase, sell, relocate, or translocate a specially protected species without a permit.
	  • It is an offence to gather, export, import, or sell a protected species without a permit. You may however buy a protected species from someone that has valid license to sell the plant.
	• No permit is required for collecting seeds or cuttings from unprotected species.

National Building Regulations and Buildings Standards Act (103 of 1977)	• Regulates construction of new buildings and alteration of existing buildings. • Sets minimum standards for buildings in terms of public safety, fire installations, and management of stormwater.
National Environmental Management Act (107 of 1998)	• Gives effect to the environmental rights contained in Constitution. • Sets out several environmental management principles which apply to all actions which effect the environment. • Regulates activities which may have a detrimental impact on the environment and for which prior Environmental Authorisation is required.
National Environmental Management: Biodiversity Act (10 of 2004)	• Was enacted to meet South Africa's obligations in terms of the 1992 Convention on Biological Diversity. • Represents a shift in the approach to species protection, acknowledging that in order to protect a particular species, such as Black-Head Dwarf Chameleon, its habitat and the ecosystem of which it is a part must also be protected. • Empowers the Minister of Environmental Affairs to publish a list of ecosystems that are threatened and in need of protection. The draft national list of Threatened Ecosystems was published in GNR 1477 (of 2009). • Also empowers the Minister of Environmental Affairs to publish a list of species which are considered to be critically endangered, endangered, vulnerable, or in need of protection. This list was published in GNR 150 (of 2007). • In terms of the Act, a permit is required for the collection, transport, and possession of any of the above listed species.

A city can promote and facilitate roof top gardening by modifying zoning and building codes or providing incentives for roof top gardens. Below two examples are given from Toronto (Canada) and Chicago.

4.1.1 The green roof bylaw of Toronto

On January 31, 2010, Toronto adopted a new green roof bylaw. New residential, commercial, and institutional buildings are required to have a certain percentage of green roof coverage (Nasr et al, 2010):

- this provision applies to all construction with a gross floor area of 2000 m^2 and over, and, for residential buildings with a height of 20 m and over.

- the coverage required begins at 20% for smaller buildings, and increases to a maximum of 60% as the gross floor area increases to 20.000 m^2 and over.

- industrial buildings are required to have approximately 10% coverage for 2011.

4.1.2 Promotion of green roof development in Chicago

Various policy tools that have been used to promote green roofs development could be adapted to promote rooftop agriculture. These include bylaws, density bonuses, incentive programs, grants, fees, and levies (usually related to rainwater runoff from buildings). Chicago provides the following incentives to promote green roofs (Kisner, 2008):

- $5 000 grants for residential or small commercial green roofs projects.
- a density bonus permitting developers to increase the number of units allowed on a piece of property if a rooftop garden is installed
- expedited permits (in 30 rather than a 100 days) for buildings with green roofs.

5 Case studies

5.1.1 An agricultural green roof in New York City

The Eagle Street Rooftop Farm is a 6000 square foot (= 560m²) intensive agricultural green roof atop a warehouse in Greenpoint, Brooklyn. The farm, which produces vegetables, is open to the public on Sunday market day when produce is being sold.

The Eagle Street Rooftop Farm (Novak A. et al. 2010)

The green roof can hold over 1.5 inches (= 3.8cm) of rain, providing a significant reduction in rainwater runoff. This captured water cools the warehouse below the roof leading to reduced cooling costs.

Option	The Eagle Street system using shallow beds	Details
Layers below plants	- growing medium - separation layer - retention layer - drainage layer - polyethylene	- 2 inches (= 5cm) depth - an irrigation layer with black plastic drip lines, using city tap water was de-installed, as the root systems of the crops rotated (e.g. carrots, microgreens, radishes) were not conducive to drip watering.
Loading weight of the growing medium	90 tonnes	- lifted onto the roof by crane - prior assessment of the carrying capacity of the roof by a building engineer
Growing medium	mixture of compost, rock particulates and shale	- retaining water, allowing for air circulation, lightweight - 4-7 inches (= 10-20 cm) depth
Installation costs	$10 per square foot = $110 per m² (Average installation costs for intensive green roof : $380 per m²)	Cheaper than most intensive green roof installations : - high accessibility (three story building, open expanse of roof) - recycled materials used

Technical aspects of The Eagle Street agricultural roof (adapted from Novak A. et al. 2010)

The Farm uses a wide diversity of rooftop acclimated varieties of produce Cucumbers, hot peppers, tomatoes, eggplants, spinach, radishes, kale, swiss chard, carrots, peas, beans, salad greens (lettuces, mustards, arugula) herbs (sage, tarragon, oregano, parsley, chives, cilantro, dill), and flowers (cosmos, zinnias, calendula, tobacco, daisys, hops), corn, and squash are grown.

The most botanically successful crops from a plant health and high yield perspective are hot peppers, cherry tomatoes, and sage. The least adaptive are winter/summer squash.

The green roof was financed by a Greenpoint–based sound stage company and was installed by a green roof design and installation specialist firm. An operating farmer works on the farm with trained interns, urban farming apprentices, and the farm hosts volunteers during the growing season.

5.1.2 A rooftop container garden in Chicago

Uncommon Ground is a restaurant with 650 square foot (= 60m²) container gardens in Devon, Chicago. Organic vegetables are used in the restaurant. Moreover, the restaurant uses drip irrigation, water catchment and domestic waste compost as organic fertilizer, and solar thermal panels to heat water.

The Uncommon Ground rooftop garden (Snyder D. et al. 2010)

Option	The Uncommon Ground rooftop container garden
Building's rehabilitation and installation	- reinforcing the foundation of the entire building with cement underpinnings and footings - removing the old wooden support beams and replacing them with steel beams - reinforced the brick load-bearing walls to hold steel beams - installing a roof top deck built with a recycled plastic and wood composite material - installing rain barrels to collect excess water of the roof - installing a programmable drip line irrigation system
The growing medium	organic mixture with : forest humus, sphagnum peat moss, perlite, earthworm castings, bat guano (sustainably harvested), humic acid (derived from Leonardite), oyster shell and dolomite lime (for pH adjustments).
Planter boxes	- 12 inches deep (= 30cm) boxes - made from steel and cedar (sustainable materials) - Trellising and cold frame allow to expand the growing season and the harvest - support structures suitable for plants
Earth boxes	New technology, supported by *The Growing Connection* grassroots project allows for a more efficient water use and a better nutrients absorption by plants. - 27 sub-irrigated planter boxes - 13.5 inches (= 34cm) deep

Technical aspects of The Uncommon Ground rooftop container garden (Snyder D. et al. 2010)

Several organic vegetables are grown:
- vegetables: varieties of sweet and hot peppers, varieties of eggplant, lettuces, heirloom tomatoes, radishes, beets, okra, spinach, fennel, mustard, bush beans, and shallots

- herbs: rosemary, thyme, chives, garlic chives, tarragon, sage, parsley, dill, mint, lavender, basil, anise hyssop
- ornamental plants: nasturtiums, calendula, marigolds, sunflowers, zinnias and morning glories.

Moreover, four beehives are installed. In 2008, two hives were installed and produced 4 pounds of honey.

5.1.3 Rooftop container gardens in Dakar, Senegal

The Rooftop Gardening Programme of the United Methodist Church promotes rooftop vegetable production in Senegal, especially in Dakar, where women's groups have already established some projects.

These projects use brick and wooden box beds, lightweight compost, and natural plant protection methods for growing crops under the semi-desert climatic conditions of Dakar. Other rooftop garden projects exist in Senegal, but they are considered too expensive and too technical for the majority of the population, who are poor and illiterate (Saydee and Ujereh, 2003).

Rooftop gardens in Dakar-Senegal

Two types of beds are used (Saydee and Ujereh, 2003):

- Brick bed : Bricks are laid to create a bed 80 cm wide and 10 cm high, in which plastic sheeting is laid before compost based soil. During the rainy season, a trough is created for drainage in the middle of the bed. The plastic sheeting is moved underneath the bottom brick layer. Soil is kept inside of the beds, while water can drain out. The problem of this method is that nutrients drain out of the soil along with the water. Therefore gardeners use "manure tea", prepared by soaking a sack of compost in water for 14 days, to water the plants.

- Wooden box bed: The beds measure 10 to 15 cm deep, 80 cm wide, and 120 cm long. The wooden bed is covered with plastic sheeting, and a draining tube is fitted into a hole drilled into a side of the box. During the rainy season, a channel is created between the soil and all four sides of the box, allowing water to flow easily through the drainage tube.

Many crops are grown, particularly those with fibrous roots because the space allowed by the box or brick frame can only support shallow fibrous root crops, for instance, tomato, hot pepper, eggplant. By increasing the volume in the beds, potatoes and other crops with larger roots can be grown.

5.1.4 Organic farm on a central kitchen roof in Mumbai, India

Mumbai Port Trust has developed an organic farm on the roof of its central kitchen. The roof is about 3000sq ft (279 m²).

The first initiative was an eco-friendly disposal of waste. Indeed, the central kitchen of the Mumbai Port Trust feeds approximately 3,000 employees daily, generating around 18 kg of organic waste every day. The terrace garden, which has over 150 plants, recycles 90 per cent of this waste.

More than 150 plants are grow on the roof garden, such as lush tulsi, mint, spinach, okra, brinjal and cherry tomatoes, guava, mangoes, coconuts, custard apples and chikoos (Purohit, 2011).

Mumbai Port Trust farm on a central kitchen roof, Mumbai-India

5.1.5 The eThekwini green roof pilot project

The Green Roof Pilot Project is part of eThekwini (Durban) Municipality's Municipal Climate Protection Programme. This Programme was initiated in 2004 and focused initially on understanding the vulnerability of the city to climate change impacts e.g. increased temperatures, changes in rainfall, rising sea levels and an increase in the severity and frequency of extreme weather events. This knowledge is being used to inform the development of appropriate adaptation and mitigation responses and strategies at the municipal and community level. A strong emphasis has been placed on identifying climate change adaptation projects that will improve the resilience of the city to future developmental, social and environmental challenges.

Green and vegetable rooftop garden in Durban-South Africa (Van Niekerk et al 2011)

A broad spectrum of vegetables were grown to test their suitability. This included eggplant, cabbage, tomato, cauliflower, lettuce, basil, spinach, nasturtium, green peppers, spring onion, chillies, and celery. With the exception of cabbage, cauliflower, lettuce, basil, nasturtium, and celery, all the other vegetables were grown successfully.

Scientific analyses are also being undertaken to assess:

- the temperature reduction that the green roof affords both the ambient atmosphere and the building itself (resulting in the reduction of the "heat island effect" and the reduction of air conditioner use respectively);
- the quantity and quality of the surface run-off from the roof; and the increase in biodiversity of the roof.

In the initial stages of the project, a simple system was set up to collect and measure storm water run-off. The system comprised rain gauges (placed on the north and south side of the roof) and two 250 litre barrels placed below each of the three rainwater outlets from the roof (six barrels in total). A dial stick was then used to measure the amount of rainwater collected in the drums. While this system could measure the effectiveness of the different areas of the green roof in reducing the amount of storm water run-off, it could not measure the effectiveness of the different areas of the green roof in reducing the velocity of the storm water run-off. EThekwini Municipality's Coastal, Storm water and Catchment Management Department then installed a more sophisticated system consisting of electronic tipping rain gauges (placed on the north and south side of the roof), water usage meters (placed on the north and south side of the roof), four water run-off loggers (three have been placed underneath different areas of the direct green roof system and one under the blank roof), and data loggers (situated on each of the water run-off loggers). This system was able to measure not only the amount of storm water run-off from the different areas of the green roof, but also the velocity of the storm water run-off. It was found that run-off from the green roof systems was significantly lower than the run-off from the blank roof.

Measuring rainfall run-off and energy use (Van Niekerk et al 2011)

Scientific analysis is also undertaken to measure the temperature reduction that the green roof affords both on the ambient atmosphere and in the building itself (resulting in the reduction of the "heat island effect" and the reduction of air conditioner use respectively. Temperature measurements to date show up to a 25°C difference between the green roof's ambient temperature and the control roof's ambient temperature ((http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Publications/Documents/Green%20Roof%20Pilot%20Project-%20information%20Pamphlet.pdf) and http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Publications/Documents/Green%20Roof%20Pilot%20project%20-%20poster.pdf)

5.1.6 Low space rooftop gardening in Bogota Colombia

Growing plants in containers, keeping small numbers of animals in cages, and vertical cultivation (cultivation towers, hanging plants, containers attached to the wall, use of trellises) are all technologies promoted by The Jardin Botanica and IPES/RUAF in Bogota, Colombia are promoting these technologies. Production technologies promoted are matched on the basis of the participants' eating habits (type of vegetables consumed); space availability (patio, rooftop); availability of low-cost growing structures or containers; growing conditions (the type of crops best grown in different containers) and taking into account aesthetic considerations. Crop production has reached up to 45 kg/yr/m2, providing a substantial part of the families' vegetable consumption.

Promotion of low-space technologies in Bogota, Colombia (IPES)

5.1.7 An hydroponic system in Montreal

Lufa Farms is a Montreal-based enterprise which develops innovative urban agriculture facilities. The first facility is a 31.000 square foot hyroponic greenhouse on the top of an office building. This roof grows 25 different crops and the yields are equivalent with a conventional farm 10 time its size. This system uses rainwater and drip irrigation. Farmers avoid use of any synthetic pesticides, herbicides or fungicides and rely on natural pest control.

The Lufa Farms hydroponic system in Montreal_Canada (Hage et al 2012)

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7 Annex 1: Instruction on how to construct a seedling table water reservoir (Alternatives and the Rooftop garden Project, 2008; pages 60-61)

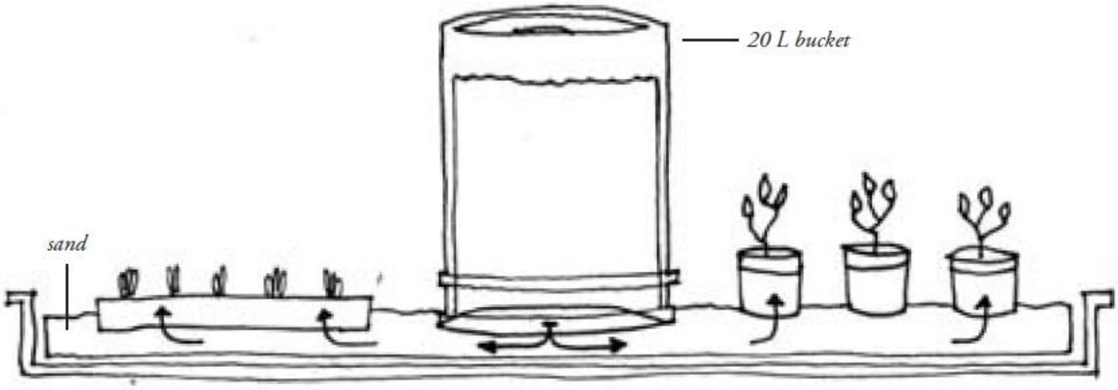
Materials

- 1 recycled 20 L (5 gal.) bucket with an air tight lid
- A ground space or raised table measuring 1 to 1.5 m2
- Wood boards from 3 to 10 cm wide (enough to frame the surface)
- Wood nails
- A flexible plastic sheet larger than the surface
- Pre-washed sand (enough to cover the surface with a 2 cm layer)
- A sheet of geo-textile for paving stones to cover the surface (optional and available in garden centers specialized in installing paving stones)

Equipment

- Level
- Saw
- Hammer
- Stapler
- Drill and ⅛ in. drill bit
- Measuring tape

1. Adjust the level of the surface that will be used as a seedling table by placing small wooden blocks under the legs. If the ground is not level, water will not be equally distributed.
2. Measure a square that is 1 to 1.5 m^2 on the surface.
3. Cut pieces of wood according to the desired dimensions and nail them together to form a frame. Put the frame on the surface.



Seedling table with water reservoir.

4. Line the frame with the plastic sheet, making sure that the bottom of the seedling table and the four interior sides of the frame are covered in plastic.
5. If you have a sheet of geo-textile, put it on top of the plastic sheet. The geo-textile will improve water circulation, but it is not necessary.
6. Spread 2 cm of pre-washed, moistened sand on the surface of the seedling table.
7. Staple the plastic to the frame.
8. Drill a ⅛ in. hole in the center of the bucket's lid.
9. Fill the bucket with water and close it so that it is air tight.
10. Turn the bucket upside down in the middle of the table and bury a small part of it in the sand to reduce the movement of air to the hole in the lid.
11. Check the pots and seed flats. For the best results, the growing mix should almost be coming out of the drainage holes.
12. Press the bottom of the pots and seed flats into the first millimeters of sand to guarantee contact between the table sand and the seedlings' growing mix via the drainage holes.
13. Fill bucket as needed. If the pots, seed flats or table sand ever dry out because you forget to fill the bucket, water them abundantly to reactivate circulation of water from the reservoir.

8 Annex 2: Instruction on how to construct a growing container with water reservoir (Alternatives and the Rooftop garden Project, 2008; pages 38-40)

Building Details for a Grower with Water Reservoir:

Percentage of the false bottom to be in contact with the reservoir: 5 to 15 %

Ideal (and maximum) length of the wick:	15 cm (20 cm)
Irrigation radius of the wick:	20 cm
Maximum distance between wicks:	40 cm

Air space (distance between the overflow and the false bottom): 1 to 3 cm

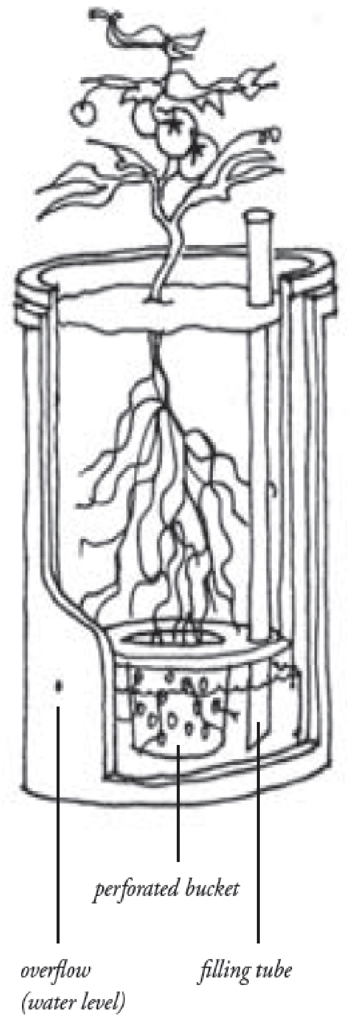
Materials

- 2 – 20 L (5 gal) buckets
- 1 large tube or rigid container approximately 10 cm (4in.) in diameter and 15 cm long (reused ABS or PVC tubes are ideal)
- 1 pipe, 1 in. in diameter and 60 cm long
- 3 tie wraps
- 12 L of potting soil
- 10 L of compost
- Organic fertilizer

Equipment

- Drill
- Marker
- Hand saw or jig-saw
- Utility knife

1. If necessary, cut the large 15 cm pipe using a saw.
2. Cut the end of the small tube at an angle.
3. Turn the bucket over, and center the large tube on the bucket's bottom.
4. Using a marker, draw the **interior** perimeter of the tube and three attachment points between the bottom of the bucket and the pipe.
5. At 2 cm from the edge of the bottom, draw the **exterior** edge of the small pipe.
6. Drill the attachment points in the pipe and to the bottom of the bucket.
7. Drill at least 20 drainage holes in the bottom of the bucket using the same bit.
8. Drill the two circles drawn with the marker using a flat wood bit and a hole saw. If you do not have these specialized bits, drill a ½ in. hole on the two circles drawn on the bottom of the bucket, and carefully cut them out using a utility knife or a jig-saw.
9. Attach the large pipe to the bucket using tie wraps.
10. Place the perforated bucket into the second bucket, and insert the angled end of the small pipe in the hole that was made for it.
11. Drill an overflow on the outside of the bucket at 1 cm below the bottom of the inside bucket.
12. Fill the large tube with wet potting soil, and solidly compact it.
13. Fill the grower with 10 L of potting soil and 10 L of compost. Add ⅔ cup



of dolomitic lime to the soil if you are placing a fruiting plant in the grower (tomatoes, peppers, etc.).

14. Mix 1/3 cup organic fertilizer in the first 10 to 15 cm of growing mix.
15. Transplant the vegetable plant of your choice and water the surface of the growing mix (do this only when you plant or if the growing mix dries over the summer because of a prolonged lack of water to the reserve).
16. Fill the water reservoir through the filling tube until the overflow spurts out water to avoid washing away nutrient elements.

9 Annex 3: Instruction on how to construct a growing container with water reservoir (Alternatives and the Rooftop garden Project, 2008; pages 36-37)

The air pump.

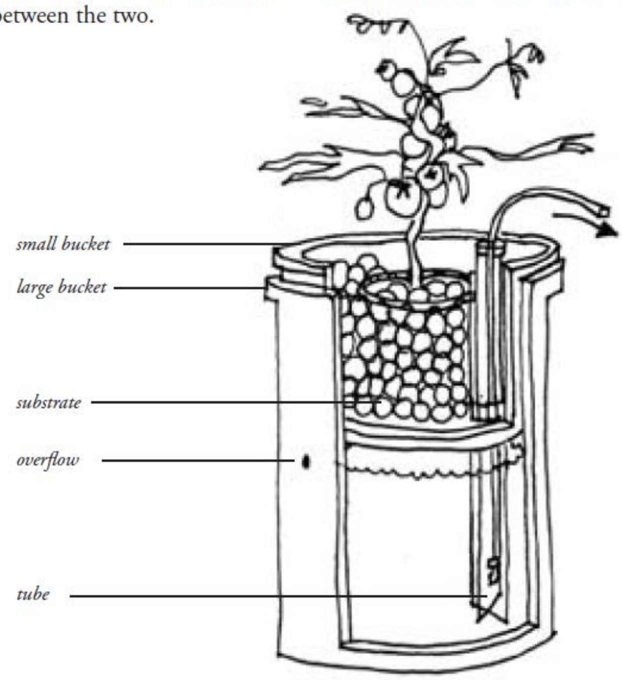
Materials

- 1 - 20 L (5 gal.) bucket
- 1 - 8 to 12 L (2 to 3 gal.) bucket that will sit in the larger one
- 1 aquarium air pump
- 1 to 2 m of air tube for the pump
- 1 rigid plastic tube, ¾ to 1 in. in diameter as long as the height of the assembled buckets
- 1 m of black or very dark, flexible plastic tube, ⅜ in. in diameter
- 1 - ⅜ in., tee fitting
- 8 to 12 L of inorganic and porous substrate (expanded clay pellets, volcanic rocks, etc.)
- 4 small tie wraps (zip ties)
- Hydroponic nutrient solution

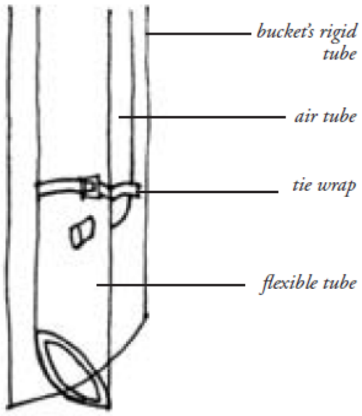
Equipment

- Drill
- Scissors
- Saw
- Utility knife

1. Drill a hole slightly smaller than the exterior diameter of the rigid plastic tube close to the edge of the bottom of the smaller bucket.
2. Drill 20 to 30 drainage holes using a ¼ in. bit in the bottom of the little bucket.
3. Sit the small bucket in the large bucket, and drill the overflow in the side of the large bucket 2 cm from the bottom to be sure there is an air space between the two.



4. Cut the rigid tube 3 cm shorter than the level of the assembled buckets.
5. Cut one end at an angle to ease movement of water, and insert the tube in the small bucket.
6. Insert the ⅜ in. flexible plastic tube in the central end of the tee fitting. Insert this tube in the rigid tube so that the fitting is sitting on the flat end (not the angled one). Cut the flexible tube at the level of the angled end, and remove it from the rigid tube.
7. Cut the end of the flexible tube at an angle. Carefully make a small hole for the air pump's tube at 2 cm above the angled end using a drill or a utility knife.
8. Cut the end of the air pump tube at an angle. Insert it into the hole cut in the flexible tube while keeping the interior passage of the flexible tube free.
9. Carefully attach the two tubes together at 2 cm from the hole with a tie-wrap, taking care not to block the movement of air in the tubes. Attach the tubes in three more areas and cut off the excess.
10. Place the assembled tubes in the rigid tube in the bucket. Insert a supple ¼ in. tube in both ends of the tee fitting so as to create a hoop a few centimeters smaller in diameter than the bucket.
11. Perforate it with irrigation holes measuring ⅛ in. at 5 cm intervals on the bottom side of the hoop, facing the bucket using a drill or a utility knife.
12. Fill the small bucket with pre-washed substrate and the water reservoir by watering the substrate at the surface. Connect the air tube to the air pump, and turn it on.
13. Carefully wash the roots of a plantlet in water in order to remove any trace of soil. Put it in the substrate in the center of the band so that the roots go toward the bottom of the small bucket.
14. Add soluble hydroponic fertilizers in the reservoir following the instructions.
15. To fill, prepare a nutrient solution in advance, and water the surface of the substrate before the reservoir contains less than 5 cm of liquid.
16. Change the nutrient solution, and clean the reservoir with a brush one to two times a month to prevent harmful accumulation of nutrients and pathogens.



Assembled tubes in the bucket's rigid tube.

For more instructions see the Guide to Setting Up Your Own Edible Rooftop Garden (Alternatives and the Rooftop Garden Project , 2008) www.rooftopgardens.ca