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Hydroponics in the Arid and Semi-Arid Lands (ASALs)

A COLLECTION OF BEST PRACTICES AND INSIGHTS

With case studies from: Turkana Basin Institute (TBI), Kakuma Kalobeyei refugee settlement (GIZ/SRHC project), Hydroponic Africa Limited (HAL), and the World Food Program (WFP)

Implemented by

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

PREFACE

Climate change and related increased climate variability is straining existing food production systems across Kenya, and especially in Arid and Semi Arid Lands (ASALs), which are already characterized by high temperatures and harsh environmental conditions with high levels of temporal and spatial variability.

Agriculture in ASALs has historically been practiced in limited regions with access to flood waters, which provide both nutrients and irrigation. Changes in population distribution, river dynamics and seasonality have placed increasing pressure on this and livestock based food production systems. Therefore complementary novel, climate smart, agricultural methods that maximize water efficiency and can withstand climate shocks could have huge potential in diversifying both income generation and food production in these historically marginalized regions.

Hydroponic agriculture is practiced globally and is increasing in prevalence in conditions where space is scarce or where environmental conditions are not conducive to traditional farming methods. Its application in ASALs could overcome challenges associated with poor soils, soil salinization, water demand and high temperatures that have plagued earlier externally driven agricultural efforts. Furthermore, hydroponic agriculture is well suited to provide access to nutritious crops that are largely unavailable, and in so doing could contribute to broader societal issues such as malnutrition.

Through this guide, we seek to share experience of the implementation of hydroponic agriculture in the ASALs of northern Kenya, in order to inform future adoption for both commercial and subsistence initiatives. The experience of GIZ, Hydroponics Africa, the World Food Program and the Turkana Basin Institute will be described, demonstrating the techniques used, the inputs required, the challenges faced, and potential for further development in this locally nascent practice. The overall intent is to explore the potential avenues of developing strategies to improve and sustain the feasibility of adopting hydroponic farming not only in the ASALs of Kenya but across the ASALs in other countries.

This handbook was developed by a diverse community of experts, with the financial support of the German Federal Ministry for Economic Cooperation and Development (BMZ) and the European Union (EU), through the international initiative Water and Energy for Food (WE4F). The handbook captures the outcomes of a partnership between WE4F and the Turkana Basin Institute (TBI) and the experience done by other institutions in the field of hydroponic agriculture in arid and semi arid lands.

CONTRIBUTIONS

This handbook was produced through the knowledge, experience, and hard work of a diverse community of experts based on the experience done with hydroponic agriculture in arid and semi arid lands. The main authors were Acacia Leakey and Kilian Blumenthal, coordinators of a project between the Turkana Basin Institute (TBI) and GIZ Water and Energy for Food (WE4F).

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Disclaimer

The information provided in this document is based on currently available literature and a collection of experiences done by various organisations involved in Hydroponic Projects in ASALs. Although every possible care has been taken in the production of this document, the authors, contributors and funding partners cannot accept any responsibility for the accuracy or correctness of the information provided nor for the consequences of its use or misuse.

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CHAPTER I

INTRODUCTION

This chapter provides basic background information on hydroponic agriculture, including how it can be leveraged to address food security and what hydroponic agriculture actually consists of – through a comparison with traditional soil based agriculture, by introducing the different types of growing systems and the different crops that can be produced in hydroponic farms.

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1.1 Why Hydroponic Agriculture?

The challenge of a changing climate dominates all discourse around food production systems. Increasing environmental variability directly results in worsened floods, more extreme droughts and higher temperatures, and indirectly impacts broader ecosystem functions. Agricultural practices must be resilient in the face of these challenges, while remaining productive within the limits of planetary boundaries.

Hydroponic agriculture, also referred to simply as "hydroponics" in this guide, is an efficient cultivation method which allows for a high level of environmental control. It is a form of soilless agriculture that uses different configurations to deliver nutrients and water to plant roots, usually in protected and controlled conditions. When compared to conventional farming methods, this results in less polluting surface runoff, reduced destruction of arable land, increased space and water efficiency and reduction in the use of chemical pesticides and herbicides.

In a changing climate hydroponic agriculture is a critical methodology of food production which is protected from climate shocks and can enable food production in diverse contexts with minimal environmental impact.

1.2 Comparison of Hydroponic Agriculture and Conventional Farming Methods.

The major difference between conventional farming methods and hydroponic agriculture is the absence of soil in the latter. This has two major implications, the first is that any nutrients required by crops must come directly from the nutrient solution used to irrigate crops. The second is that the water used in hydroponic systems is recycled, maintaining maximum water efficiency. The consequences of these and other differences are discussed below.

The benefits of hydroponic agriculture when compared to traditional farming methods include:

- High water efficiency due to recycling of water that is not taken up by plants.
- High space efficiency in systems where plants are grown in vertical systems.
- Systems with protective structures result in reduced incidence of pests.
- The highly controlled nature of hydroponic systems means that there are no weeds, and therefore no herbicides are required.
- The absence of soil means that there are no soil borne disease threats.
- Hydroponic agriculture does not result in land degradation, soil erosion, soil salinization or depletion of nutrients in soil.
- Due to the nature of water and nutrient delivery, and the structures used in most hydroponic systems, crops are somewhat protected from unfavorable weather and other environmental conditions.
- This removal from dependency on seasonality means that hydroponic agriculture systems are better suited to growing crops throughout the year.
- The nature of hydroponic systems means that food can be grown in otherwise non-arable locations, such as arid lands or urban environments.

The disadvantages of hydroponic agriculture when compared to traditional farming methods include:

- Depending on the type of the hydroponic farm, the system installation does usually have slightly elevated costs when compared to basic traditional farming methods.
- There is a limited range of crops that can be grown in hydroponic agriculture systems. This applies especially to calorific grains and some other key crops.
- When hydroponic systems are not well managed, they can fail more rapidly than other systems because they do not have any "cushion" of latent moisture or nutrients stored in soil.

1.3 Misconceptions about hydroponic farming.

As with all novel technological systems, there are misconceptions about hydroponic agriculture. This section addresses some of the most common misconceptions, discusses the validity of these assumptions and proposes the ways in which these challenges can be addressed.

Biological nutrients can be affordably produced from readily available ingredients.

"It is expensive to set up a hydroponic farm" – this can be true in that hydroponic farms usually require structures to deliver and recycle water and to hold growing media. However, these structures need not be prohibitively expensive, as they can often be made from relatively affordable materials. Additionally, any investments required in hydroponic farms should also be weighed against the potential income generated.

"Hydroponic farms are difficult and complicated to operate" – hydroponic farms can be very complicated, even relying on programmed automation that requires very technical skills. However, hydroponic setups can also be entirely manual, with no more technical expertise required than very basic traditional farming methods.

"Hydroponic farms require a lot of system maintenance" – this is true of all agricultural infrastructure. However, well designed and properly used systems will not have prohibitively expensive system maintenance costs.

"Hydroponic farming nutrients are complicated to use and hard to come by" – due to the nature of nutrient delivery through irrigated water, the nutrients in the system need to be readily available to the roots, unlike soil based systems where nutrients can continue to break down after application before being absorbed by roots. This is easily addressed through an understanding of the plants' nutritional requirements and the local water chemistry. Biological nutrients can be affordably produced from readily available ingredients.

"Consumers won't want to eat hydroponic produce" – this is not something we have experienced in practice. Hydroponically grown vegetables are healthy, and often have fewer blemishes due to the more controlled conditions with fewer pests.

"Hydroponic farming is not natural" – some plants grow hydroponically naturally, these include plants such as water hyacinth, which floats on the surface of lakes or rivers and extracts nutrients from the water.

As these points demonstrate, a large factor in misunderstanding of hydroponic farming is the anticipation of high levels of cost and complexity, which is largely a result of the wide breadth of types of hydroponic farming systems – and particularly the association of hydroponic agriculture only with high-tech, highly mechanized and controlled systems often used in high-value markets.

1.4 Types of Hydroponic Agriculture Systems

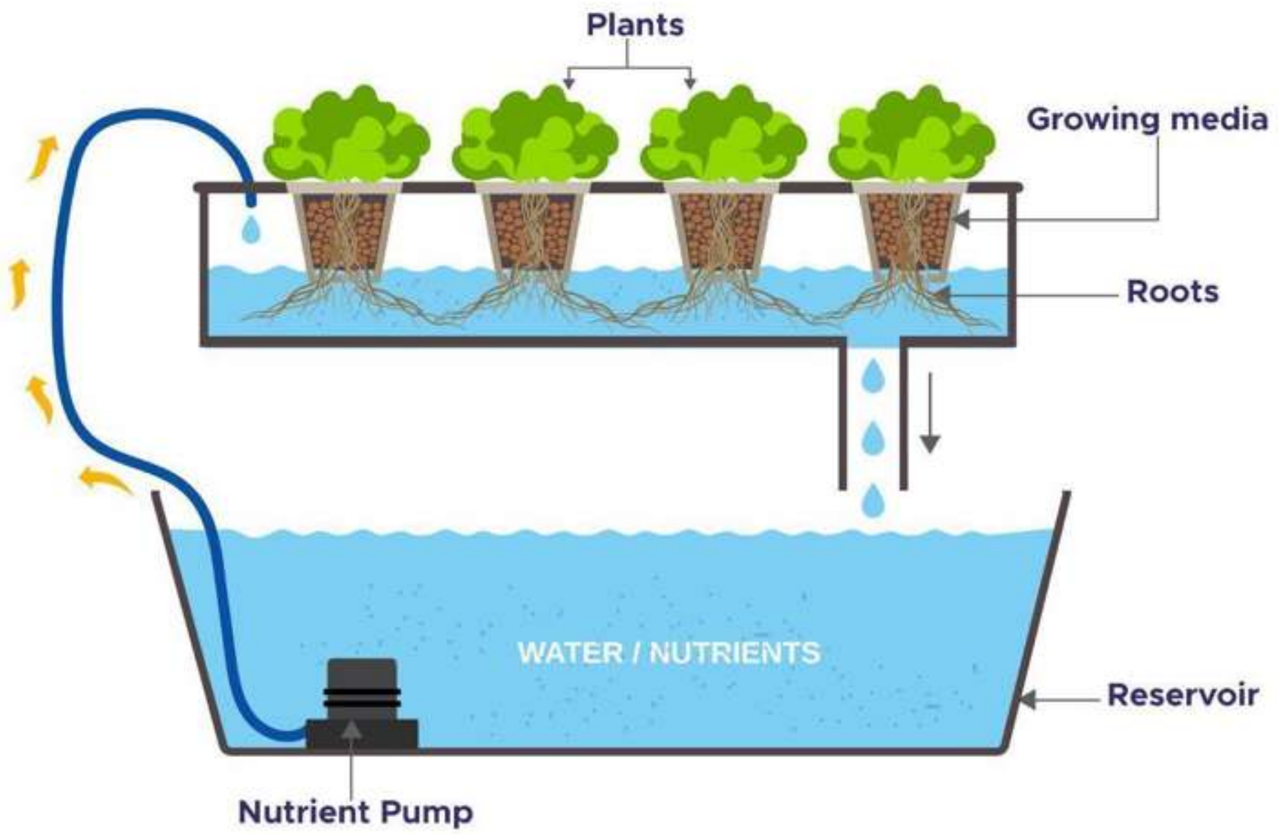
The main objective of a hydroponic system is to deliver a nutrient solution to the root zone of the plant in order to enable growth while ensuring the plant has the appropriate light, air circulation and temperature. There are many configurations of hydroponic systems, the main ones of relevance to applications in ASALs are discussed below. There are also combinations of different configurations, and adaptations of configurations based on factors such as local conditions and material availability so this list is not exhaustive.

In order to introduce types of hydroponic systems, some key terms must be introduced and defined:

External structure *- this is the framework around the rest of the farm, and may include large structures such as a greenhouse, or smaller structures such as a simple fence. Media - this is the substance that provides structure for roots to grow and become established.*

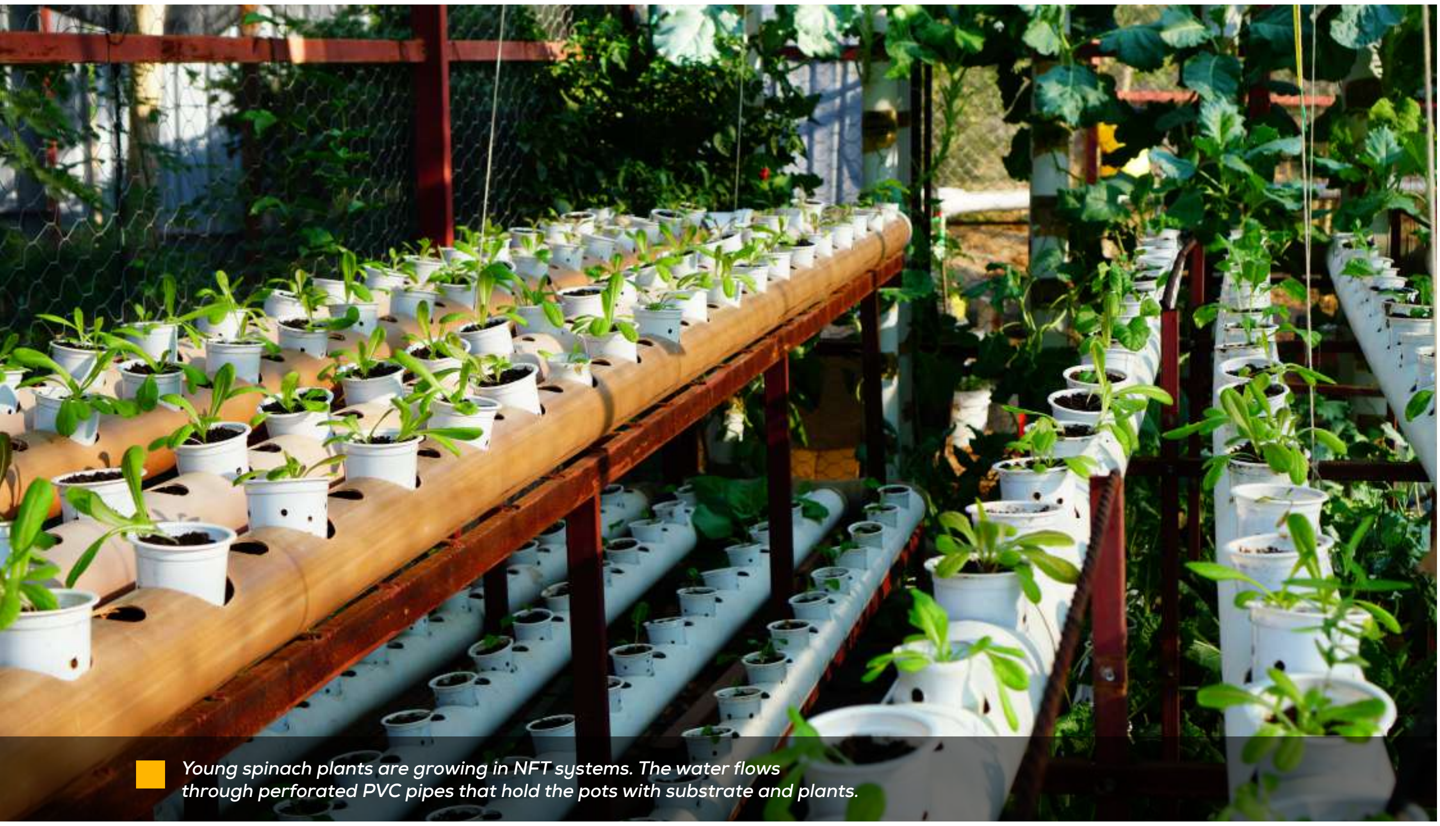
Nutrient Solution - *this is a mixture of water and nutrients, and is the main mechanism of delivery of both to the plants' roots. Reservoir - this contains the nutrient solution, and is used for mixing, storing and recycling nutrient solution.*

Nutrient Film Technique (NFT)



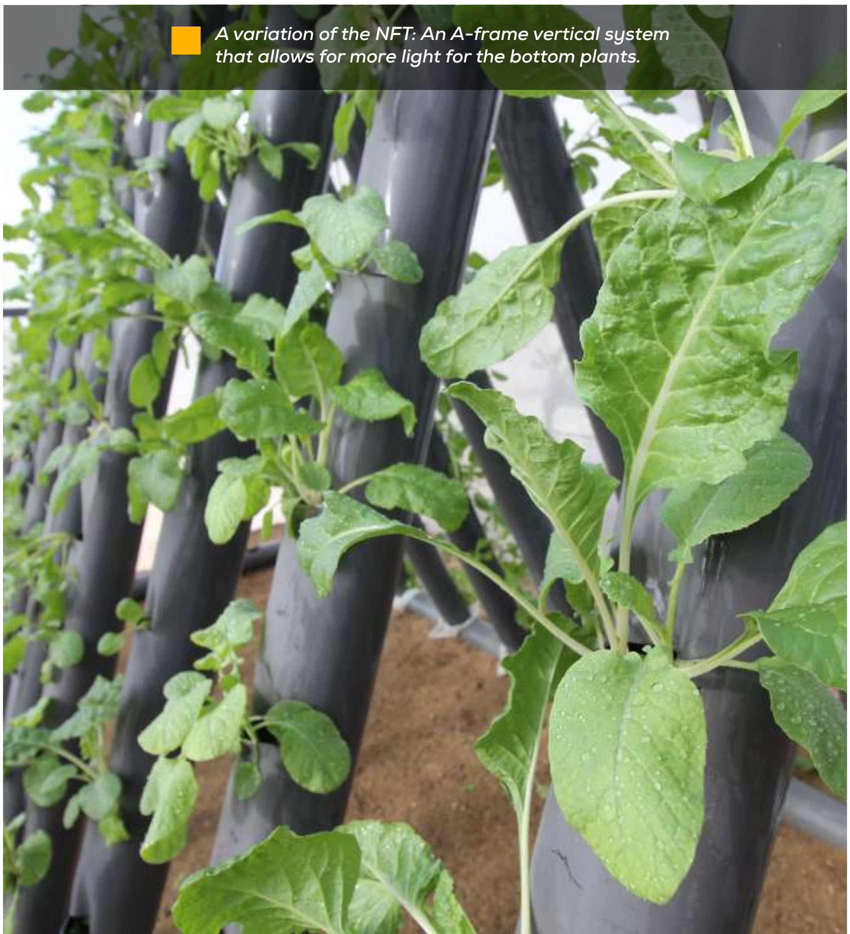
The basic setup of an NFT - system. Nutrient-enriched water circulates through horizontal pipes.

NFT systems are comprised of horizontal pipes which hold containers of media in which plants are grown. The roots of the plants access water which flows through the pipes, and when healthy grow together to form a mat or film in the horizontal pipes. Water is flooded through the pipes, and can either be continuously circulated or held in place before being recycled to the reservoir tank. NFT systems are best suited for shallow rooted leafy vegetables.



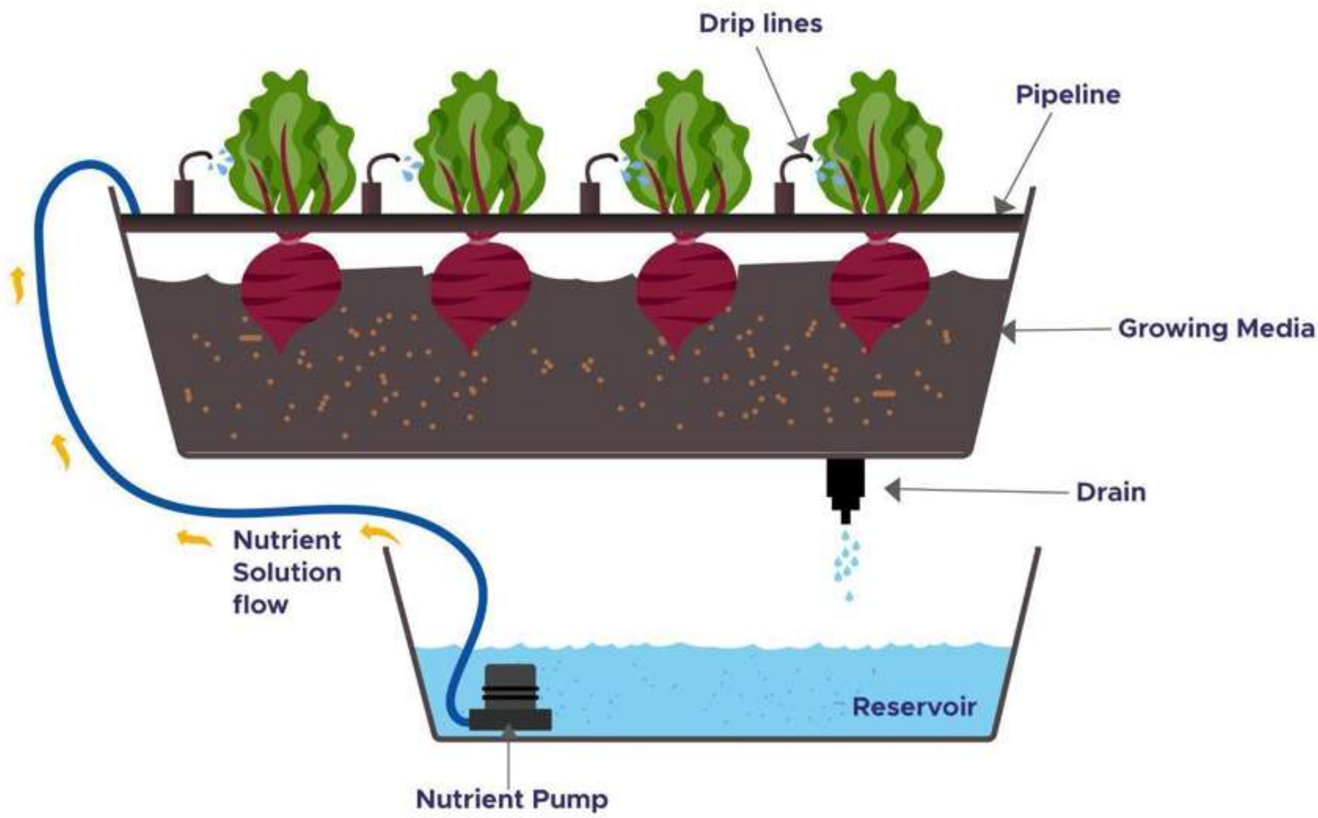
Young spinach plants are growing in NFT systems. The water flows through perforated PVC pipes that hold the pots with substrate and plants.

NFT systems, and vertical growing systems (discussed below) can be arranged in different ways, depending on factors such as the availability of space or the preference of the farmer. Adaptations might include A-frame systems where NFT pipes are designed to flow into each other, these maximize space. Or A-frame vertical systems where the tilt allows for more light for the bottom plants.



A variation of the NFT: An A-frame vertical system that allows for more light for the bottom plants.

Drip Irrigated Troughs

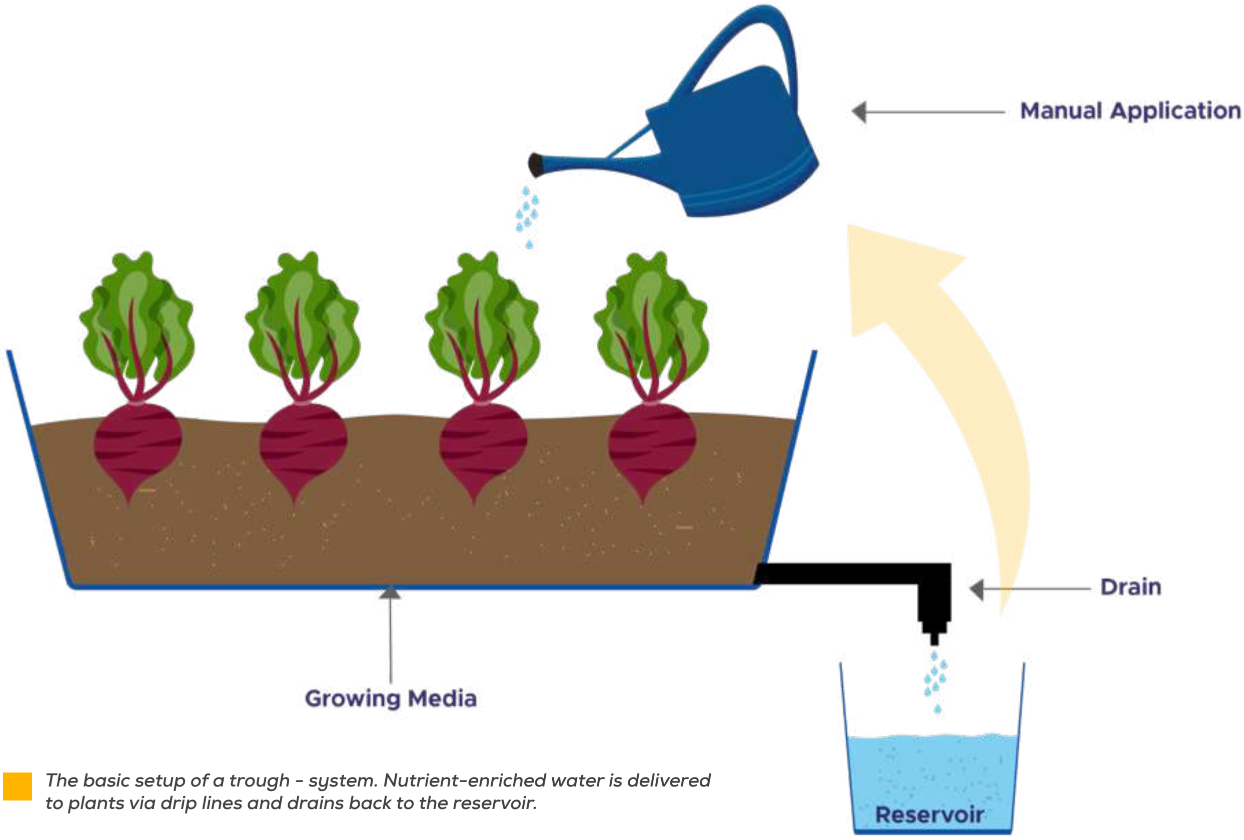


The basic setup of a trough - system. Nutrient-enriched water is delivered to plants via drip lines and drains back to the reservoir.

Trough systems are comprised of impermeable containers of media that hold plants, which are irrigated usually with drip lines. These systems are usually ground based, the nutrient solution is delivered through drip lines or in some cases manually, before recirculating to the reservoir tank. Trough systems are best suited to relatively deep rooted systems, such as tomatoes, and some tubers, such as beetroot.

The trough system is well suited for plants with deeper roots - chillies, beetroot, tomatoes and more.

Manual irrigated troughs



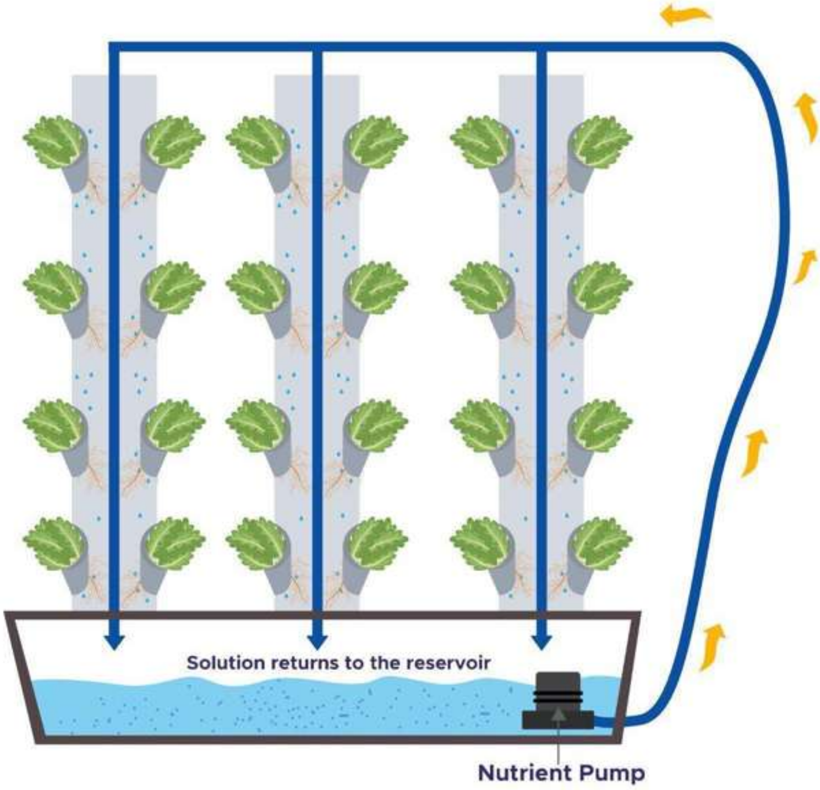
The basic setup of a trough - system. Nutrient-enriched water is delivered to plants via drip lines and drains back to the reservoir.

A simplified variation of the drip irrigated troughs are trough-systems that are manually watered. Instead of a drip system the user would water the troughs once or twice a day.

The water circulates through the substrate and root system back into a bucket located beneath from where it can be used for the next watering, removing the need for an electric pumping system.

The setup of a manual trough system. After watering, the recirculated water is captured in buckets and can be used for the next watering.

Vertical Growing Systems



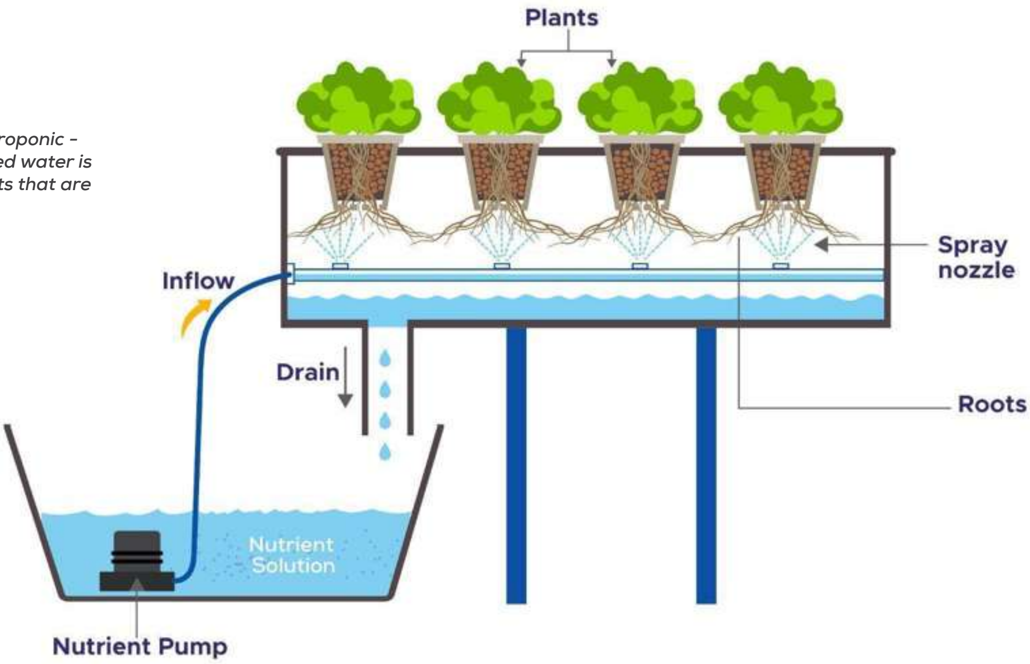
The basic setup of a Vertical Growing System. Nutrient-enriched water is pumped to the top of vertical pipes, in which it moves to the bottom and feeds the plants.

Vertical systems consist of pipes or other containers which hold media in which plants grow. These systems are usually irrigated by releasing nutrient solution at the top of the system, and allowing gravity to move it through the whole system. This configuration is especially space efficient, and is well suited to shallow to moderately deeply rooted plants such as spinach and kales.

Vertical systems are space efficient and well suited for shallow to moderately deeply rooted plants.

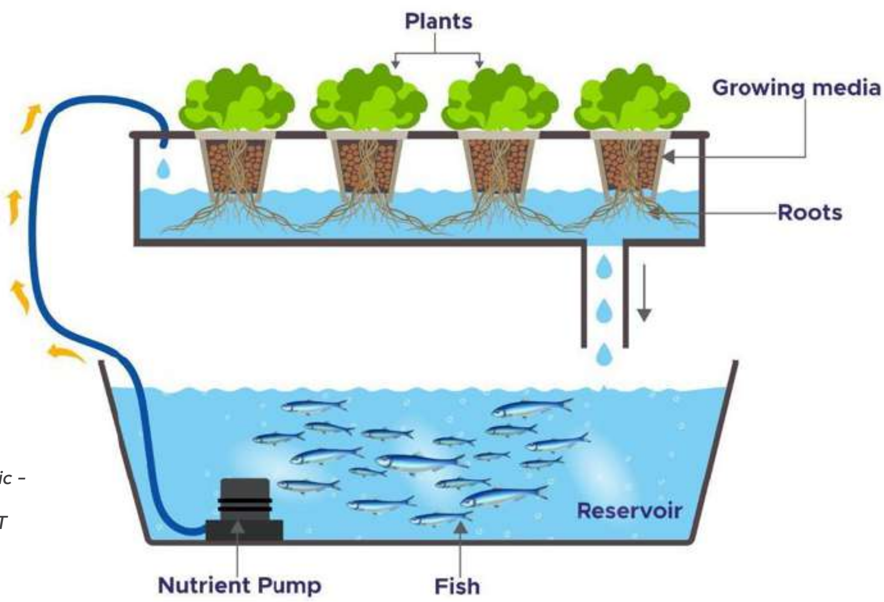
Aeroponics

The basic setup of an aeroponic - system. Nutrient-enriched water is sprayed to the plant roots that are suspended in air.



Aeroponic agriculture systems deliver nutrient solution in the form of mist on the roots, which are suspended from a growing structure. This system is ordinarily more technologically complex.

Aquaponics



The basic setup of an aquaponic - system. It combines a hydroponic system such as NFT with the cultivation of fish.

Aquaponic systems combine the cultivation of crops hydroponically with fish farming. In these systems, plants can either have direct root access to a fish pond or water container, or they can be grown hydroponically, utilizing the fish pond as a nutrient-rich reservoir.

One key advantage of this setup is that fish waste serves as a natural fertilizer for the plants' roots, promoting their growth and health. There are many other types of hydroponic systems that are not described here, these include Capillary Wick Systems and Ebb and Flow Systems among others.

1.5 Types of Plants Grown in Hydroponic Agriculture

This section reviews the different types of plants grown in hydroponic agriculture systems. In general, it is possible to grow almost any plant in the right hydroponic system with the requisite setup, however, it may not be practical or economical to do so. This section divides crops into three categories; leafy greens, fruiting plants and tubers, the focus is put on the crops that have been most productive in Hydroponic Agriculture in ASALs so far. The hydroponic production of fodder crops is also reviewed.

The crops that are most extensively grown hydroponically globally are leafy greens such as lettuce, chard, herbs and kales. Hydroponically grown leafy greens can be very high quality without the use of herbicides or pesticides.

Fruiting plants are also widely grown, especially tomatoes, cucumbers, capsicum peppers, aubergines, pumpkins and fruits such as berries.

These are generally slightly more complicated to grow as the nutritional requirements of the plants change through transition from vegetative, to flowering, to fruiting stages. These crops can be very profitable.

Tubers and bulb crops are not as widely grown in hydroponic farms, however some varieties can grow very well, and these include beetroots, sweet potatoes and onions.

Hydroponic Agriculture Fodder Crops

In order to meet the demand for fodder, especially in arid areas, fodder can be grown hydroponically by germinating cereals such as barley, maize and alfalfa. This process results in shoots that can be consumed by livestock within a short period of time, usually less than 2 weeks. The resultant product is very high in fibre, starch, vitamins and minerals. Hydroponically grown fodder can be grown in very basic systems with shallow troughs in which grain is kept hydrated.

Hydroponically grown fodder from cereal grains. The fodder has higher weight and nutritional value than the grains.

CHAPTER II

HYDROPONIC AGRICULTURE IN ASALs

02

2.1 Introduction

ASALs are defined by their aridity, with consistently high temperatures and low rainfall with a propensity for drought. The annual rainfall ranges between 150 mm to 550 mm for arid areas and between 550 mm to 850 mm for semi-arid areas per year (Government of the Republic of Kenya, 2012). Temperatures in arid areas are high throughout the year, with high rates of evapo-transpiration. This is the degree to which a climate lacks effective and life-promoting moisture. These environmentally dynamic environments make up 89% of Kenya's land mass, and are home to 39% of Kenya's population.[1]

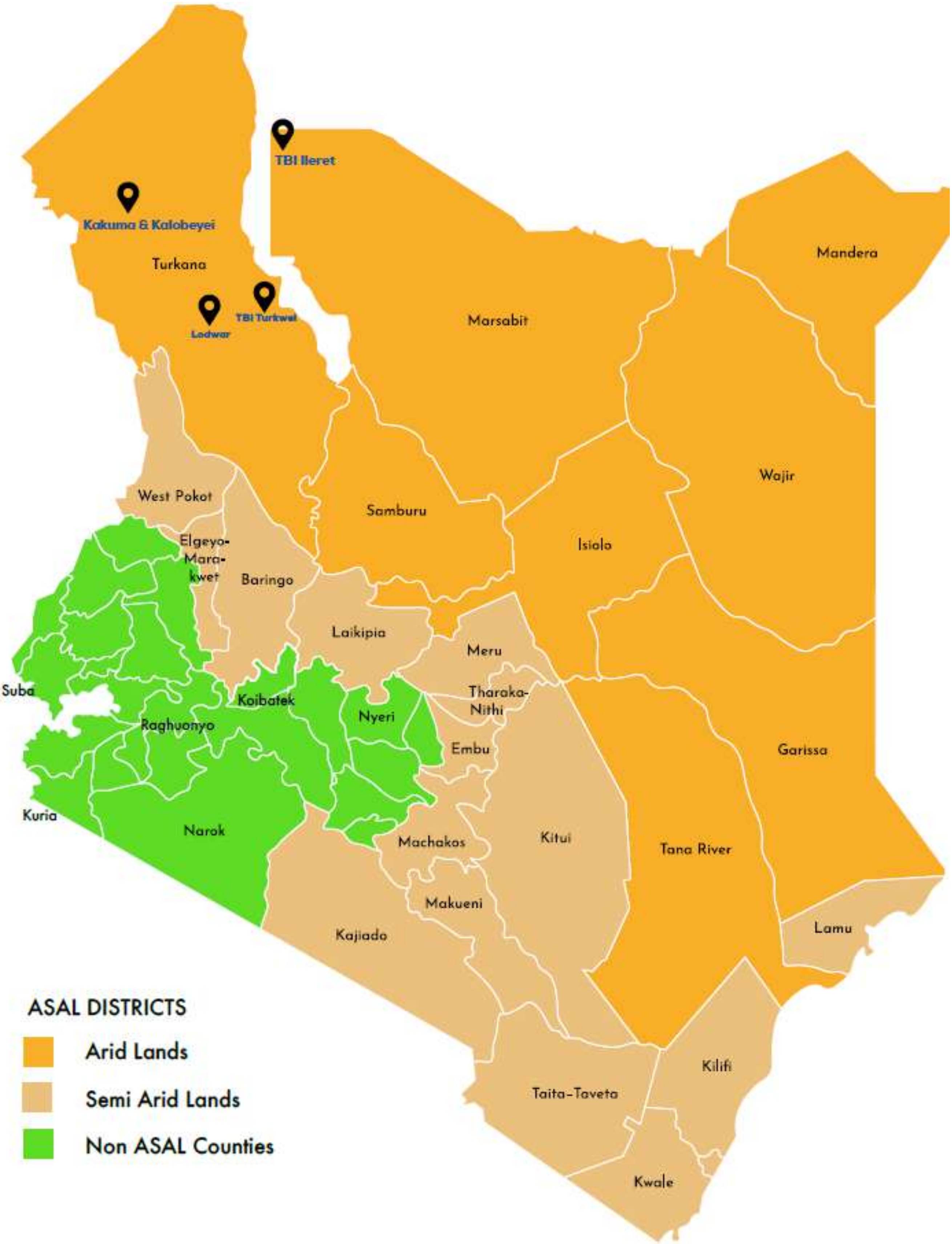
89%

The environmentally dynamic environments make up 89% of Kenya's land mass, and are home to 39% of Kenya's population .

The communities in ASALs rely on an array of livelihood systems including rearing livestock, fishing and farming, all of which are heavily dependent on ecosystem services and are therefore particularly vulnerable to changes in climate. In this chapter the characteristics of ASALs of most significance to hydroponic farming in Kenya are discussed, and why hydroponic farming has particular relevance in these settings, and in ASALs of other countries.

[1] https://www.asals.go.ke/

Arid and Semi Arid Lands (ASALs) are characterized by sparse vegetation and limited water availability; nevertheless, livestock production frequently serves as a primary means of livelihood.



Arid and Semi Arid Lands make up the biggest part of Kenya's land mass and counties.

2.2 Characteristics of ASALs

The ASAL counties of Kenya have shared characteristics that are critical to understanding the potential performance and impact of successful hydroponic agriculture, especially on historically marginalised communities. Some of the most relevant characteristics are listed below, these are highlighted to identify the policy and development relevance of hydroponic agriculture, what challenges might be faced in the implementation of new initiatives and also the scope for significant beneficial impact.

History

Much of the arid lands of northern Kenya were neglected by successive colonial and postcolonial governments, leading to limited infrastructural and economic development. The process of reversing this marginalisation began in earnest with devolution brought about by Kenya's new constitution, but the legacy of decades of lack of investment is still evident through relatively low literacy levels, especially among women, and limited infrastructure. This has implications on the implementation and impact of hydroponic agriculture in these areas.

Geography

The ASALs cover a huge area, with very large counties, for example Turkana and Marsabit counties are the largest and second largest in Kenya at around 70,000 km2 each. This has implications for infrastructure and logistics, with relatively limited road networks and connections to markets, and especially to the large food producing regions in the south and centre of the country. The decentralised production of fresh produce, particularly perishable items, could meet demand that is difficult to serve due to these logistical constraints.

1 Million

ASALs have rapidly growing and very youthful populations, for example the population of Turkana county surpassed 1 million people in 2023.

Demographics

ASALs have rapidly growing and very youthful populations, for example the population of Turkana county surpassed 1 million people in 2023.

These growing populations are beginning to shift from being almost all rural, to having large urban and peri urban populations through the growth of existing urban centres and the development of rural villages around key infrastructure. Therefore, the provision of both new high productivity food systems and jobs is critical to meeting the growing needs of the region.

Additionally, ASALs host a large number of refugees, with Turkana County's Kakuma Refugee Camp and Kalobeyei Settlement exceeding a quarter of a million people. These communities are often in high density settings, with a high demand for fresh produce.

Climate

By definition, rainfall in arid lands is limited and temperatures are high, however an additional key environmental factor which is often overlooked is the high level of spatial and temporal variability. The food production systems of flood irrigation agriculture, mobile livestock rearing and fishing are well suited to these conditions and are adaptable to interseasonal variation. As new less flexible modes of living in ASALs emerge in villages and urban areas, new stable and predictable food production systems are required to meet growing demands.

Soils

Soils in the ASALs are typically thin, lacking distinct soil horizons, which limits their ability to support vegetation and organic matter buildup. ASAL soils tend to have low clay content because mineral breakdown is limited due to arid conditions. Additionally, they often have a high salt content, making them infertile and impermeable. This saltiness hinders air penetration, crucial for healthy plant growth. As a result, ASAL soils present significant challenges for agriculture and plant life in these arid environments, creating a niche for hydroponics as a soilless form of agriculture.

[2] https://turkana.go.ke/download/final-turkana-cidp-iii-2023-2027/

2.3 Hydroponic Agriculture in ASALs

Potential Impact of Hydroponic Agriculture in ASALs

The potential beneficial impact of hydroponic agriculture has been alluded to throughout sections of this publication. Here are listed the specific direct benefits that successful hydroponic agriculture could have.

- Improved nutrition – malnutrition is a chronic issue in both urban and rural communities in ASALs. Hydroponically grown fresh produce could provide one solution to help alleviate this, especially in urban areas where undernutrition due to unbalanced diets is increasingly a challenge.
- Income generation and empowerment – hydroponics could provide consistent income generation, especially for women and youth, in urbanising contexts where other forms of employment are limited.
- Environmentally sensitive agriculture – hydroponic systems are partly isolated from environmental systems, especially rainfall and soil. As such, they are less vulnerable to environmental shocks such as extreme droughts, while also limiting the potential for negative impacts which have been associated with soil based agriculture, such as soil salinization.
- Local, distributed food production – Hydroponic agriculture can offer a new solution to provide perishable vegetables and fruits throughout the year without necessitating expensive transport or logistics.

Hydroponic System Design for ASAL Suitability

The field of hydroponic agriculture is immense and there is a great diversity of practice of hydroponic agriculture across the world, from basements in large cities to massive purpose built farms. Here, some of the considerations relevant to working specifically in ASALs are highlighted, especially in the type of systems employed, the types of crops grown and how best to adapt to the often harsh environmental conditions.

Types of hydroponic agriculture systems best suited to arid conditions. Troughs, NFT and vertical systems can all perform well in arid conditions with the right management. However, it was found that troughs are particularly well adapted, both to the climatic conditions and to the level of technical capacity of available labour.

Crops best suited to environmental conditions.

All plants that are grown in arid conditions need to be reasonably resilient to heat, especially as the temperature can rise to above 40°C. It was found that in these conditions popular leafy vegetables such as chard, kales and amaranthus can thrive. Fruiting vegetables such as tomatoes, capsicum peppers and okra also grow well, and some tuberous vegetables such as beetroot will also grow. In addition to the temperature, the low humidity and pests that thrive in these conditions should be considered as well, these all need specialised management techniques, discussed below.

Managing arid conditions.

Hydroponic farming can be highly technical, at this end of the spectrum, farms may be completely isolated from the outside environment through containerization with specially controlled air temperature, humidity, light levels and more. The hydroponic agriculture discussed here is at the lower end of the spectrum, with smaller investments, and as such it is more exposed to weather extremes. In ASALs, most farm environmental controls consist of some form of shading, to reduce the impact of harsh direct sunlight. In the case study farms shade nets with 60 – 75% were used. Additional measures taken to create a more favourable growing climate include windbreaks and wetting – the process of increasing the moisture available for evaporation in a growing space, both to reduce dust and to reduce the temperature through evaporative cooling.

CHAPTER III

FACTORS TO CONSIDER BEFORE STARTING A HYDROPONIC FARM

The aim of this chapter is to enable prospective hydroponic farmers to maximize their investments before even starting, by providing a summary of the factors that influence how, when, where and what hydroponic farming technologies should be used. This section covers the site selection, the human capital, and the input requirements required for hydroponic farming.

03

The hydroponic farm in construction. After clearing and levelling the ground, the greenhouse structures are set up.

3.1 Site Selection

One of the major advantages of hydroponic farms is that they can be installed almost anywhere, provided the appropriate technology and investment is available. However, when capital for investment in equipment and structures is limited the site should be carefully considered to ensure that the farm is as successful as possible with the available resources. Listed here are some of the key environmental, physical and economic factors to consider, some fundamental factors such as water are discussed in further sections.

Space: One of the greatest advantages of hydroponic agriculture is the capacity to grow crops using vertical space, maximizing the plants, and therefore productivity, per unit area. This however required increased investment in structures, and can also require more pumping infrastructure.
Where the availability or cost of space is not a limiting factor, farms can be designed to reduce the investment required.

Slope: Most hydroponic farms utilize gravity to recirculate water through the growing spaces and back to the reservoir tank. Therefore, having a site with a slight incline is often advantageous for facilitating this process.

Microclimate: If a hydroponic farm can be situated within a favorable microclimate, the impact on crops can be significant, especially when extreme high temperatures are reduced.
However, large amounts of vegetation around your farm may harbor pests and diseases.

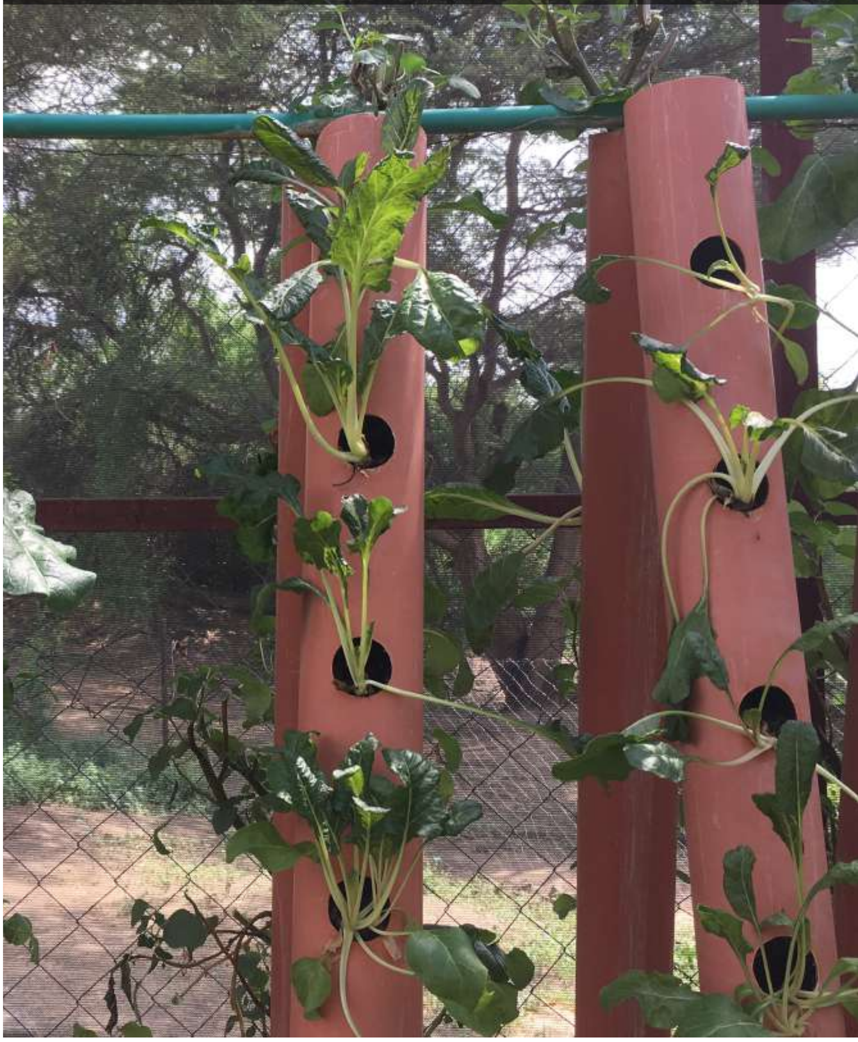
Orientation: In low-tech hydroponic farms, the contextual environmental conditions can still have a large impact on the temperature and other conditions for the plants.

As a result, it is important to consider the orientation relative to the sun - a north/south oriented growing space will heat up differently from an east/west oriented building.

The local prevailing wind direction can also be very impactful as high wind can impact the wear and tear on your structure, it can have a big impact on the temperature inside the growing space, the amount of dust brought into the structure, as well as directly physically impacting plants - for example by causing dropping of flowers or by damaging leaves.

Proximity to markets: A key economic consideration is the accessibility of the farm to key markets, both in terms of proximity and the reliability of transport links. A farm near a large population center will benefit from both a market to consume produce and labor availability. A specific discussion on human resources and skills, below.

Security: The security of the site will impact the level of investment required to protect the farm and crops. Where there is a risk of theft, or even of consumption of crops by livestock and wildlife, investment should be made in protecting the crops.



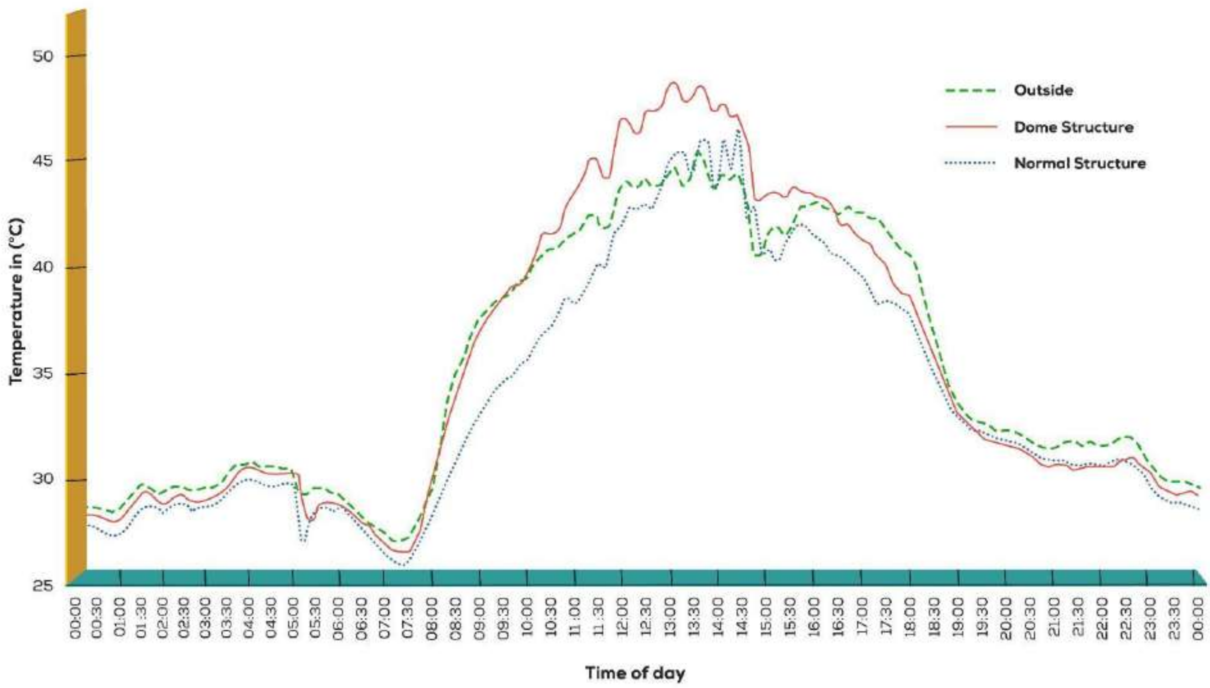
Hydroponic farm set up in proximity to Acacia trees, providing a cooling effect in harsh climates.

Case Study 1 – TBI site selection

The location and orientation of a farm can make a huge difference in the productivity and health of any crops grown. Based on the experiences of TBI Ileret and TBI Turkwel, here are some of the factors to consider as you decide where and how to build a farm:

Proximity to vegetation: *nearby vegetation can be beneficial in providing a cooling effect from the local micro-climate. However, vegetation can also increase pest load, especially for plants that produce large amounts of blossom.*

Orientation and structure: *the layout and structure of a greenhouse relative to the sun and prevailing wind can have a large impact on the light intensity and the temperature of a greenhouse. The graph below shows the temperature difference between two greenhouses, (1) rectangular with an east/west configuration and (2) domed with a north/south orientation.*



Temperature measurements throughout the day at different locations.

3.2 Human Capital

As a novel technology, hydroponic agriculture requires skills beyond those required for traditional farming techniques. While in Chapter 6, capacity building is discussed more broadly. Here the focus lies on the key skills and human capacity requirements for hydroponic farming.

Hydroponic agriculture requires skills beyond those required for traditional farming techniques.

The most critical characteristic of a good hydroponic farmer is a high level of attentiveness. Hydroponic farms can experience rapid changes as a result of variation in conditions, for example a change in water or a new pest threat, as such careful and continual observation is required to ensure that any issues are caught and addressed as quickly as possible.

In a lot of traditional soil-based agriculture settings, there may be periods when crops are growing with little input or oversight from the farmer. By comparison, non-automated hydroponic farms need at least daily attention for watering and monitoring. This is compounded by the hydroponic farming's potential to produce food on a continual basis, without seasonal periods of minimal labor requirements. This has implications especially for wholly mobile populations.

An understanding of plants' growth is also very important for a potential farmer, regardless of the farming method. This intuition allows the farmer to anticipate progress, quickly identify issues and best care for plants.

One potential barrier for hydroponic farming's application more broadly is the need for literacy in most farming applications. This is due to the need to measure especially the total dissolved solids (TDS), the pH and the salinity or electrical conductivity (EC) of the nutrient solution. While some visual measurement systems exist, such as litmus paper, these are limited and proper measurements require meters and the capacity to read numbers. The prevalence of mobile phones means many people are capable of using meters, however this may still act as a barrier to more marginalized members of society.

In addition to capacity required for farm operation, additional capacity is usually required to construct and set up a hydroponic farm. This can include welding or carpentry for the external structure, and plumbing capacity for the internal growing structures and water system.

3.3 Inputs

As with all agricultural activities, hydroponics requires inputs such as seeds, fertilizers and pesticides. This section reviews some key considerations, and is broken down into the requirements for farm installation and those required for farm operation. A case study of use of locally available materials by the Turkana Basin is also presented.

Capital (Initial) Inputs

External Structure

Hydroponic farming development has largely been driven to date by the production of high value crops. This has accompanied large investments in growing structures such as green houses or even converted shipping containers.

In the case studies in this publication, the farms usually have some form of structure, the functions of which are to provide shade, protect from pests, provide a wind break and to keep the crops secure.

These structures should ideally be robust and low maintenance, requiring only minimal attention after construction. As such, many systems use metal structures with some form of metal mesh to support shade net, which is especially important in ASAL contexts where solar irradiance and ambient temperatures are high. However, it is possible to use locally available materials such as local timber and thatching, though consideration should be given to the life span of these materials and the risk that they might harbor pests.

The external structure can have different forms - heavily influencing the cost of materials.

Case Study 2 - Use of Locally Available Materials

At TBI Ileret, wind is a major challenge, as such, reeds washed onto the shore of Lake Turkana, were used as a windbreak, utilizing the same techniques used in making houses locally.

Reeds collected from the nearby lake are used to create a windbreak.

Plumbing

The delivery and recycling of nutrients and water is the most important aspect of hydroponic system setups, for this reason the plumbing in hydroponic systems is really critical.

Plumbing systems should be robust, low maintenance and built to avoid leaks and blockages. The plumbing system should also be able to withstand high temperatures of ASALs, with particular sensitivity to the potential for pollution of nutrient solution due to breakdown of plastics releasing chemicals and micro-plastic particles into nutrients which may be taken up by plants.

A complicated plumbing system is not always required, and systems can be designed to simply operate with manual water provision and basic water recycling driven only by gravity.

Plumbing of an A-Frame system to supply nutrient-enriched water to each of the horizontal pipes.

Growing structures are put together here in the form of horizontal and vertical A-Frames.

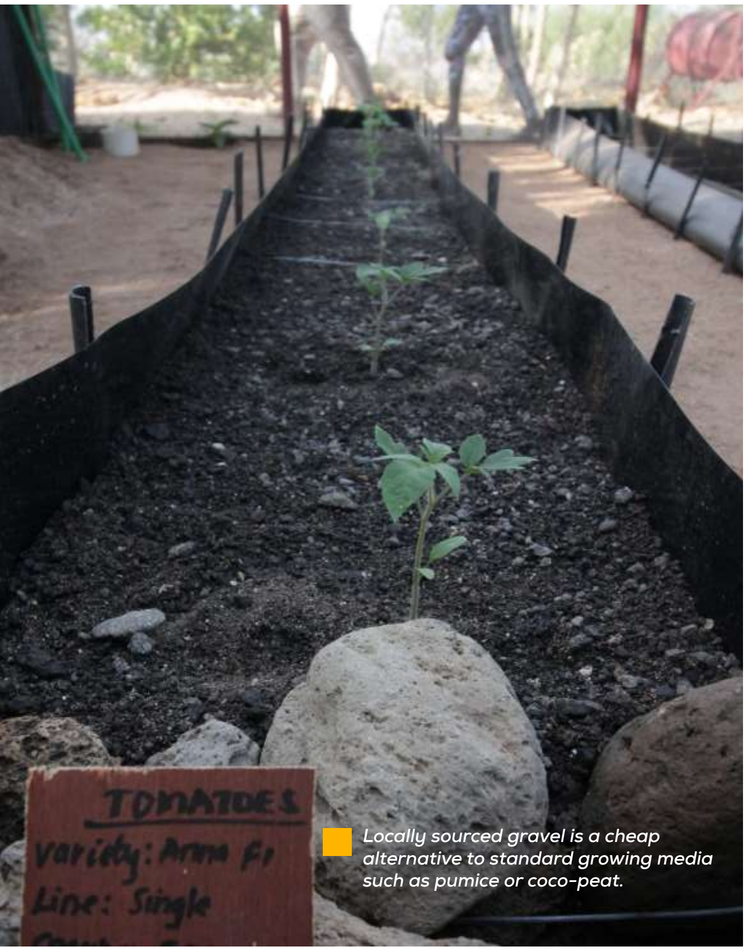
Growing Structure

In addition to the external structure, support for growing systems may be required. These can include platforms for the pipes in NFT systems, support for vertical pipes, or even vertical support for plants themselves such as tomatoes growing in troughs. As above, these can be made from metal for long-lasting systems where capital for investment is available, or from locally available materials.

A broken water tank is used as a growing bed. The use of locally available material can significantly reduce the overall system costs.

Case Study 3 -Use of Locally Available Materials

Growing beds or pipes can be a source of high cost in hydroponic farming. We have experimented with using broken water containers, such as water tanks and drums, to grow crops. By adding a drain, we maintain the water recirculation that is key to efficiency in hydroponic agriculture.



Locally sourced gravel is a cheap alternative to standard growing media such as pumice or coco-peat.

Growing Media

Growing media provides the structure for root growth, and is critical for successful hydroponic farms. Good media ensures that roots are able to physically support the rest of the plant, while being aerated and receiving sufficient water and nutrients, without harboring pests and diseases or reacting with the nutrient solution (being inert). There are many different types of growing media, in the case studies presented here there are a few main types discussed:

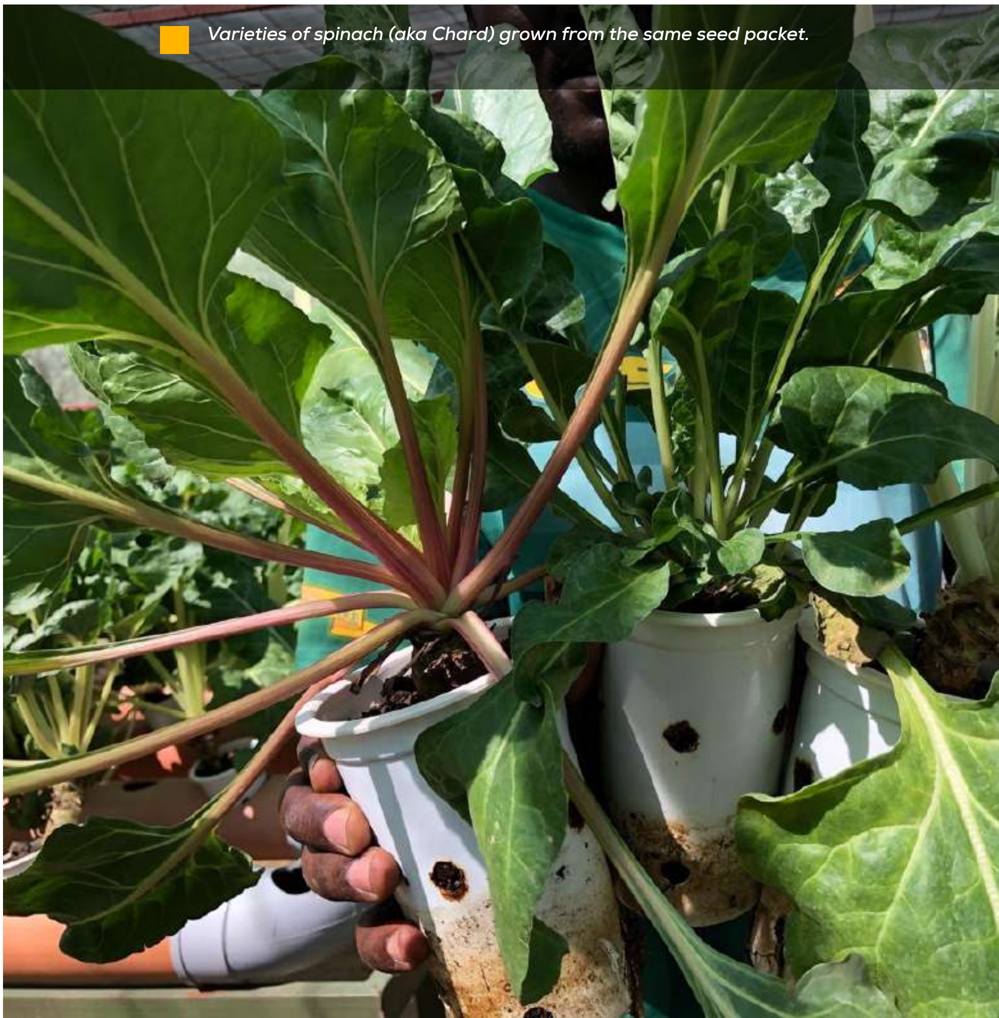
- **Coco-peat:** this is derived from broken down coconut husks, and is especially good for nursery applications as it holds water very well.
- **Pumice:** this is a form of volcanic rock, which is very light weight due to the large quantity of air bubbles in its structure. It is very effective in all hydroponic applications.
- **Gravel:** in some cases locally available gravels can be used for hydroponic farming, provided they are inert and relatively porous. These can be advantageous if other growing media is not readily available.
- **Synthetic foams:** recycling foam for use as hydroponic media has been trialed widely and been shown to work effectively. However, care must be taken to ensure that there is no breakdown of synthetic chemicals that can result in contamination of produce.

Operating Inputs

Seeds

The quality of the crops grown is underpinned by the genetics of the plants, and the quality of the seeds or seedlings procured. The key crops discussed in this publication are usually grown from seed, some readily available varieties that work best in these conditions for each crop are identified, this is presented in Chapter 4, Good Agricultural Practices.

In addition to the types of seed grown, it is important in ASAL conditions to consider the risk that high temperatures for prolonged periods will cause seeds to lose their viability. This is especially a challenge in supply constrained contexts.



Varieties of spinach (aka Chard) grown from the same seed packet.

Fertilizers

Fertilizers are particularly sensitive in hydroponic farming, as the nutrients must be biologically available to the roots when delivered through the nutrient solution. This is unlike soil based crops, where the nutrients can be delivered and undergo further breakdown in the soil before being absorbed by roots.

Commercially available nutrient mixes are available and can be used with great success. These usually come in the form of macronutrients, consisting of nitrogen, phosphorus and potassium, and micronutrients, consisting of sulfur, calcium, magnesium, iron, manganese, zinc, boron, molybdenum, chlorine, copper, and nickel.

These commercial nutrient mixes or compounds can be hard to come by, especially in contexts with limited agricultural supply chains. As such, biologically produced nutrient solutions can be a great way to address this shortage, while also cutting costs. These consist of various components, such as manure, compost, ash and molasses, and ordinarily need to be fermented, in order to allow the nutrients in the constituent parts to break down so that they can be absorbed by the roots of the plants.

During the lifetime of plants, the nutrient requirements evolve, this is especially true of fruiting plants. As such, specialized feeds may be required, this is discussed further in Chapter 4, Good Agricultural Practices.

Fermentation tank for locally produced bio nutrients in Ileret.

An old oil bottle is coated in grease to trap insects, especially white flies.

Pesticides

Control of pests is critical for healthy plants. Ideally, pests should be prevented rather than controlled. Once established, however, this is not always possible, and chemicals are required to neutralize pests. These can either be commercially manufactured chemicals, or locally made solutions derived from plants or readily available supplies. In this publication, the focus is on the latter due to the risk of contamination and toxicity from commercial chemicals, and due to economic factors such as cost and supply chain constraints.

Case Study 4 - Use of Locally Available Materials

The capital cost for Hydroponic farm installation can be prohibitively large. This document presents some of the ways in which the Turkana Basin Institute has innovated with locally available materials to demonstrate how they can be utilized to reduce cost.

Use of discarded plastics as insect traps. A piece of 'mutungi' (yellow jerry can) or (as the image below shows) an old oil bottle is coated in grease and hung up as an insect trap. We have found these highly effective in attracting and trapping insects, especially white flies.

Water

Water is self-evidently critical to any agricultural enterprise. In most traditional soil based farming methods in ASALs, water is either derived from rain or surface water sources such as rivers, and crops are grown in sync with seasonal availability of water. Commercial irrigated agriculture enables crop production to be more decoupled from seasonal variations, and hydroponic agriculture's water efficiency takes this advantage further.

Water quality and reliability is key to any hydroponic farm, due to the nature of nutrient delivery hydroponically grown crops are more vulnerable to poor water quality than soil based crops. However, due to the water efficiency of hydroponics and the reduction in water consumption per unit of output, it can be economical to use more "expensive" sources of water, such as water treated by reverse osmosis systems.

Water quality within hydroponic farms can be carefully monitored and controlled to maximize the health of plant roots and the uptake of required nutrients. Important factors include electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO) and pH. The latter can be manipulated by adding acid or alkali solutions to reach an optimum pH of approximately 6.5.

Electricity

Hydroponic farming setups that use pumps are almost exclusively reliant on electric power. This may come from grid or alternative power sources such as specifically installed solar power installations. It is important to note that manual hydroponic systems do not require electricity.

In more commercial operations, electric power might also be used for artificial lighting to accelerate growth, or in automation, these applications are not discussed further in this publication.

Data Collection and Monitoring

It is useful to monitor aspects of hydroponic farms, this necessitates some specialist equipment, such as TDS, EC and pH meters. In commercial operations, equipment to weigh produce can also be helpful for monitoring output.

A basic solar power system, supporting 600m2 of hydroponic farm.

CHAPTER IV

ESTABLISHING AND RUNNING A HYDROPONIC FARM

The aim of this chapter is to outline the basic activities involved in successfully managing a hydroponic farm, with special consideration for factors that are specific to ASALs. Here, "success" is defined as the production of healthy, in demand produce in a manner that is economical, environmentally friendly and socially acceptable. This chapter will draw heavily on case studies to demonstrate each practice, and begin by giving a general overview of two of the farms that have informed this work. The chapter will then review the basics of media, plant nutrition, types of crops, crop protection, data collection and post harvest activities. In order to further illustrate the points made, three crops of relevance to hydroponic farming in ASALs are focused on, specifically, "spinach" (also commonly known as swiss chard), kales (sukuma wiki) and tomatoes. This chapter is not designed to be a comprehensive guide to farming, but rather will provide an in depth review of the range of factors that underpin success.

04

4.1 Introduction to Good Agricultural Practices (GAP)

This chapter draws upon case studies from work conducted by GIZ, Hydroponics Africa and TBI in Turkana and Marsabit Counties. To situate this work, the chapter starts with an introductory case study of a day in the life of a hydroponic farmer, informed by work at TBI Ileret.

Case Study 5 - A day in the life of a hydroponic farmer: Good Agricultural Practices, TBI

Good Agricultural Practices (GAP) are key to maintaining a healthy and productive farm. By presenting the day in the life of a farmer, this case study will present GAP in action. In ASALs, it is particularly important to bear in mind the impact of heat on crops, and to plan accordingly.

Before heading to the farm, the farmer must consider hygiene. This is critical to ensure there is no spread of disease to crops, and also to maximize the cleanliness of the food produced at the farm. This is especially important to consider where there is limited WASH infrastructure.

The first activity the farmer must conduct at the farm is scouting. This is an inspection of the farm checking for any changes, especially those that would be indicative of a new issue. The farmer checks the crops and infrastructure, looking for pests, signs of disease or structural issues such as leaks.

When the scouting is complete, the farmer will conduct the bulk of the day's work. This will include irrigating crops, in most hydroponic systems this is relatively easy, as only the pump or water source needs to be switched on, and the system will do the hard work. The farmer will check that water is flowing and draining as it should, that no plants get too little or too much water. The water can be left running for a long period of time in well drained systems, and can be turned on and off several times a day - depending on the crops and environmental conditions. Or is conducted once a day or less for flooded systems.

The farmer will periodically need to mix new nutrient solutions. This usually involves removal of the remaining nutrients from the last batch, flushing of the nutrient tank, refilling the tank with clean water, adding the concentrated nutrient solution, and finally, checking the TDS, EC and pH to ensure the mixture is as desired.

Before the heat of the day, the farmer will conduct any general farm maintenance such as:

Gapping: *the thinning of crops to ensure the right distribution.*

Formulation and application of pesticides as required.
Formulation of fertilisers, This is especially key where bionutrients are being utilised, as the mixture can take up to 1 month to produce.

Planting: *seeds are placed either directly in growing structures, or more often into a nursery comprising cocopeat.*

At the peak heat of the day, the farmer might conduct wetting or misting. This is the use of water to reduce the temperature of the growing space through evaporative cooling by spraying water on the canopy of the plants.

The farmer will harvest some crops for consumption or sale. In hydroponic farming, crops can be grown through the year, so harvesting is usually an ongoing activity, dictated as much by demand as it is by supply. The farmer harvests during the coolest part of the day; early morning or late afternoon, because during the heat of the day the crops will be dehydrated or wilted.

The scouting of pests is one of the important daily tasks in hydroponics.

4.2 Hydroponic growing media

By definition, hydroponic agriculture does not use soil. As a result, some other mechanism must be found for providing structural support to the roots of plants as they provide nutrients and water to facilitate growth. This usually comes in the form of "media".

This section discusses media, introducing the characteristics to consider the different types of media, how to prepare and utilise media, and some case studies of experience in ASALs.

Growing media, shown here with watermelon plants.

Media Characteristics

Good hydroponic media has the following characteristics:

- **Porosity:** allowing both air and water or nutrient solution to reach the roots, enabling them to respire without drying out, and absorb the required nutrients and water for the whole plant.
- **Anchorage:** healthy root systems provide the support for the rest of the plant. In some farm set ups and with some crops, some extra structural support can be provided, however a stable root structure ensures healthy undisrupted growth.
- **Chemical inert:** the media and nutrient solution are in very close contact, as such, inert media is preferable as it won't alter the solution, for example by changing the pH or leaching minerals that may inhibit growth or harm plants.
- **Easy to clean:** being able to clean media reduces disease or nutrient build up, and is a key requirement of a healthy hydroponic farm. Media that can withstand flushing and drying is key to being able to 'reset' and continue farming without having to buy new materials.
- **Robust:** the media used must not degrade. Any media that breaks apart can decrease porosity and clog the hydroponic system.
- **Affordable:** in order to be feasible, media must be reasonably affordable and accessible.

While these criteria are all desirable, in practice there are usually some compromises that need to be made, especially for farming set ups with limited financial resources. These alternatives can be found, and success with a range of available media is key to successfully scaled hydroponic farming.

Types of Hydroponic Media

There are many types of media in use across the world, the list below is not comprehensive, but focuses on the media most commonly found and used in low resource contexts. The media is described with its characteristics.

Media Type	Sourcing	Characteristics, Performance and Considerations.
Pumice (Volcanic Rock)	Commercially available and used, but usually not in ASALs.	Highly porous and usually chemically inert (though this depends on the specific source site). Widely used in commercial farms.
Cocopeat		Less porous but inert and highly water retentive, very good for use with seedlings and in nurseries.
Riversand	Locally available, depending on farm site.	Usually chemically inert and water retentive, but may compact around roots, blocking air, and may also block parts of the farming system.
Gravel		Not as porous as pumice, but in the right sizes, usually 5-15mm, this will hold space for roots and air.
Charcoal		Porous and usually chemically inert, though it may adsorb some nutrients initially. Care must be taken to source sustainable charcoal, such as that made from invasive species

Combinations: the media types listed here can be used in combination. For example mixing coco peat and pumice to maximise both water retention and aeration.

Case Study 6 - Locally Available Media - Kakuma River Sand

GIZ Kakuma tested the utilization of locally available materials while adhering to the technical design. The most used mediums for hydroponic agriculture are pumice and cocopeat. The substrates are not available in Kakuma and were sourced for Naivasha @ KSh 20/kg. The cost increases to KSh 30/kg when it reaches Kakuma due to transportation. This rendered hydroponics very expensive for refugees and host communities in Kakuma. To mitigate against this high cost, the project tested the use of local river sand as low-cost, and locally available material.

The local river sand supported growth of all the pilot crops i.e., tomatoes, kales, and Swiss chard. The sand particles were tightly packed together. This reduced the amount of air available to the roots. It is therefore critical for the sand to be mixed with other media for an improved air circulation. It was also observed that the local river sand retained more moisture when compared to pumice making irrigation less frequent. However, the higher retention of moisture favoured mould growth on the surfaces and regulated water application is required. There was no significant difference in the performance of the crops grown on local river sand when compared to crops grown on pumice.

Kales are growing in a mixture of river sand and gravel. Combining the media two helps to retain moisture while allowing air to get to the roots.

Case Study 7 - TBI Local Media Use

The most commonly used mediums for hydroponic agriculture are pumice and cocopeat. As these are not widely available locally, TBI has tested some other media. Pumice is available between KSh 1-20/kg in Nairobi, but costs an additional KSh 18/kg to transport to Ileret.

In Ileret TBI has experimented with a local gravel, sourced from a quarry used for road making materials. This gravel is dense, has a particle size of approximately 2mm - 15mm and is fairly inert. The gravel is used either alone, or mixed with pumice, for example at a ratio of 1:5 (pumice to gravel) in troughs. The gravel beds have performed well, with productive cultivation of fruiting, vegetative and tuber crops.

Young tomato plants are growing in a trough filled with locally sourced gravel.

Water melon is growing in a container filled with bigger gravel and charcoal.

In TBI Turkwel further experimentation has been carried out with the use of pumice and charcoal mixtures, with a view to increasing aeration and moisture retention in the medium.

The charcoal was sourced from Prosopis Juliflora - so as not to promote deforestation - and was broken into 5mm - 2mm pieces, rinsed and then mixed with pumice at a ratio of 1:1, pumice and charcoal, and used in troughs. This mixture has worked well, although direct comparison to other troughs has not been possible due to differing shading.

Other experimentation with different media has included the use of foam, inspired by work in the Zaatari refugee camp in Jordan.[3]

This was effective, though the foam held moisture more effectively than pumice and needed a different, less frequent, watering regime. This was also not explored further due to concerns about the type of foam, and the potential for uptake of harmful chemicals by the crops grown.

[3] https://www.sheffield.ac.uk/research/features/sheffield-zaatari-and-back-feeding-world-foam

Spinach growing in a system using foam as media

Preparation and Maintenance of Media

Plant health is contingent on clean and supportive media. It is therefore necessary to take steps to ensure media is appropriately maintained. This can be done between each crop or less frequently, depending on the ease of access and the need for sanitation, for example NFT cups are very easy to replace, as the media can be taken right out after each crop, where as vertical pipes are a bit more difficult to clean and can be cleaned at a longer interval such as every 3 years.

The steps that can be taken to ensure media is optimal are listed below.

- Flushing with clean water. This removes build up of salts from water or nutrients that might make increasingly toxic growing conditions for plants.
- Drying in the sun. Drying the media will disrupt the cycle of microorganisms that rely on wet environments to propagate, such as algae or mould, and the UV rays in direct sunlight will help to sanitise the media by neutralising pests and diseases such as nematodes. This is especially easy to do in ASALs with ample sunlight!
- Sieving. Sieving media through even a rudimentary mesh can help remove small particulates or even the residues of pests and diseases. This removal of dust and other small organic matter between growing cycles helps reduce clogging of pipes and enables the media to stay more aerated.

4.3 Plant Nutrition

In hydroponic agriculture, the vast majority of the nutrients that plants need are provided through the nutrient solution that is passed through or saturates the growing media. Crucially, the nutrients must be bio-available - that is to say readily absorbed by roots for use by the plant - when they are in the solution, as the hydroponic setup does not allow for further processing of nutrients, unlike soil, which enables further breakdown of nutrients over time. Additionally, the nutrient solution must meet other requirements of the plants, such as having enough dissolved oxygen, having the right pH, the right temperature and the right electrical conductivity (EC).

Formulating and delivering the nutrient solution is the most challenging aspect of hydroponic farming, and is further complicated by ASAL specific factors such as poor water quality - especially higher salinity - and high ambient temperatures, which cause increased nutrient interactions, concentration due to evaporation and reduced dissolved oxygen with increased temperature. For example, at 20°C water holds 11.29 mg/L of dissolved Oxygen, whereas at 40°C, this level drops to 6.41 mg/L.[4]

[4] *Genc, Yusuf, Julie Hayes, and Yuri Shavrukov. "Hydroponics - A Standard Methodology for Plant Biological Researches," December 19, 2012.*

Nutrient Types

Nutrient requirements can broadly be categorised as either macro or micro nutrients, depending on the quantity of each nutrient required by the plant. Some of the main nutrients required are listed in the table below, this is not a comprehensive list, but illustrates the breadth of requirements and diverse range of quantities of nutrients required. These requirements will change between different plants, and for the same plant will also change through different stages of growth.

Nutrient	Symbol	Range (mg/L, ppm)
Nitrogen	N	168 - 236
Phosphorus	P	31 - 60
Sodium	K	156 - 300
Calcium	Ca	160 - 185
Magnesium	Mg	34 - 50
Sulphur	S	48 - 336
Iron	Fe	2 - 12
Copper	Cu	0.02 - 0.1
Zinc	Zn	0.05 - 0.11
Manganese	Mn	0.5 - 2
Boron	B	0.3 - 0.5
Molybdenum	Mo	0.01 - 0.2

Adapted from: Genc, Yusuf, Julie Hayes, and Yuri Shavrukov. "Hydroponics - A Standard Methodology for Plant Biological Researches," December 19, 2012. p8.

It is also really important to be aware of nutrient interactions, an excess of one nutrient might inhibit the absorption of another by the plant, or conversely, a lack of one nutrient might result in an inability to utilize a different nutrient. These relationships are complex, and further complicated by the sensitive nature of hydroponic agriculture which lacks the broad reservoir of nutrients provided by soil.

Sources of Nutrients

Nutrient solutions can either be made locally or purchased from commercial suppliers, both of these avenues have advantages and disadvantages, below are two case studies.

Case Study 8 - Commercial Nutrients: Hydroponics Africa

Hydroponic nutrient solution is the sole source of nutrients for plants grown hydroponically because the media used to replace soil is virtually inert. Consequently, hydroponic nutrient solution must have the full spectrum of nutrients needed by the plant. This comprises 23 elements, three being major elements since they are needed in large quantities and the other being trace elements since they are needed in a smaller quantity.

Hydroponically grown plants require nutrients in a form that is ready for absorption because the media and water are inert. Nutrients in soil-based fertiliser are first broken down to ionic forms which can be absorbed by the plant. In contrast, a hydroponic nutrient solution has nutrients which are already in their ionic form hence are readily available to the plant.

In addition, since there is no microbiota to regulate the pH and EC of the media, a hydroponic farmer must periodically check and adjust the pH and EC.

The raw materials of making hydroponic nutrients are not available in the local Kenyan market but can easily be imported. The major challenge of making the nutrients is in the ever-rising cost of raw materials for the last five years. Hydroponics Africa Limited is able to maintain a constant price for the nutrients for the local market since it imports the raw materials in bulk.

Case Study 9 - Bionutrients: Locally Made Nutrients, TBI Ileret

The use of inorganic fertilisers is relatively expensive in hydroponic farming particularly in ASALs and the challenge of procurement is particularly acute in remote areas with limited demand and a constrained supply chain. Yet nutrition required for food production (quality and quantity) remains a food priority in food security. Therefore small household farmers have not delved much into hydroponics due to the fear of high cost of fertiliser in relation to the high capital cost. It is in this context that TBI has implemented and used a very simple bionutrient in the hydroponic garden using the locally available goat manure, which can be made into a rich nutrient solution in hydroponics.

Ingredients and Equipment:

- *Preparation tank: radius 1.5m by 0.6m height.*
- *15 wheelbarrows of Goat manure.*
- *2 buckets of ash.*
- *3 litres of Molasses.*
- *200 litres of water*
- *Container e.g half cut drum*

Method

- *Add 15 wheelbarrows into the container. Ensure it is not full to the brim to allow space for water above the mixture.*
- *Add water into the container with manure .*
- *Add molasses and thoroughly mix.*
- *Mix the ash with water and add this slurry to the mixture.*
- *Ensure that the mixture remains underwater always to facilitate anaerobic respiration.*
- *Cover the top.*
- *Leave after 1-2 months for fermentation then start collecting the extract. This fermentation process is akin to the breakdown of nutrients that would happen when manure is applied to soil in a traditional agricultural setting.*

Nutrient mix ratio

- *Depending on concentration, mix 2 litres of Bio-nutrient into 100 litres of water.*
- *Control the pH of the nutrient solution before feeding the plants and ensure that the TDS measures a range of 900 ppm-1200 ppm always.*

Extraction of concentrated bionutrients out of the fermentation tank.

Comparison of different Nutrients

	Bionutrients	Commercial nutrients
Costs	Very affordable	Somewhat costly
Ease of use	Time intensive preparation	Ready to use
Availability	Readily available ingredients	Restricted in ASAL areas
Efficacy	Mixed, highly effective for some crops	Good, but influenced by high temperatures
Standardisation	High level of uncertainty	Standardised product
Technical requirements	Know-how required for production	Precise mixing required

Application of Nutrients

The nutrient solution is the principal delivery mechanism for both water and nutrients, the specifics of this process is determined by the type of crop grown, the configuration and external conditions such as ambient temperature. In a normal farm set up, especially one where there is constant innovation and learning taking place, as is the case in most case study sites, the following parameters are usually measured on a daily basis, or even more frequently in some cases.

- **TDS:** Total Dissolved Solids: this is a measure of particles in solution in the nutrient mix. This reflects the concentration of nutrients, as well as other solubles, such as dust particles or even broken down growing media. Unclean water - such as river water - can increase the TDS, even before any nutrients have been added. A larger range of TDS can be tolerated, and the limits on plant growth will usually come from the other parameters listed below.

- **pH:** the pH is an indicator of how acidic or basic/alkali the nutrient solution is. Plants are usually very sensitive to pH, while different plants prefer different conditions, the optimal pH range is usually around 6.5 - which is very slightly acidic.
- **EC:** Electrical Conductivity is a measure of the ions in the water. It is important to know the EC of raw water being used in agricultural processes, as high EC will inhibit plant growth.

- **Temperature:** while this is usually not measured on a daily basis, it is important for the farmer to be aware of the ambient temperature, and particularly if there have been any changes. This might explain increasing concentration (increase in EC or TDS) or other changes seen in the other parameters.

All of these parameters can be easily measured using basic hand held probes. It is advisable that these parameters are monitored closely, especially when the farm is being established or when there are external factors such as extreme heat or rainfall that could result in concentrating or diluting the nutrient solution respectively.

Measuring the pH of nutrient solution using a basic metre.

In some rare cases, nutrients might be added in solid form directly to growing media, or sprayed directly onto plants as a solution. This usually happens in rare cases when there is a severe deficiency, or when a foliar feed needs to be applied which can not be added to the nutrient solution.

Changing Nutrient Requirements

Different plants require different nutrients, and the same plant will require different nutrients at different stages of growth. For example, a tomato plant will require different building blocks (nutrients) to produce leaves in its vegetative stage as compared to its fruiting stage. The specifics of these dynamics are reviewed in the case studies for tomatoes, kales and spinach.

Plants have different nutrient requirements when they are producing fruit, leaves or tubers.

Troubleshooting Nutrient Deficiency.

Just as humans need a balanced diet to be healthy, so too do plants, and deficiencies can lead to a weakened and unproductive plant. It is important to look out for signs of deficiency, a few potential signs are listed below, with the key concerns for tomatoes, kales and spinach listed in the respective case studies.

- Pale leaves: insufficient Nitrogen or Magnesium, both of which are a key component of chlorophyll, the green part of leaves which conducts photosynthesis.
- Yellow leaves: insufficient Iron may result in yellow young leaves, whereas insufficient Manganese may result in spotty yellowing in older leaves.
- Black spots on tomatoes: this might be "Blossom End Rot" a condition in which tomatoes grow a large black spot on the site of the fallen flower as a result of calcium deficiency.
- Curling of leaf, leaf edges/margin burn, turn brown and eventually die may be as a result of potassium deficiency.

The vibrant color of kale leaves can serve as a visible indicator of nutrient deficiency.

These observations should not be confused with the impact of pests or environmental factors such as high temperature. Often plants exhibit symptoms of multiple interacting issues, complicating troubleshooting and treatment!

4.4 Types of Crops Suitable in ASALs

A wide variety of crops has been successfully grown and harvested in the hydropic farms, driven by curiosity, local preferences, and a desire to develop systems that could be replicated in the region. In order to make this guide as useful as possible, it focuses on 3 crops which have been most successful in hydroponic agriculture, are fairly easy to cultivate and for which there is a relatively dependable market, these are spinach (also known as chard), kales (sukuma wiki) and tomatoes. These case studies are presented in this section, along with key information pertaining to all stages of cultivation.

Spinach Fact Sheet

Comparison of NFT grown spinach (left) and trough spinach (right) these plants are the same variety and age.

Spinach is the name used in Kenya to describe Chard, and is widely consumed. It is especially popular due to perceived lower acidity compared to Kales.

Varieties Grown in Hydroponic Systems

"Fordhook Giant"

Hydroponic Structure Used

Spinach is widely adaptable and can grow in a range of structures, listed below, however, it is most productive in troughs.

- NFT
- Adapted NFT – with growing media filling horizontal pipes.
- Troughs
- Vertical pipes.

Cultivation (Nursery)

Spinach can either be planted directly into hydroponic media or into a nursery, usually consisting of cocopeat. The latter is preferable due to the greater amount of control of nutrient solution chemistry and quantity.

- The seeds should be planted at a depth of 1.5cm.
- The seeds will take 5-6 days to germinate and 20-28 days to be transplanted.
- During this period, care must be taken to ensure that the plants have adequate moisture but do not get flooded.

Maturation
If planted directly into growing media, spinach will take 6 weeks to reach maturity, or 6 weeks after transplanting if a nursery is used, pruning should be conducted when the first leaves are wilting.
The plants mature when the stem is more rigid and the plant has reached a height of 20cm. Spinach will have differing rates of reaching maturity and different size depending on the growing structure, e.g trough vs NFT cups.
(Image of spinach 6 weeks after direct planting)

Harvesting
Spinach leaves are harvested from the bottom up, taking the oldest leaves first. Care must be taken not to uproot the plant as the leaves are picked. Spinach can be harvested by hand, or preferably with a knife or scissors, in order to reduce force and disruption of plant roots.

Spinach once established can continue to grow and be harvested for over 2 years, however the virility of the plant may decrease.

Yield
The yield of spinach is approximately 1kg per year per NFT grown spinach, this is calculated from TBI Turkwel's original spinach growing area, which has 435 spaces, of which about 75% would be in use at any one time, and produced on average 400kg, or as much as 510kg per year.

Nutrient Requirements
As a vegetative plant spinach requires plentiful nitrogen.

Common Pests	Common Diseases
White flies	Powdery mildew
Caterpillars	Ringspot fungal infection
Aphids	Rust
Nematodes	Leaf curl
Mealybugs	Dumping off - excessive water.
Leafminers	
Beetles	
Thrips	

Young spinach plant in a nursery shortly before transplanting.

Kales Fact Sheet

A kale plant that elongates due to the continuous harvesting of bottom leaves in a vertical system

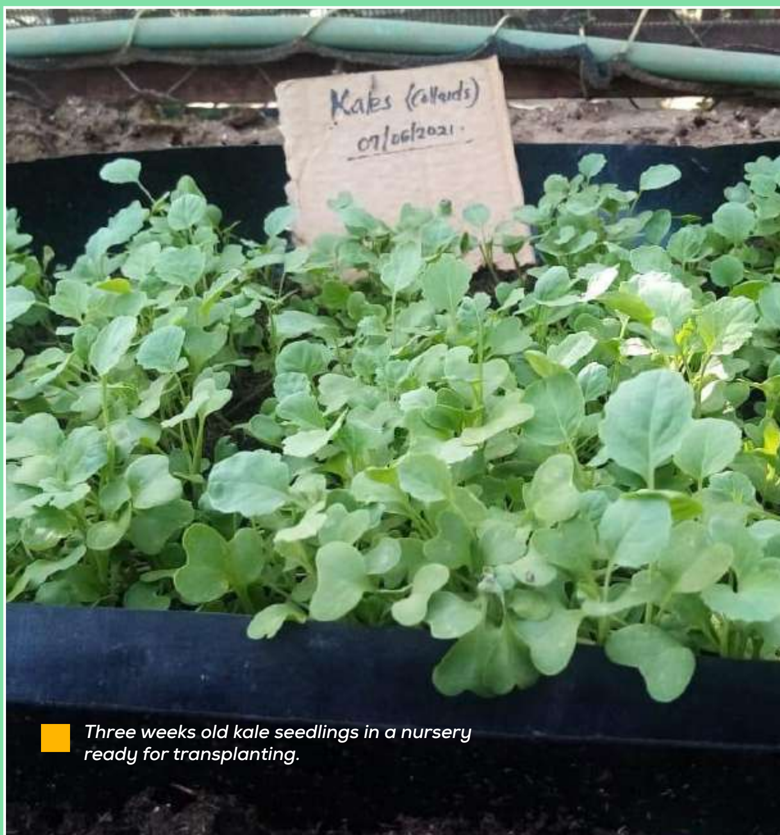
Kales are most commonly known in Kenya as "Sukuma wiki" and are a key staple crop. Kale is a member of the Brassica family.

Varieties Grown in Hydroponic Systems

- "Collard" – this thrives in hydroponics systems, and can keep growing for many years, with some plants lasting over 2 years.
- "Ethiopian Kales" – this grows well and has a good flavor, however it can only be harvested for 4 months then bolts. This is commonly used as a "micro" vegetable.
- Lacinato (Italian Kale variety) It is highly productive. It grows 60cm to 90cm tall. It produces many tender and slender leaves around the stem.
- (Note: "1000 headed" is susceptible to stem rot in our experience.)

Hydroponic Structure Used

Kales have deep root structures and can grow into large plants with stems of more than 2m, as such, they require more support than other leafy vegetables. They grow best in:
Vertical pipes
Troughs



Three weeks old kale seedlings in a nursery ready for transplanting.

Cultivation

Nursery

Kale is majorly propagated by seeds. The seeds can either be planted directly into the installed hydroponic system or first raised in a nursery, usually consisting of cocopeat then transplanted. The latter is preferable due to the greater amount of control of nutrient solution chemistry and quantity.

The seeds should be sown at a depth of 1.5-2cm.
The seeds will take 3 days to sprout, and 21-28 days to be ready to be transplanted.

During this period, care must be taken to ensure that the plants have adequate moisture but do not get flooded.

Maturation

If planted directly into growing media, kales will take 4 weeks to pruning of lower (first) leaves and conducting gapping, then a further 2-3 weeks to reach maturity. Or if transplanted, it will take 2 weeks to prune, and 4 weeks for the plant to be mature.
The plants mature when the plant has a change of color and texture of the leaves, the stem of the plant at the base is beginning to become rigid, and the plant has 4-5 true leaves.
Frequent harvesting and proper feeding of the plant will prevent it from bolting - ie. forming a head of flowers and dying.

Harvesting

Kale leaves are harvested from the bottom up, with the oldest leaves being consumed first. Care must be taken to harvest the leaves ~5cm from the main stem leaving a small stalk that will dry up and fall off on its own, in order to prevent excessive evaporation and damage to the stem that can be a source of disease.

Yield

In vertical farming configuration, the yield is 550 kg per year, per 1000 plant spaces, in an area of ~50m2.

Nutrient Requirements

As a vegetative plant Kales require plentiful nitrogen, however they are also susceptible to potassium and phosphorus deficiency. Foliar feed can also be used to promote vegetative growth.
Common Pests:

Common Pests	Common Diseases:
White flies	Stem rot due to poor harvesting
Caterpillars	Powdery mildew
Aphids	Ringspot fungal infection
Nematodes	Rust
Mealybugs	Leaf curl
Leafminers	Dumping off - excessive water
Beetles	
Thrips	

Kale plant with symptoms of stem rot, which the Thousand Headed cultivar is especially susceptible to. Often caused by poor harvesting or excessive moisture in the trough in contact with the stem.

Tomatoes Fact Sheet

Tomatoes are widely consumed in Kenya and a basis for various dishes. The demand is high - its production could be one of the most profitable products grown with hydroponics.

Varieties Grown in Hydroponic Systems

- Tylka F1 as a drought & heat tolerant variety has given good yields in hydroponic systems in Kakuma. However, fruit sizes are small-medium. Lifespan of tomato plants in Kakuma was limited to 6 months with the plant starting to shrink and losing most flowers after the 4th month of production.

Hydroponic Structure Used

Horizontal net-tube systems and through systems have been assessed by HAL. Net-tubes gave good results with slightly bigger fruits as compared to the trough system. This might be due to root heating in the trough system that inhibits nutrients & water uptake by the plants. Cocopeat, laga sand and pumice have been trialled with pumice giving the best results. After every crop season the media should be cleaned to remove any accumulated salt.

Tomatoes freshly harvested are being checked and sorted.

A tomato with blossom end rot, due to calcium deficiency.

Nursery

Tomatoes can either be planted directly into hydroponic media or into a nursery, usually consisting of cocopeat. The latter is preferable due to the greater amount of control of nutrient solution chemistry and quantity.
The seeds should be sown at a depth of 0.5-1.5 cm.
The seeds will take 5-10 days to sprout and can be transplanted once the first real leaves have developed. During this period, care must be taken to ensure that the plants have adequate moisture but do not get flooded.

Maturation

Different tomato cultivars have different maturity periods. Some varieties like Anna F1 can start fruiting 2-3 weeks after flowers fully open. Most varieties bear mature ripe fruits as early as 50 days from setting out. The average maturity period for most varieties ranges between 60-100 days from transplanting.

There are several reliable external and internal indices of tomato fruit maturity.
The external fruit maturity index is based on: skin colour, while the internal indices is based on seed development and locular gel formation.

Location of the fruit on the plant i.e the first fruits formed and fruit size may be used as rough guides in determining where to look for a mature fruit. However, these indicators alone are not reliable. The most widely used index of tomato maturity is skin colour. Skin colour remains green during fruit development on the plant. The ripening stages of a mature tomato fruit is categorized as green, breaker, turning, pink, light red and finally red.

Harvesting

Tomatoes are harvested by removing the fruit from the plant by gently twisting or rotating them in order to safely remove the stem from the fruit without causing bruises. In some cases, a pruning knife may be used.
Harvested fruits should be handled with care and not be thrown or dropped into the picking container as they are very susceptible to bruise damage. Harvesting should be done preferably during the coolest part of the day, ideally in the morning or late afternoon when the temperatures are very low.
The harvesting period can be very prolonged, with fruits being produced up to 7 months after transplanting, though the size of fruits gradually decreases through the harvesting period.

Yield

In Kakuma, the Tylka variety yielded on average 5 kg per plant within the plant's life cycle of 6 months. This is less than the estimated 10 - 20 kg per plant for 12 months in cooler settings.

Nutrient Requirements

Most tomato cultivars are heavy feeders. In the early development the plants will thrive with a general mix of NPK, with a phosphorus-rich foliar feed starter and a vegetative foliar feed rich in Nitrogen. At this stage it is also recommended to start adding calcium in preparation for the flowering and fruiting stages, at which point increasing potassium improves the fruit development.

Common Pests	Common Diseases
Tuta absoluta	Blights
White flies	Powdery mildew
Mites	Root rots
Aphids	Blossom End Rot
Caterpillars	
Leafminers	

A tomato plant heavily affected by the red spider mite.

4.5 Crop Protection

Thriving crops need to be protected from pests, diseases and harsh environmental conditions. In this section good agricultural practices for maintaining a healthy farm and for keeping crops productive are reviewed, and some basic troubleshooting information is presented. In the ASAL context it is best to adopt an IPM (Integrated Pest Management) approach - which advocates holistic farm husbandry. The usage of chemical crop protection should only be used as a last resort.

Good farm husbandry

There are some basic steps that can be taken to prevent the spread of pests and diseases, to maximise plant health and to make farming easier in general. This general list is a good "rule of thumb" by which to operate a hydroponic farm to maximise productivity and efficiency:

- **Hygiene:** when entering the farm and dealing with plants it is important to have clean hands and to minimise the transport of organic matter from other sites, especially where this might result in the transport of diseased materials.
  The farm itself should also be kept reasonably "clean" this means reducing dust through sweeping and wetting (where water availability allows).
- **Pruning and Trellising:** providing support to plants as they grow is critical because the root systems in hydroponic farmed crops will likely be weaker as compared to those in traditional soil based systems. Pruning removes dead or unnecessary leaves, and together both activities ensure that the plants have the best shape for maximised productivity.
- **Harvesting:** while it might be self-evident, it is important to remove produce when possible, in order to not leave rotting material within the farm as this is generally inefficient and can promote disease growth.
- **Crop rotation:** pests and disease load can accumulate over time, crop rotation disrupts the growth of pests and disease burden. (Note: in traditional soil based cultivation crop rotation can also promote soil nutrients through nitrogen fixing crops, but this is not relevant in hydroponic agriculture as the media should be inert.)
- **Spacing:** the density of crops must be carefully managed to ensure that the farm is maximally productive, however, this does not mean density should be maximised as trade off such as air circulation and light access need to be considered.
- **Intercropping:** plants naturally grow in diverse landscapes, where they compete or provide a range of services to each other. Growing different crops can either assist or harm, beneficial combinations can promote positive interactions such as pest management.

Pests and Diseases

The greatest practical impediment to farm management, perhaps aside from lack of water, is harm to crops from pests and diseases. These can be very challenging to control and can cause entire crop failure in short periods of time. An annex of images and information about common concerns is provided, an example of an entry is provided on the right. There are also many resources available online with information for identifying and addressing pest and disease issues.

Damage	1;Cultural practices
Generally, mites feed on the underside of the leaves. They use their sucking mouthparts to suck plant saps. Infested leaves may turn yellow, dry up, and drop in a few weeks.Mites produce webbs. Heavy infestation will result in a fine cobwebby appearance on the leaves. Plants die when infestation is severe.	Provide plants with adequate water. Water stressed plants are prone to damage by mites. Avoid the use of broad spectrum insecticide for this may cause a mite outbreak. The practice kills the natural enemies/predators of mites and stimulates mite's production. Avoid dust in the hydroponic system. Avoid sweeping the ground when it is dusty. This causes the dust to settle on the leaf surfaces providing a conducive environment for mites. Remove the host weeds in and around the farm. High temperatures activate the mites' action, therefore reducing the temperatures by misting/showering the plants 2-3 times a day.
Description	**2;Physical control**
They are tiny insect-like creatures with eight legs. They have two body parts, the head and abdomen. They are mostly found on the underside of the leaves. They cause chlorosis or yellowing of the leaves where they produce spider-like webbing. The eggs are tiny spherical, pale-white, and are laid on the undersides of leaves, often under the webbings. Eggs hatch in 4-5days. Nymphs look similar to adults but are only the size of an egg.it has 6 legs. It molts 3 times before becoming an adult.	Showering with a strong jet of water knocks off mites and destroys their webs. Target the underneath of the leaves while doing this. Apply water on pathways and other dusty areas at regular intervals. This will reduce temperature by increasing humidity in the hydroponic garden. Plant extracts **1: Coriander seed extract** Pound or crush 200gm of coriander seeds. Boil in 1 litre of water for 10minutes. Cool and strain. Dilute extracts with 2 litres of water. This extracts also prevents fungal diseases. **2: Basil leaf extract:** The adult is also very tiny, and may be yellowish. It looks like a tiny moving dot. It has an oval body with 8 legs and 2 red eyespots. The male is smaller than the female. Spider mite is not an insect but a carcicide of the same family of ticks. Grind 50 gm of basil leaves. Soak overnight in2-3 litres of water. Strain. Add 8-12ml of soap. Stir well. Pests controlled are: caterpillars, fruit flies, red spider mites, red scales, spotted leaf beetles, fungal diseases and nematodes. **Milk spray** Mix 1/2 litre of milk to 4.5litres of water. Milk and water ratio is 1 part milk to 9 parts water. Spray weekly intervals as a preventive control measure. Pests & disease control are: spider mites, mildews, mosaic virus leaf blights and fungal diseases e.g powdery mildew.. Spider mite webs (L) and small red spider mites (R) both on tomato leaves.

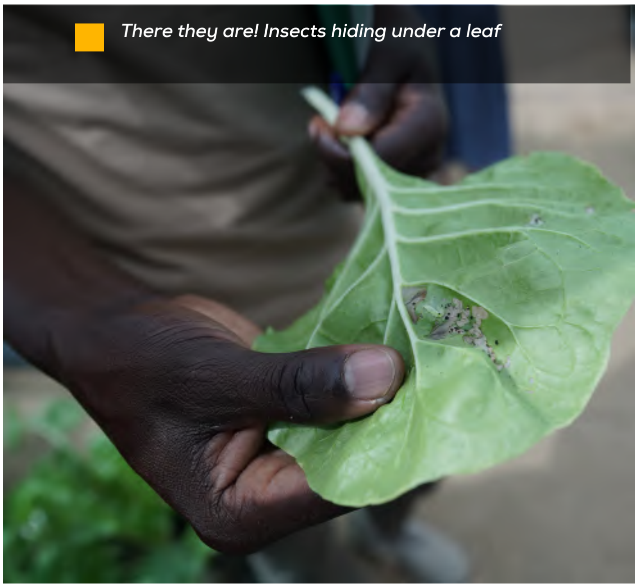
Link to the complete Pests and Diseases List

hydroshamba.org/info

Spider mite webs (L) and small red spider mites (R) both on tomato leaves.

The most critical step in managing pests and disease is scouting, as the old adage goes - prevention is better than control. Scouting is the at least daily activities of checking the crops for any changes in colouration, structure or other factors, and looking for pests, or traces of pests such as tracks, eggs and bite marks.

Scouting for pests on a hydroponic farm. Mites, aphids and caterpillars often hide at the underside of the leaf.



There they are! Insects hiding under a leaf

Once pests have been identified there are several courses of action that can be taken. The treatment options below are focused on utilizing locally available methods, primarily due to practicality, but also due to the nature of potential harm from potentially toxic agrochemicals, especially when used in contexts with few controls, high levels of contact with environment and low literacy. These methods include homemade pesticides, such as neem extract, as shown below and also homemade traps for white flies and other pests. Other measures, such intercropping can also reduce pest burden, basil has some pest deterrent properties and grows well in ASALs.

Leaves of the neem-tree are soaked in water. The mixture can be used to repel pests.

4.6 Sensors and Data Collection

Understanding the progress and performance of a hydroponic farm is very important to optimise production and accelerate troubleshooting. This section discusses the what, how and why of data collection in the case study farms.

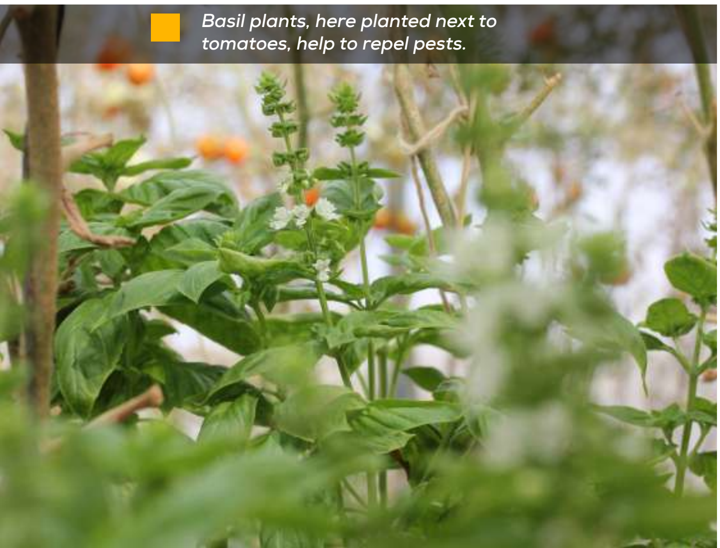
The most sensitive element of a hydroponic farm is the nutrient solution, this needs to be monitored very closely to ensure that it is not too dilute or too concentrated and that the pH is appropriately balanced. Temperature is an important factor both directly to the plants, and indirectly as it can cause evaporation resulting in increased concentration of the nutrient solution. Monitoring these factors provides an empirical understanding of the farm dynamics.

The need to monitor nutrient water is possibly the greatest limiting factor in scaling hydroponic farming in ASALs. Literacy is a key barrier, however, as mobile phone use continues to spread the capacity to use basic sensors will be more prevalent.

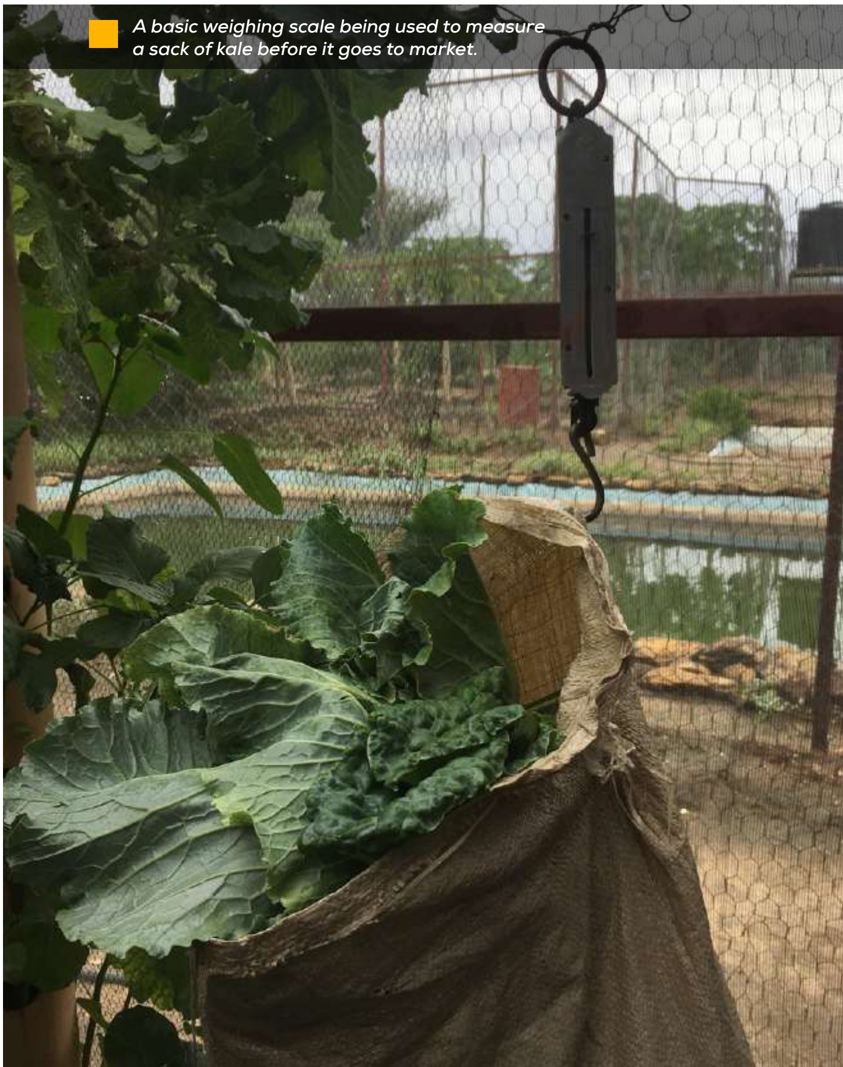
In addition to taking individual measurements, detailed record keeping helps to understand how parameters change through time, this can illuminate long term trends and allow for comparison across seasons.

The table below shows some of the equipment used in farm monitoring.

A recycled yellow container being used to trap insects, especially white flies.



Basil plants, here planted next to tomatoes, help to repel pests.



A basic weighing scale being used to measure a sack of kale before it goes to market.

Parameter	Motivation	Equipment
TDS: Total Dissolved Solids	The most technical task of hydroponic farm management is mixing the nutrient solution, and ensuring that the mixture has the sufficient nutrients without excess. The TDS is an indication of dissolved nutrients.	Hand held TDS probe.
EC: Electrical conductivity	The EC is an indication of the free ions in the water, as most nutrients are delivered through dissolved ionic salts. Too much salt can harm the plant, too little will result in undernourishment.	Hand held EC probe.
pH of nutrient solution	Plants have preferred pH, which is required for optimal growth.	pH meters provide a quick and easy way to measure the acidity or alkalinity of any solution.
Water quantity	Often water is a costly input, monitoring the consumption can inform the performance of the farm, or let you know there might be an issue with equipment such as a leak.	Water meter.
Temperature	In conditions where temperature might critically impact growth, knowing the specific temperature can inform troubleshooting.	Thermometer, digital sensor.
Production	Recording productivity of a farm is central to ensuring the investment is justified.	Weighing scale

Case Study 10 – The importance of measuring Electrical Conductivity (EC), pH and Total Dissolved Solids (TDS)

The nutrient water used in irrigating and feeding crops must have the correct EC and TDS levels in order to ensure healthy growth. This is especially critical in ASALs where water quality and other conditions may be more changeable due to drought, and nutrient feed is more likely to concentrate due to evaporation, or be diluted due to wetting. Additionally, the high temperatures in ASALs may affect the nutrient composition, for example by making the ions more reactive and therefore more biologically available to the plants, or by accelerating reactions which create inert or harmful compounds. These conditions can also cause a reduction in the dissolved oxygen of the nutrient solution.

One instance in which the importance of measuring pH was clear is in the installation of new storage tanks at TBI Ileret. The nutrient mixture was measured as usual and found to be ok, however, overnight, the new tank had significantly increased the pH of the stored nutrient solution from around 6.5 to 10. This had to be rectified with acidic solutions (pH down) before the nutrients could be utilized.

Measuring the conductivity of nutrient solution.

The basic handheld sensors commonly used to measure EC, TDS and pH are available locally in Kenya and cost between $15-$35. We have had varied experience with this with about 30% of machines not working within 1 month of use, and find that calibration and cleaning with Deionised Water is required on a regular basis, at least weekly.

TBI has also experimented with using a graded litmus paper to enable trainees who can't read the meters to measure the water. But we found this to be impractical and imprecise.

Spinach and tomatoes are harvested and are ready to be consumed.

4.7 Harvest and Post harvest management

The last steps in the cycle of hydroponically produced crops are harvesting and post-harvest processes. The ultimate aim is to get the highest portion of food from the plant to the plate by effective collecting and good handling after the harvest. This section will provide an overview of practices to ensure that crops are properly harvested and treated to maintain their quality and freshness.

Harvest

Timing and frequency
It is important to understand the right time to harvest the different crops based on their growth cycle and maturity. The time is determined by the selected variety, but may be influenced by local conditions (weather, pests, nutrients,...) during the growth stage. The spinach variety Ford Hook Giant will for example mature in 40-60 days after sowing, the tomato variety Tylka F1 matures in around 75 days after transplanting. However, the characteristics given from seed manufacturers are only a first indication, as the harvest should finally be based on a physical assessment of the crop. This refers to its picking based on colour, size, texture or smell.

The timing of harvest can also depend on the following post-harvest processes. Some crops can be harvested at an earlier stage and will ripen during the time of transport or storage. This increases the shelf life and makes the yield less susceptible for damages after harvest. The Tylka F1 tomato variety can be picked at a mature green stage and then has an extended shelf life of over 21 days.

Leafy vegetables such as spinach or kale should be harvested as needed e.g. shortly before sale or consumption. This keeps the product fresh and avoids wilting.

Many plants produce the crops over a longer period. The Tylka F1 can give fruit for 4-6 months (although this might be reduced in hydroponic settings in ASAL), which are picked once mature. Spinach and kale continue producing leaves for many months and up to years if properly handled. The frequent harvesting promotes the formation of new leaves and prevents the plant from forming a head of flowers and dying off.

Techniques and tools

The right harvesting techniques and tools are important to keep the plant healthy and the yield without damages. For spinach and kales, the "cut and come again" technique can be used. The outer leaves at the bottom are cut first, while the inner leaves are left on the plant, where they continuously grow. The leaves should be selectively picked once they have reached maturity (size, colour, texture).

Harvesting can be done by hand but preferably with a clean and sharp knife, scissors or pruning shears to reduce force and disruption of plant roots. Tomatoes are usually hand-picked once they reach maturity. They can be twisted to detach from the stem and should be carefully handled to avoid damage to the skin.

	Spinach	Kale	Tomato
Colour	Rich green colour without yellowing or browning	Rich green colour without yellowing or browning	Full rich colour of the particular variety for full ripeness. If transported or stored can be harvested earlier when the colour is changing from green to the final colour.
Size	Can be harvested at various sizes	Mature leaves at around 20 cm	Depending on variety
Texture	Tender and smooth	Crisp yet tender, firm but not leathery	Firm yet slightly yielding for ripe tomatoes. Relatively firm for early harvest.


Kale leaves, freshly harvested, are placed into a bag for transportation to the market.

Post-harvest management

The final quality of the produce is determined by its handling from the field to the consumer. The most common causes for losses during this time should be avoided:

- Rough handling leading to physical injuries
- Pest damage or shrivelling caused by improper storage
- Contamination with pathogenic bacteria, pesticides and chemical residues

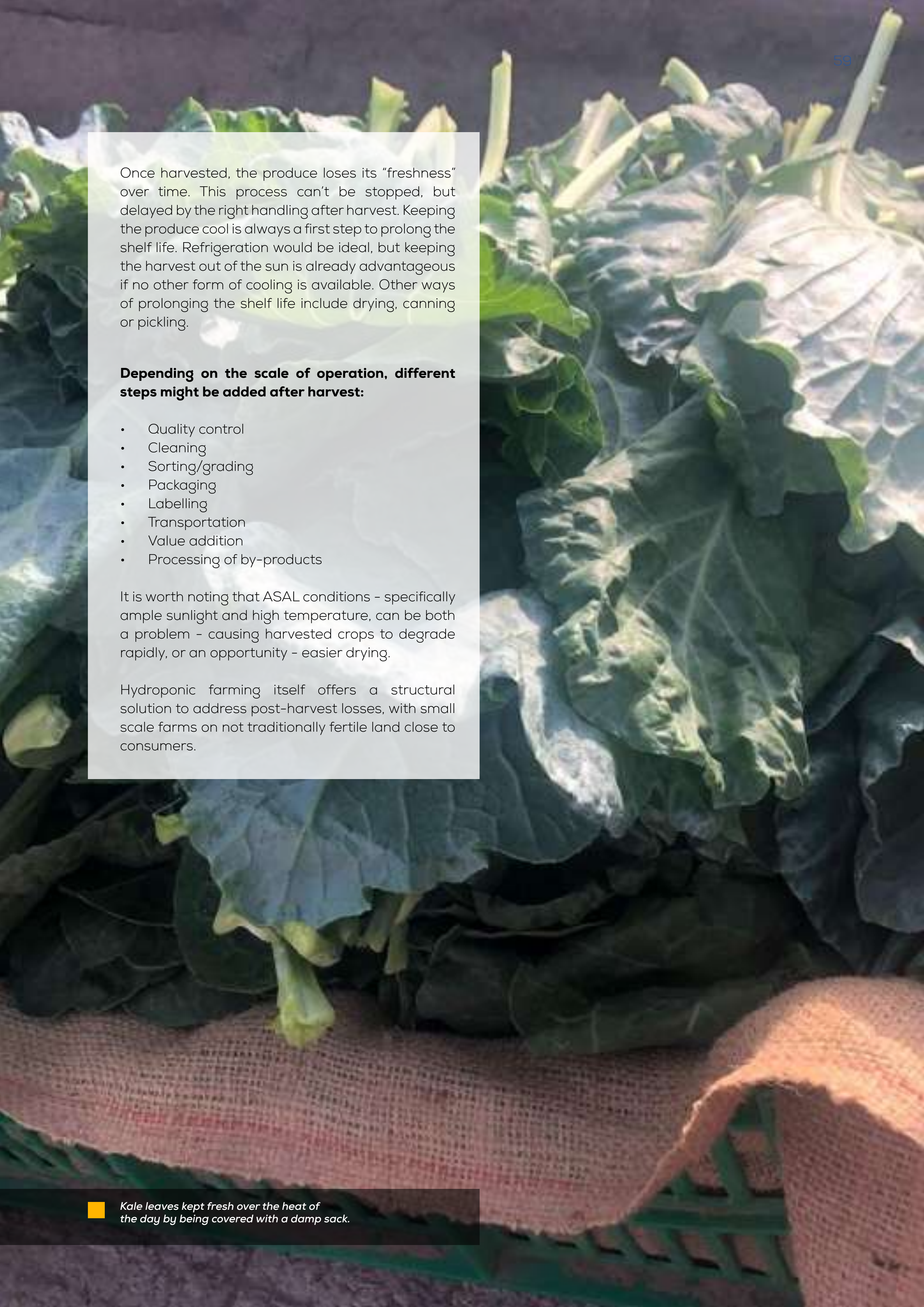
Once harvested, the produce loses its "freshness" over time. This process can't be stopped, but delayed by the right handling after harvest. Keeping the produce cool is always a first step to prolong the shelf life. Refrigeration would be ideal, but keeping the harvest out of the sun is already advantageous if no other form of cooling is available. Other ways of prolonging the shelf life include drying, canning or pickling.

Depending on the scale of operation, different steps might be added after harvest:

- Quality control
- Cleaning
- Sorting/grading
- Packaging
- Labelling
- Transportation
- Value addition
- Processing of by-products

It is worth noting that ASAL conditions - specifically ample sunlight and high temperature, can be both a problem - causing harvested crops to degrade rapidly, or an opportunity - easier drying.

Hydroponic farming itself offers a structural solution to address post-harvest losses, with small scale farms on not traditionally fertile land close to consumers.



Kale leaves kept fresh over the heat of the day by being covered with a damp sack.

CHAPTER V

ECONOMICS

The greatest barrier to widespread adoption of hydroponic agriculture is the perception of high capital cost as compared with "traditional" farming activities. This may be due in part to the common imagination of hydroponic agriculture as containerized, high-tech urban farms on top of skyscrapers in large affluent cities. Not all hydroponic systems are alike, and as shown here, hydroponic systems can come in many different sizes, shapes and levels of complexity.

This variation makes conducting an economic analysis challenging, however in this section some figures are presented to guide potential future investments and quell concerns about very high costs. Additional variation, arising from different settings (e.g. refugee community versus rural homestead) means there is a large range in both the set-up costs and potential profit due to differences in demand and market access. This section includes a discussion of the specific implications of working in ASALs on the evaluation of hydroponic farming, and the opportunities for cost reduction through the use of locally available materials in the most basic hydroponic systems.

05

TBI's Ileret farm from the air, the shade net structures in the foreground constitute 800m2 of hydroponic farm.

5.1 Budgeting for a Hydroponic Farm

Hydroponic farming usually has a high capital investment due to the significant plumbing ordinarily required to recirculate water and nutrients to achieve the critical high water use efficiency. Once a farmer has committed to making this investment, it often then follows that this should be protected and optimised by significant external structures such as a greenhouse or shade net structure.

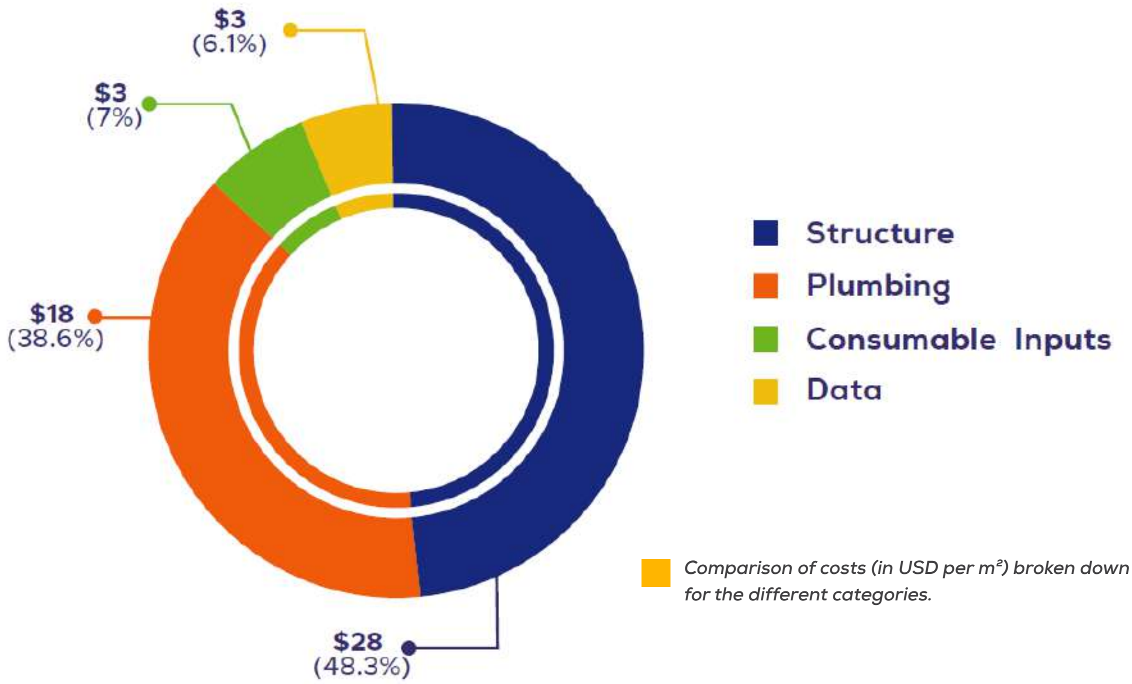
The use of artificial and specialised nutrients further drives up the cost, and also necessitates the use of monitoring equipment to ensure the nutrient solution parameters are optimised. These costs aggregate to result in high initial investment cost, and therefore necessitate highly productive growth of valuable crops to make economic sense. Below is a case study from TBI Ileret, giving an indication of the relative cost of set up.

Case Study 11 - TBI Hydroponic Farm Budget and Set-Up

This case study shows the cost per square metre (in 2023 prices) for farm establishment materials, from the 4 different units established at TBI Ileret. One point to note is the significant transport costs for many ASAL contexts, which is either borne by the farmer directly or through higher material costs that would be expected in urban centres such as Nairobi.

The cost for the farm is broken down into the following categories:

- ***Structure*** *- this refers to the overall metal frame, shade netting and chicken wire.*
- ***Plumbing*** *- this refers to all of the growing beds and spaces utilised for crops, and includes water delivery, water recirculation and growing media such as pumice.*
- ***Power*** *- in any hydroponic systems which rely on pumps to recirculate nutrients, these must have some power source. At TBI's Ileret farm we rely on the internal solar power system and consume approximately 2.5kWh per day for pumping water for around 1000m2 of hydroponic farm space.*
- ***Inputs: Seed, Fertilizer and Pest Control*** *- this is enough to establish and maintain a "season" or see a crop through to maturation and harvesting. This will naturally vary between crops.*
- ***Data Collection*** *- this is the equipment for monitoring key water parameters such as TDS, EC and pH, as well as for recording crop harvest.*



Comparison of costs (in USD per m²) broken down for the different categories.

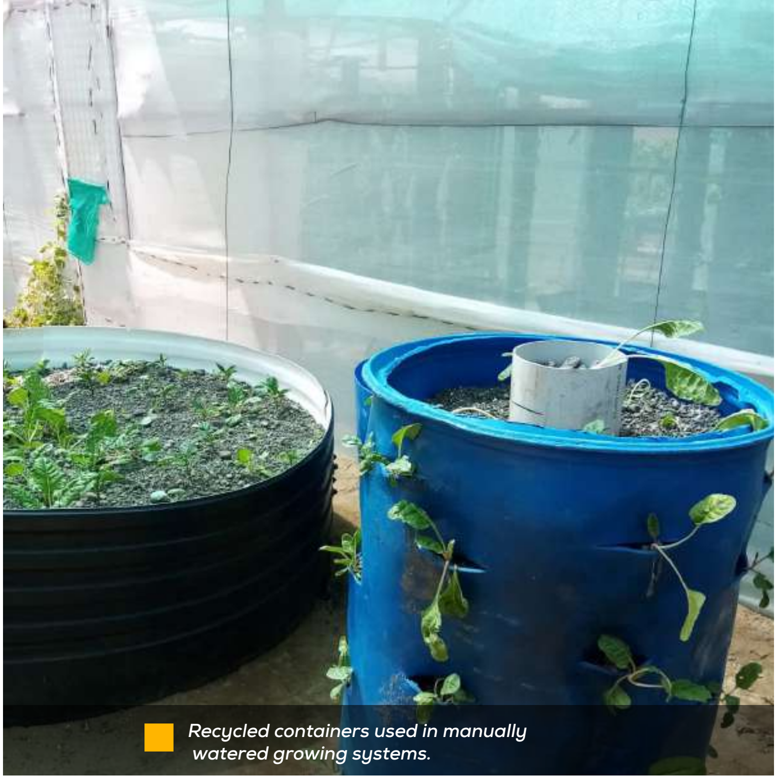
This approach to hydroponic farming works with institutional or commercial backing and funding to cover the investment cost, but is prohibitively expensive in many cases, especially homesteads where the impact of hydroponic farming could be most profound.

5.2 Making Hydroponics More Accessible

In order to resolve this issue, different options for removing the financial barriers by reducing the cost of hydroponic farming and make it more suitable to ASAL contexts have been explored, these are listed below. (Note, other barriers, such as capacity, as discussed in following sections.)

- **Manually watered troughs.** These remove the need for electric pumping, removing a significant cost, and are also extremely modular, so can be added gradually, rather than in one large investment.
- **The use of large containers for stand alone growing beds**. At TBI Ileret the use of both plastic 200l drums and broken water tanks for hydroponic use was successfully demonstrated. This only requires a small container to catch the recycled nutrient solution and growing media, though it should be noted that the growing media might not be efficiently used due to the dimensions of the containers.

Manually water troughs, these enable farming on a modular, small scale without expensive investment in pumps.



Recycled containers used in manually watered growing systems.

- **Using locally available materials.** As above, there are often materials available that have been disposed from other uses and can be repurposed, or that exist in ASALs and can be integrated into hydroponic farming in novel ways. An example of this is the use of etriae or Prosopis juliflora (invasive plant species occuring in many ASAL regions). The wood can be used for posts in constructing support and external structures for farms, from materials that cost ~$1 per 4m post. It is locally available, and fairly resistant to insect damage.

Prosopis timber and used cans turned into a manual hydroponic growing system.

- **Locally produced nutrient solution.** Once a farm has been established one of the highest contributors to the operating cost is the nutrient solution required to fertilise the plants. This is typically available as a commercial solution or powder, as discussed in Chapter 4. However, producing bionutrients from locally available products can significantly reduce the cost of nutrient solution.

5.3 Value Chain Integration and Financing a Hydroponic Farm

From a domestic perspective, the availability of newly accessible fresh fruits and vegetables can significantly improve household nutrition by complementing existing foods. Capturing the value of this contribution, especially in ASALs where malnutrition is such a critical challenge, is not straightforward and as such calculating a true ROI for small scale systems is not directly possible. However, in settlements, where investments are made in commercial scale farms serving larger populations it is possible to assess the economic impact of hydroponic farming efforts.

Tomatoes are harvested in Kakuma before being sold on the local market.

Trainees at TBI's Ileret farm sorting the harvest before taking it to market and home for consumption.

5.4 Financing for Hydroponic Farming Initiatives

The organic widespread proliferation of hydroponic farming without government or non-governmental development support is possible but unlikely. However this need not be an impediment as county governments in ASALs are investing billions of shillings annually in irrigated agriculture, and the performance of the status quo shows that new approaches are needed. Also, development partners can play a major role in the financing of initiatives or in supporting the enabling environment (see chapter VII).

The topic of hydroponic agriculture in ASALs is most relevant for most development agendas, linking to many of the SDGs and aligning to adaptation to climate change, efficient natural resource use, employment and gender. The information provided in this guide should sensitize decision makers on the topic of hydroponics. Only these hydroponic farm initiatives should be financed that are fully thought through. Well-intentioned but poorly thought-out projects have little chance of success and usually end up as "white elephants", damaging the reputation of hydroponic agriculture in ASAL regions.

Case Study 12 - Price stabilization for Kale's production at Ileret- TBI

The TBI Ileret hydroponics work has introduced produce which is otherwise unavailable on the market. Ileret village is 500 km from Marsabit town, and the road networks to the rest of Kenya and to Ethiopia are very poor with little private, and no public transport. As such, there is minimal availability of fresh fruits and vegetables, especially leafy greens. Therefore, when the trainees of the TBI Ileret Water and Energy for Food Program project began selling produce into Ileret, there was no precedent to follow.

The price of 100 KSh per kg was suggested to trainees, however, the produce was being sold at double this, 200 KSh per kg. There were challenges in assessing the accuracy of collected data - due to trainees not wanting to fully disclose their income and due to the difficulty of checking how much produce is being sold as a kilo, especially as in the arid conditions the leafy produce loses mass rapidly due to wilting. However, it is clear that the price is being restricted by people's ability to pay, rather than a balance between supply and demand, but even this factor is being impacted by local socio-economic dynamics especially the influx of cash transfers due to the ongoing drought. These "cash transfers" enable families to cope with the impact of the drought and result in a large increase in liquidity within local communities. The knock-on effects of this on the price of food items, especially those that are locally produced, is not clear.

CHAPTER VI

CAPACITY BUILDING

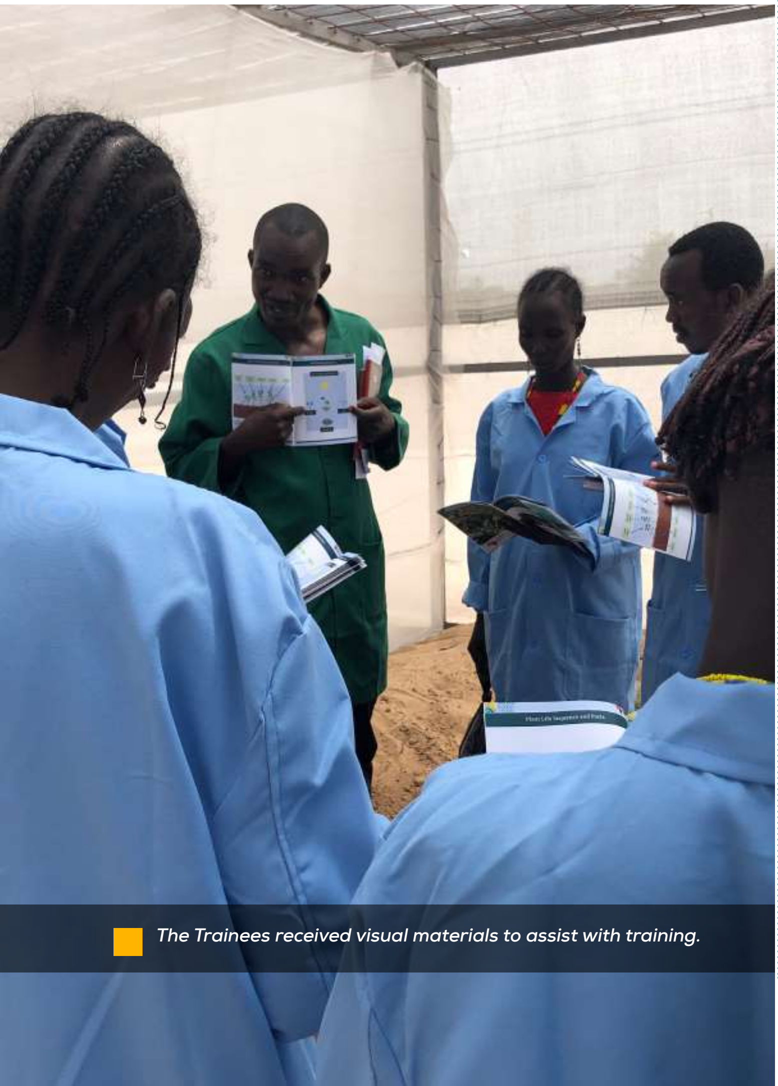
Proper capacity building is critical to enabling the successful adoption of hydroponic agriculture. This section presents the case studies from capacity building efforts in both Turkana and Marsabit Counties, and then outlines some key factors to consider when designing and implementing hydroponic farming efforts.

06

6.1 Introduction

Good training is the key to successful hydroponic agricultural dissemination, and must be conducted through thorough programs which provide all required information in an accessible way. This must also be tailored to the local context and the particular factors of conducting hydroponic farming in hot, arid conditions. Some key factors are highlighted below:

- **Educational background:** literacy levels in ASALs are lower than the national averages, and therefore training programs in these areas, especially those that target women, need to be designed to be accessible.
- **Customary agricultural practices:** many ASAL communities have incorporated some form of agriculture in their economies for centuries, recognising this and incorporating the rich local knowledge it entails in hydroponic agriculture dissemination is critical to success.
- **Perceptions:** poor capacity building often leads to failure, which in turn results in negative perceptions about the systems or technologies being deployed. For this reason, it is especially critical that good capacity building is conducted when deploying hydroponic farming as a new agricultural technology.



The Trainees received visual materials to assist with training.

Case Study 13 - TBI Ileret WE4F Project

As part of the Water and Energy for Food project activities, TBI conducted a capacity building program in Ileret from 2021-2022.

Trainee selection

The trainees were nominated by their communities, with each of the 4 clusters within Ileret village providing 3 trainees, for a total of 12 trainees in the initial cohort. The only requirement was for each cluster to nominate individuals who would be committed to the training program, both hard working and not likely to leave midway. The first cohort had varied but limited literacy, with 8 of the trainees speaking minimal Swahili.

Schedule and Remuneration

The trainees reported to TBI Ileret at 8:00am, one hour after the usual working day had begun, to allow routine activities and planning by key staff, especially the Hydroponic Farm Manager. The trainees were active until 12:30pm, this timing was designed to make the program as convenient as possible for women who likely have ongoing household responsibilities. The trainees were given morning tea and lunch on site, and a small stipend to compensate for missed economic opportunities.

Trainer

The trainer who implemented this training program has experience in diverse agricultural settings, including commercial scale NFT elsewhere in Kenya, and developed expertise in ASAL settings by leading the expansion of the hydroponic farming at Ileret. In addition to technical expertise, the trainer's enthusiasm and patience enabled the trainees to feel comfortable and cut across cultural, language and literacy barriers.

Training Program

The training program was split into 3 sections, each of which was 8 weeks long, transitioning from more theoretical to increasingly practical. The curriculum (see annex) was developed by TBI staff, based on experience with in-house staff training and a review of online resources. The initial training covered:

- *Plant growth basics: parts, requirements, health.*
- *Basic introduction to hydroponic systems.*
- *Establishing, managing, planning and troubleshooting with a hydroponic farm.*

The 2 later sections transitioned to implementing and practising hydroponic farming, including eventually to harvest and sale of hydroponically grown crops locally. The attendance of the first section of the training was over 90% this reduced slightly as one of the trainees opted to leave the program and 2 others sought employment from new NGO activity in the area. Assessments were conducted to measure the knowledge retention and general understanding of the trainees, all of the scores were over 80%.

Hydroponic expert and trainer Shadrack in one of the theoretical classes.

Challenges

Literacy: *Language fluency was a limitation of the training program, however given the variable Swahili fluency in the group, this was overcome by emphasizing visual learning and through some of the trainees acting as translators. A remaining major challenge faced in training was the lack of literacy amongst the trainees, while this was overcome for the majority of the teaching, use of meters to measure key characteristics such as EC, TDS and pH was not possible by a majority of the trainees. To mitigate this, two efforts were made: using visual guides were possible, such as litmus paper in place of pH - this was found not to be precise enough, and secondly, conducting a voluntary adult education program. The latter developed organically between trainees and TBI staff, but was voluntary and therefore did not adequately address the need.*

Local volatility: *One of the major challenges we faced during this training program was the major drought of 2020-2023. This placed extra stress on the families in the area generally, but specifically impacted the training program in two ways. Firstly, the vast majority of absence by the trainees was as a result of needing to be present at home for the receipt of food aid and other humanitarian support to mitigate the worst impacts of the drought. Secondly, the drought brought increased conflict, and led to the temporary migration of some families away from Ileret.*

Outcomes: *The trainees enrolled are now all proficient at Hydroponic Farming, they have been harvesting, consuming and selling produce locally, with over 4000kgs sold to date in Ileret. An organic training program has developed, where new trainees are brought on board and trained by members of the initial cohort as they go about their daily activities in the farm, with some oversight from the original training manager.*

A trainee harvesting Amaranthus leaves.

Case Study 14 – GIZ Capacity Building

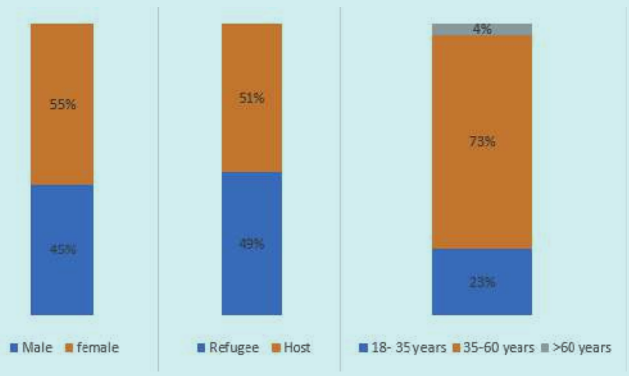
Participant Selection

The project targeted participants from Turkana West Sub-County with a special focus on Kakuma and Kalobeyei settlement. A total of 121 participants were selected through a competitive and participatory process comprising of the following steps:

1. ***Community mobilisation*** *carried out with support from County Ministry of Agriculture, Pastoral Economy and Fisheries (MoAPEF), Department of Refugee Services (DRS), WFP, FAO, Sub-County Administrator, Deputy County Commissioner, water pan management committee, village leaders and the Member of County Assembly (MCA)*
2. ***A selection committee*** *comprised of representative from DRS, MOAPEF, Social Development office, Sub- County Administrator, GIZ and MIF was set up to steer the process of selecting the participants.*
3. ***A selection criterion*** *for participants was developed by the selection committee. The criterion focused on identifying participants who had prior experience in agriculture and had shown interest in starting agriculture as a business.*
4. *An expression of interest was developed, distributed, and placed in strategy locations such as chief office, ward administrator office, community centers etc. Help desks were set up to assist people who could not read and write. Mobilization was also done through local administrators, media, church leaders and village leaders.*
5. ***Vetting and Selection*** *of the applicants: Vetting of all applicants was done by the selection committee against the selection criteria developed in 3 above.*

Beneficiary Profiles

The gender and refugee dynamics were balanced for selected participants. This was in line with the targeting and selection criteria developed by the selection committee. A total of 121 participants were selected and participated in the theory and practical trainings. Fifty percent of the participants were refugees. Fifty four percent of the total participants were female. Below is the graphical representation of the participant profiles. Majority of the participants' age was 26 – 60 years.



Profiles of the beneficiaries

Trainings

Theory and practical sessions were carried out over a period of 6 months. Participatory methods such as group discussions, use of illustrations and demonstrations were used. Practical sessions were done for a period of five months. Principles of learning by doing were used. The participants were taken through all the production cycles for diffrent crops i.e tomatoes, and green vegetables . The main concepts covered during the trainings include: site selection, introduction to hydroponics concepts, hydroponics greenhouse orientation, crop production and nutrition, crop management practices, media treatment, nursery management, nutrient solution mixing, fertigation, harvesting, postharvest handling and Business Development Services (BDS).

A pre and post training assessment on the participants was carried out to check on the check on knowledge and skill gained. Ninety percent (90%) of the participants passed the post training assessment. a fruther On job training, and handholding and business incubation was carried out for 2 crop cycles i.e 1 year. this contributed a lot in improving the knowledge and skill among the participants.

6.2 Designing Hydroponic Farming Capacity Building

The case studies above highlight some key considerations in designing and implementing hydroponic farming capacity building, below these factors are explored with a discussion about the decision making process involved for each.

Content

The content of the training is presented in annexes to this publication, but roughly follows the information presented previously in Chapter 4. Depending on the project emphasis and the background of the trainees, for example the program might emphasise basic agricultural practice, or encourage innovation through continued local adaptation.

Level of training

- **Farmers:** when training is being conducted directly with the end users who will be managing their own farms, hands on information and practical experience is of great value.
- **Trainers of trainers (ToTs):** training that is given to disseminators, who will then go on to train the actual farmers needs to be higher level, to enable the ToTs to critically engage with any training contexts and conditions and tailor the information they have for maximum impact.

Duration of training

The training conducted in both Ileret and Kakuma both lasted for several months, this is critical because trainees must be taken through the entire life cycle of the crops they will grow, and must have enough time to encounter and resolve challenges, such as pests or maintenance issues.

This time investment is inherently costly, but very necessary, short training programs that seek to maximise efficiency or the numbers of people trained are a false economy, leading to insufficient information, unconfident trainees and therefore failed projects that can perpetuate inaccurate negative perceptions about hydroponic agriculture.

Theory and practice

Training that prepares both farmers and ToTs well needs to have a balance of theoretical information and hands-on practical experience, in order to build a theoretical understanding of processes and plant development, while also fostering the practical ability to act upon the theoretical knowledge.

CHAPTER VII

ECOSYSTEM

07

7.1 Introduction

"It takes a village to raise a child" - and it takes a well functioning ecosystem to enable sustainable hydroponic projects in ASAL regions. The ecosystem - also called enabling environment - describes the conditions in which hydroponic systems operate. The better the conditions, the better will hydroponic projects work - now and in the long term.

Some of the conditions have already been mentioned in previous chapters and they are only briefly summarized for completion:

- Markets, to connect producers with consumers (depending on the size of operation)
- Infrastructure, including roads and ways of transportation to access markets
- Inputs, such as nutrients, seeds and pest control
- Capacity building, to equip individuals and groups with skills to operate hydroponic systems
- Community involvement, can go hand in hand with capacity building, to engage local communities and create an awareness for the technology and produce
- Resources, including equipment and parts, advisory and finance
- Reliable water source, which might include harvesting, treating, storing.

Case study 15 - Water (RO) infrastructure TBI Ileret

As part of the Water and Energy for Food Programme, TBI installed a solar powered reverse osmosis machine (figure 7.1) in Ileret. This machine has the capacity to produce 20,000 liters of water per day, with zero carbon emissions using only solar power from a 7.2 kW PV array. This will allow for expansion of the TBI Ileret hydroponic farming and also use the farm for training the local community. Further the project supplies water to the local community.

The RO system provides critical water supply in a region with very limited fresh water. In Ileret, water is sourced from Lake Turkana - which is brackish and contaminated, shallow hand dug wells in dry rivers - which are limited and also risk contamination from biological contaminants, and from boreholes - which are also largely brackish. Access to rainwater is limited by very low and very variable rainfall.

Hydroponic agriculture in Ileret was limited due to the lack of fresh water; the new reverse osmosis system has enabled all of the Ileret farming activities discussed in this text. However, the farms are still restricted due to the lack of freshwater, which is still limited to TBI Ileret due to the relatively small amount of water available. This illustrates the importance of basic services in facilitating new economic opportunities.

The solar powered reverse osmosis system in Ileret - a critical infrastructure enabling hydroponic farming activities.

The above points describe local conditions required for systems to function. If all of them are available (or made available), individual/local hydroponic sites will function. An example is given later in Case Study 7.1.1 which describes the long term operation of a system at the Turkana Basin Institute in Ileret, where most of the described conditions have been created before the systems was established.

However, when scaling up hydroponics to a more regional level (e.g. on county level or for ASAL regions) or even national level, the required conditions also scale up to a more broader level, as the following subchapters describe.

7.2 Public awareness and communication

Public awareness for hydroponics is rising around the world, while numerous startups (mostly highly complex systems) or even supermarkets have adopted the technology and communicate about it. Awareness is also rising in Kenya and other African countries, where local suppliers started operating in the market, catering for a demand often created by donor funded organisations or projects. Beyond the rising interest, a balanced communication is vital, drawing a realistic picture of hydroponics (see SWOT analysis below) to demonstrate opportunities, avoid misconceptions (see chapter 1.3) and manage expectations.

Strengths	**Weaknesses**
• Water efficient & soilless • Year around cultivation • Simple adaptations	• Investment costs & material • Technical expertise • Resource dependence
Opportunities	**Threats**
• Diversification of farming • Entrepreneurship & employment • Climate resilience	• Water scarcity • Pests & diseases • Extreme weather events

There can be different forms of communications, depending on the audience and existing experience on hydroponics, classified here under internal and external communication.

Internal would be the communication among stakeholders (see chapter 7.4) that are already aware of and working on hydroponics. Such a communication could be in form of the following:

- Gatherings (conferences, workshops, platforms)
- Newsletters to stakeholders
- Website of hydroponics

The aim of the internal communication would be to exchange information and experience on hydroponics within a certain context and enable a cross-collaboration between stakeholders. Indeed, this publication arose out of a gathering of hydroponic agriculture practitioners in northern Kenya.

External would be the communication to a wider public who don't know about hydroponics, or have only heard of it. These people could be reached via:

- Radio, TV
- Social media, youtube
- Print media

The aim of the external communication would be to inform a general public or a certain target group (e.g. customers, beneficiaries, decision makers) on the opportunities of hydroponics.

When scaling hydroponics to a bigger extent, both internal and external communications are to be thought of. The communication should be done in a realistic way, specific to a national or regional context. Experiences from demonstration farms (see below) are well suited to raise public awareness. Reaching public authorities (e.g. Ministries of Agriculture, Water, Natural Resources) or having them part of internal communication is key for a large-scale deployment.

7.3 Education, Research and Development

One condition for an enabling environment on a bigger scale are human capacities, research and development. This includes:

- Institutionalise hydroponic trainings or develop curricula with universities or schools to train students on the theory and practicals of hydroponic agriculture. The flower industry in Kenya has adapted hydroponics into their operations - leading to a demand on people trained on hydroponics, but also increases the overall capacities within the country - a favourable condition.

- Establish pilot sites in ASAL regions to do applied research on hydroponics in ASALs. This includes research on suitable crops, system improvements & adaptations, new approaches or other knowledge gaps (see chapter 8 - Research).

- Research and development on the long term operations of hydroponic farms including operation procedures, maintenance, assessing different materials under ASAL conditions and impacts of hydroponics to local communities.

Best practices can be used for internal or external communications. Such an example is the Hydroponic Farm in Turkwell as highlighted in Case Study 16.

Case Study 16 – Long term operations at TBI farm operations

Hydroponic agriculture at TBI Turkwel was started in October of 2017. The aim of this farm was to provide fresh produce to support the institute's activities, while developing and refining hydroponic agriculture in a novel context. The farm was installed alongside traditional farming and a small aquaculture project.

The Hydroponic Farm Manager received training from Hydroponics Africa. The existing staff were proficient in traditional soil-based agriculture in Turkana, and the team has experienced no turn over since the inception of the farm.

The farm initially consisted of a mild steel structure, with the 'rooms', one for NFT cultivation of spinach, one for vertical pipes cultivating kale and amaranthus, and a central space for nursery and small quantities of other plants such as coriander and lettuce. This consisted of a total of 92 m2 and produced over 1100 kg annually. The nutrient solution is mixed in a single 2000-liter tank which is circulated using a solar powered pump. The farm utilizes entirely organic solutions to address challenges associated with pests and diseases, these and other issues faced are listed below in table 7.2 below.

This farm has been producing vegetables continually since 2017 and is still in operation.

The TBI Turkwel Hydroponic Farm as seen from the air.

The water for the farm comes from two sources, the Turkwel River in small quantities, and from the facility's borehole. The chemistry of these is generally adequate for farming, however both have a high pH of around 8.5, and this can vary with seasonality. The water is not treated, rather "pH up" and "pH down" solutions are utilized to adapt the water as required.

Following the success of this initial investment, the farm was expanded to include spaces with troughs, as well as more horizontal and vertical growing pipes. The total area now under cultivation is 424 m2, and the total annual production from the farm areas is over 4500 kgs.

The hydroponic farming activities of the TBI in Turkwel started in 2017 and is still in operation.

Challenges and possible solution at the hydroponic farm Ileret

Challenge	Solutions
There are many pests and diseases which routinely affect the hydroponic farm, especially white flies, red spider mites and other insects. These are worsened by the presence of large trees, whose blossoms attract many insects.	• The most important factor in addressing these challenges is scouting and early detection of potential issues. Once a pest or disease is established, it is very hard to address it, and more effective to remove all plants, sanitize the space and start again. For further details about pests and diseases - see annex. • Site selection is critical in avoiding trees/vegetation that spread or harbor diseases.
Seed quality. The seeds used for this project have been sourced from Nairobi, as there are limited sources locally. The same variety from different seed companies will perform very differently.	• It has taken some years to develop an understanding of which seeds are best to use through trial and error and careful observation. Do not write of a certain crop for your specific context but explore other varieties of this very crop.
Water quality.	• Variability in water composition, especially pH, requires careful management in nutrient mixing.
High temperatures. This has a physiological impact on the plants, and increases pest burden, especially for pests such as red spider mites, which thrive in hot conditions.	• Showering is used to increase evaporative cooling within the greenhouses to reduce the negative impact of high temperature on crops.
The high wind and dust in the region also impact plants, especially during periods of drought. This impacts the plant's ability to photosynthesize and conduct gas exchange, and can accelerate evapotranspiration.	• Showering also address these challenges, by removing dust on leaves and decreasing the quantity of particles suspended in the air.

Maintenance

Each of the growing sections is emptied of plants at least once every two years. The media, mostly pumice, is removed and rinsed with clean water and dried in the sun to allow UV to sanitize the media. The growing structure is then reinstalled and crops planted as usual. This ensures that pests and disease cycles are interrupted.

General maintenance includes replacement on NFT growing cups, nursery trays and reforming of PVC growing troughs. The greatest wear on the system is seen on the plastic components.

In the last 12 months (year 5) of the farm's operation, we have been conducting maintenance of the first structure. This includes replacing rusted metal where necessary and repainting the overall structure, while also fixing perishable components such as shade netting, which is particularly prone to wear in the high temperature, wind and UV conditions.

7.4 Stakeholder collaboration

Participants from various organizations at a hydroponic workshop organized in July 2022 at TBI Turkwell.

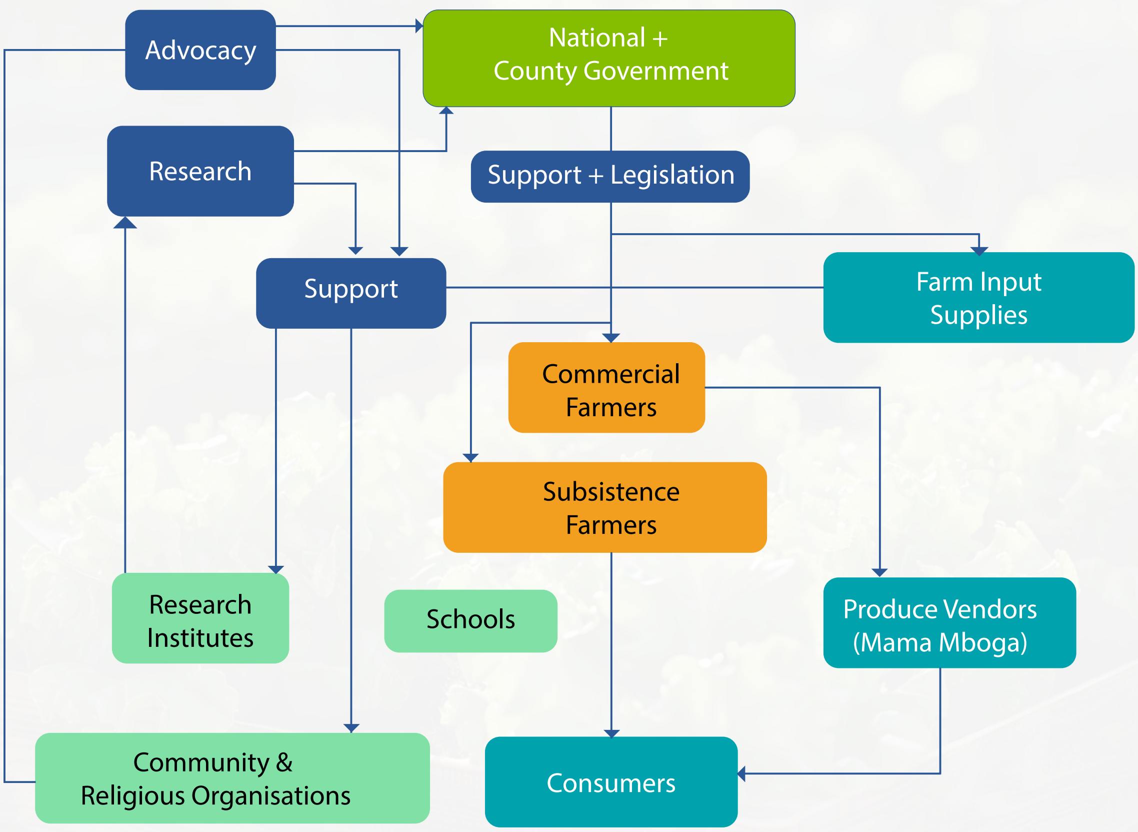
Depending on the national context, there might already be different actors working with hydroponics. In the case of Kenya there are system suppliers, input providers, research organisations, development agencies, county governments and more already involved. They can be broadly grouped into:

- Public (County and National Governments, Agencies & Authorities)
- Private (Companies, farmers and their organizations)
- Institutions (Academia, Research, Civil, TVETs, Financial)
- NGOs & CBOs (Development Agencies, UN organisations)

The stakeholders have different interactions with each other, e.g. regulatory, commercial, informative or supportive.

A positive condition for an enabling environment would be a good collaboration between the different stakeholders, making it indispensable that the different actors are aware of each other. There are usually many stakeholders, with many and varied expectations. Mapping stakeholders in relation to their influence and interest in the project makes it easier to leverage on their strengths and to communicate (internal and external) with them.

Identified stakeholders' analysis with potential area for partnership	
Stakeholders	**Partnership areas**
Public • Government (national and county) & Ministries • National Drought Management Authority (NDMA) • Kenya Plant Health Inspectorate Service (KEPHIS)	• Contributions to government development priorities (national strategies, action plans) • Strengthening service delivery systems (capacity development). • Facilitation of enabling regulatory/ policy environment. • Leveraging/sharing resources (human, financial, materials, data etc.).
Private • Suppliers • Market for produce • Commercial Practitioners (e.g. HAL) • Subsistence Farmers	• Hydroponics technology adoption in communities • Facilitation and capacity development. • Sharing resources (human, financial, materials, data etc.) • Investment
Institutions • Religious/communities • Schools • Universities • Research Institutions (e.g. TBI)	• Inputs towards training curriculum development. • Partnership in research, innovation and product development in hydroponic farming • Technology transfer and capacity development • Sharing resources (human, financial, materials, data etc.)
NGOs • International and National • GIZ • WFP (and other UN agencies)	• Support in development of technical guidelines. • Sharing of knowledge, evidence, and data/ information. • Financing/investment in development of hydroponic technology



7.5 Policy regulations

Public authorities such as governments and their ministries have a special role in the enabling environment as they are in a position to change laws and regulations, decide on national strategies or coordinate the action of development agencies. With their mandates they have a detrimental influence in the speed with which hydroponics can develop on a national scale.

In an ideal scenario, the different stakeholders collaborate and public authorities are aware of certain situations and can act upon. However, especially with new technologies, the sector is often not yet organised and communication channels between public and private sectors not yet established. Stakeholder mapping and internal communication are a good start to create a more organised group of actors and to exchange with representatives of public authorities. In a more formalised process, roadmaps or actions plans for hydroponics can be worked out to advise the public site on needs to improve rules and regulations.

From another angle, also the public authorities can have an interest in the development of hydroponics and might be actively involved in its promotion. In Kenya, County Governors from different ASAL regions expressed interest in the technology as it provides an opportunity for regional entrepreneurship and employment, can help to develop ASAL counties and caters to national strategies.

CHAPTER VIII

RESEARCH (KNOWLEDGE GAPS)

08

The topic of hydroponics has gained a lot of attention in recent years, that's especially the case for the more complex and automated systems. These hydroponic farms are getting less labour-intensive and more cost-effective while increasing yields. Outcomes from research and academia have led to these advances and are continuously pushing the growth of the sector.

However, the research is often geared towards the more complex and profitable systems in industrialised nations, while research specifically on hydroponics in ASALs lacks behind.

Inspiring new research connections on a farm tour at TBI Turkwel.

Sources of information

To also drive the development of systems specifically adapted to the ASAL context different sources should be plugged into. In Kenya alone, quite some farms are already in operation in ASALs - run by different institutions, organisations, companies or groups. In all of these existing systems, experience is made, data captured and analysed. Sharing the best practices and learnings would be crucial to also drive the application of hydroponics in the ASAL context. This however requires well established connections between the different stakeholders - government, innovators, institutions, users, consumers and more.

Also, universities especially in ASAL countries could focus some of their research to the assessment of hydroponics in harsher environments and drive knowledge on system designs, business cases, plant varieties, pests & disease control, greenhouse structures, the use of local material and much more. As already described in chapter 7, research is a huge enabler for the upscaling of hydroponics in ASAL settings.

In the meantime, hydroponic practitioners in the ASAL regions (only) have the possibility to use data and research that was done elsewhere and to apply it to the local context. Such an adaptation will obviously require certain trials and experiments.

Knowledge gaps

There is a need to identify key existing and emerging issues relevant to hydroponics farming in agricultural production in the ASALs that would benefit from a stronger evidence base and help to develop the sector and to steer policies. This includes questions such as:

- Are there any chemical residues in crops, seen that they grew in plastic?
- How effective are the biopesticides and bionutrients?
- What should be the expectation on water quality, could even waste water (e.g. brine from reverse osmosis) be used?
- How to avoid flower abortion and ensure pollination in closed greenhouses?
- Which type of shade nets are most effective in the ASALs and for which crops?
- What plant spacing should one maintain to maximize yield with minimal inputs in hydroponics farming?
- Under which growing media would tomato, kales, or spinach cultivars do best in hydroponics in the ASALs?
- How can high temperatures and high evaporation of ASALS be controlled in hydroponics?
- How do hydroponic systems perform economically in ASALs?
- What is the nutritional value of hydroponically produced crops and what are ways to add additional value to them?

Harvest of sweet potatoes grown in a trough system

Case Study 18 - TBI cultivation of sweet potatoes in hydroponic troughs.

One of the main aims of the hydroponics activities at TBI following proof of concept and production of basic vegetables is to increase the variety of crops produced, with a focus on those of particularly high calorific value, in order to have a greater impact on nutrition.

At the time of the workshops held in preparation of this document, minimal progress had been made, however in the time taken to prepare this document TBI has been able to successfully cultivate yellow sweet potatoes (the early part of the first harvest yielded 2kg from 3 plants) in pumice troughs at Ileret. This effort has been accompanied by trial and error, failure of several varieties and configurations, and demonstrates the need for continual research to improve the performance and scope of farming activities.

Harvested sweet potatoes after cutting and frying

CHAPTER IX

CONCLUSION

09

In this guide, we aim to share the experiences of organizations operating in ASAL areas, offering insights to a broader audience. While not exhaustive or highly detailed, the guide seeks to serve its purpose by guiding individuals in their thought processes and sparking discussions on topics and ideas that require further consideration when applied.

The guide's depth makes it applicable across various scenarios in the ASAL context, emphasizing the crucial thought process involved in planning and designing hydroponic systems tailored to local conditions. The hydroponic systems at TBI, in the Kakuma refugee camps, and other ASAL locations have evolved through years of trial and error, experimenting with different structures, plant varieties, nutrient solutions, and more. While these experiences may offer guidance to some, others may have developed their own adaptations to make hydroponics feasible in ASALs.

Hydroponics has a wide range of applications, from simple to highly complex systems, addressing niches like urban production or regions with challenging climatic conditions for traditional agriculture. While complex applications have extensive literature, the guide aims to fill a gap by sharing practical experiences and examples of relatively simple hydroponic systems in the ASAL context. Its motivation is to publish these experiences, shedding light on the opportunities and challenges that hydroponics presents in harsh and neglected areas. The guide serves as an initial step in addressing this information gap, with the hope that more institutions will share best practices or conduct further research on the topic.

Acknowledging the importance of ASAL regions, both current and former presidents of Kenya have emphasized their role as a "food basket," contributing to food security and the National Agenda. Hydroponics, when properly adapted to the ASAL context, can be a transformative technology driving development and improving livelihoods in rural settings. However, this necessitates substantial stakeholder engagement from various sectors, including the public, private entities, research institutions, organizations, and end users. The development of systems should prioritize usability, maintenance, and replicability by local communities.

In environments conducive to its implementation, hydroponics emerges as a sustainable technology supporting consistent vegetable production in regions with high demand but challenging climatic conditions. This approach goes beyond food supply, creating local employment opportunities and encouraging innovative solutions to maximize the use of locally available resources. The hydroponic systems at TBI serve as a compelling example of how this technology can bring transformative change to local communities, underscoring the importance of ensuring all necessary factors are in place for its full potential.

Annexes

Training Documents
On this page we've curated hydroponic training information.

www.hydroshamba.org/training

More Information
On this page, you can find other curated information.

www.hydroshamba.org/info

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