APPENDIX

- **A—** Approved project brief and timeline
- **B—** Design process: double diamond approach and phases in depth
- **C—** Research Documentation: 15 expert interviews, field visits, focus group and co-creation
- **D—** Technical validation: hydraulic calculations, solar pump sizing
- **E—** Expert validation: three expert interviews to validate the toolkit
- **F—** Bill of materials (BOM) and costs – CAPEX, OPEX, supplier costs, model layout
- **G—** Site and context documentation: Sankana Dam, timeline and protocols
- **H—** Design requirements: full program of must and wishes with classification

A – PROJECT BRIEF

IDE Master Graduation Project

Projectteam,procedural checks and PersonalProject Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA&MASTERPROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Dubbink	IDE master(s)	IPD ☑ DfI ☐ SPD ☐
Initials	S.V.W.	2nd non-IDE master	
Given name	Vera	Individual programme *(date of approval)*	
Student number	5312418	Medisign	☐
		HPM	☐

SUPERVISORYTEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	JC.Diehl	dept./section	SDE - Design forSustainability
mentor	Wim Schermer	dept./section	HCD - Design Aesthetics
2nd mentor	Nanouk de Leng		
client:	Sommalife		
city:	Amsterdam / Wa, Ghana	country:	Ghana
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in by the Chair of the supervisory team

Sign for approval (Chair)

Name ____________ Date ____________ Signature ____________

Personal Project Brief – IDE Master Graduation Project

Name student Vera Dubbink **Student number** 5,312,418

PROJECTTITLE,INTRODUCTION,PROBLEMDEFINITIONand ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Designing sustainable shading and irrigation strategies for large-scale agroforestry nurseries in Northern Ghana

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The Great Agroforestry Initiative Africa (GAIA) is a project from Sommalife that aims to restore degraded savannah ecosystems in northern Ghana through large-scale agroforestry and reforestation. The initiative combines Sommalife's resources with local, mostly female, farmers to eventually in +- 10 years plant millions of trees, such as shea, baobab, cashew, and mango. These trees will enhance biodiversity in Northe, trap carbon, and improve the livelihoods of the farmers.
To achieve this goal, Sommalife plans to scale up nursery production in northern Ghana to reach 1.5 million seedlings annually. The current Village-Based Nurseries (VBN) provide strong community and social benefits but face logistical and quality issues due to their location and little oversight on management. To meet the planting goals, Sommalife wants to add to the VBN model with larger, more centralised nurseries capable of producing around 400,000 seedlings each year.

However, this transition introduces new sustainability and cost challenges, particularly around irrigation and shading. Existing solutions, such as shade nets, often tear under the harsh Harmattan winds, while current irrigation systems are expensive and resource/labour intensive. Developing durable, efficient, and context-specific solutions will improve both the nursery performance and environmental resilience. Shading and irrigation are closely linked as effective shading helps the soil retain more moisture, reducing the need for watering. For an area where droughts are persistant, water is always costly. Currently, shade is provided by natural trees or simple nets, and watering is mostly done manually with water cans or hoses. In some cases, boreholes are used to access water, but these are costly. Images will be in appendix.

The project will therefore explore a systemic and design-level strategy to improve irrigation and shading in large-scale nurseries. This will be achieved through a combination of analytical research and hands-on prototyping and field testing.

→ space available for images / figures on next page

A – PROJECT BRIEF

introduction (continued): space for images

image / figure 1 Current set up of a smaller scaled nursery which has natural shade

image / figure 2 A mid range nursery, which had shade nets which have teared and manual watering

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Sommalife aims to expand its tree nursery capacity efficiently while managing costs and minimizing environmental impact. Current irrigation and shading systems are not optimally adapted to the dry conditions of northern Ghana, where high temperatures, strong Harmattan winds, and seasonal droughts lower seedling survival rates and increase maintenance costs .

The main design challenge lies in developing robust, low-cost, and sustainable irrigation and shading systems that can be built and maintained local, while being culturally accepted and context-specific. These should enhance seedling quality, reduce water and material waste, and support large-scale nurseries in a resource-efficient way.

This project creates added value by combining systemic analysis with field research, hands-on design, and prototyping. It aims to generate practical insights and tangible solutions that support Sommalife's upscaling project. Improved irrigation and shading will directly increase seedling yield and reduce operational costs. For local communities, these innovations can improve working conditions and strengthen resilience to climate changes. Within the 100-day timeframe, the project will deliver actionable design guidelines and prototypes that contribute to Sommalife's long-term goal of sustainable and scalable agroforestry in northern Ghana.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format*:*

Design and validate sustainable irrigation and shading solutions to enhance seedling quality, reduce environmental impact, and enable the scalable production of tree seedlings for Sommalife's agroforestry nurseries in northern Ghana.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The project will combine a systematic research phase with a design-driven prototyping phase. It will start with a baseline study and desktop research to analyse existing irrigation and shading systems and identify key challenges. Based on these findings, new design opportunities will be explored through material research, concept development, and iterative prototyping. Data will be collected on-site through stakeholder interviews, field observations, and environmental impact assessments. The prototypes will be tested in Sommalife's nurseries to evaluate durability, water efficiency, and usability in context. Gathering quantitative data about materials and the approach. The process integrates analytical research with hands-on experimentation to ensure practicality.

It will also be important to consider the cultural and social dimensions of the northern Ghanaian context, as well as the growing impact of climate change and drought in northern Ghana. Increasingly harsh Harmattan winds and high temperatures and limited access to water will be key environmental factors that will shape the design solution.

A – PROJECT BRIEF

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting****,* ***mid-term evaluation meeting****,* ***green light meeting*** *and* ***graduation ceremony****. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting 6 Nov 2025
Mid-term evaluation 13 Jan 2026
Green light meeting 16 Mar 2026
Graduation ceremony 16 Apr 2026

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	✔
For how many project weeks	18
Number of project days per week	4,0

Comments:
Having toworkasidejobtosustainmyself during thesis.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

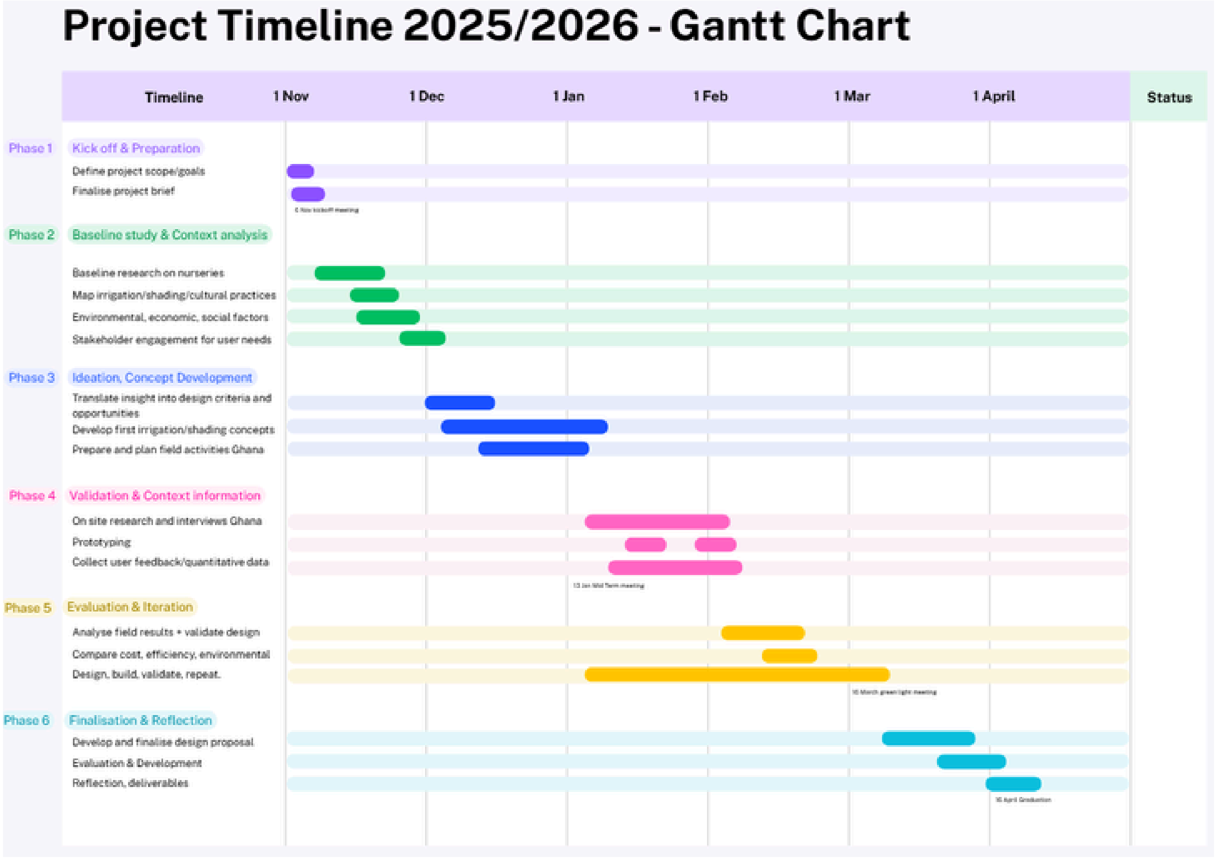
I am really motivated by the chance to work on a project that brings together sustainability, design, and social impact. With Sommalife, I can apply my design background in a context where environmental restoration and community development actually come together in practice. I find it exciting to explore how design can contribute to reforestation and climate resilience in a low-resource setting and to create something that is both useful and realistic while dealing with large issues like deforestation. During my master in Integrated Product Design, I became interested in how design can drive change in larger systems and make a positive impact on the world. This project gives me the opportunity to make that more concrete and test it in the field.

My personal learning ambitions are:
1.I want to learn how to apply sustainable design principles in an agricultural context while prototyping and testing under real conditions while working acress cultures and disciplines.
2.Designing for a low resource setting, with extreme weather conditions, while adhering to a local social and cultural system.
3. Design for scalability, instead of a one term project a project that can be re-used and upscaled in the future.
4.I see this project as a way to connect hands-on design with broader sustainability goals, and to grow as a designer who works on socially relevant and tangible impact.

AI STATEMENT

Generative AI tools were used during this project to support language refinement, proofreading, and the exploration of alternative formulations of text. All research activities, analysis, design decisions, calculations, interpretations, and conclusions were conducted and verified by the author. The author remains fully responsible for the content of this thesis.

A — TIMELINE


Project Timeline 2025/2026 - Gantt Chart
Timeline
1 Nov
1 Dec
1 Jan
1 Feb
1 Mar
1 April
Status
Phase 1
Kick off & Preparation
Define project scope/goals
Finalise project brief
6 Nov kickoff meeting
Phase 2
Baseline study & Context analysis
Baseline research on nurseries
Map irrigation/shading/cultural practices
Environmental, economic, social factors
Stakeholder engagement for user needs
Phase 3
Ideation, Concept Development
Translate insight into design criteria and opportunities
Develop first irrigation/shading concepts
Prepare and plan field activities Ghana
Phase 4
Validation & Context information
On site research and interviews Ghana
Prototyping
Collect user feedback/quantitative data
13 Jan Mid Term meeting
Phase 5
Evaluation & Iteration
Analyse field results + validate design
Compare cost, efficiency, environmental
Design, build, validate, repeat.
16 March green light meeting
Phase 6
Finalisation & Reflection
Develop and finalise design proposal
Evaluation & Development
Reflection, deliverables
16 April Graduation

B– DOUBLE DIAMOND APPROACH

METHODOLOGY

The process moved through a constant state of zooming in and out. But the double diamond provides a general sense of when knowledge was expanded or narrowed to better understand the whole.

1 **Context immersions** Environmental, social, and economic conditions. Literature research. Stakeholder mapping, forming initial assumptions.	2 **System framing** Field visits. Expert interviews. The problem space narrowed here from shade → water with reframe.	3 **Stakeholder Engagement** Deep engagement with workers and practioners within and outside Vitara. Design requirements derived from systhensis.	4 **Design exploration** Three irrigation strategies and two technological pathways (high, mid, low end). Location scouting on end → Sankan dam selected.	5 **Refinement and Integration** Final concept calculated and validated. Nursery toolkit produced as the primary deliverable.

Main areas of research used

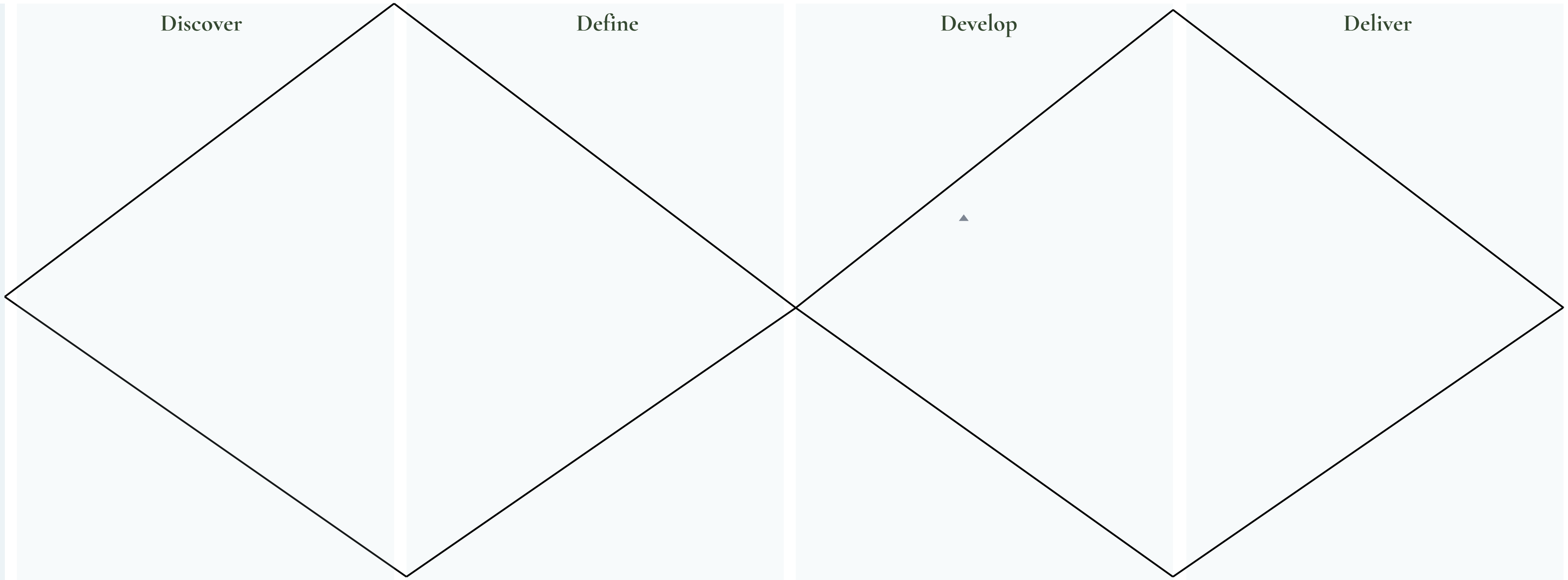
Landscape and context
Climate, ecology, water systems, land use

Organisations & Stakeholders
Institutions, governance, programmes and roles

Operations and practices
Nursery workflows, labour, maintenance, water use

Technical systems
Water sources, irrigation pathways, infrastructure

Landscape and context
Climate, ecology, water systems, land use



Conclusion at the end	Understanding of the Ghanaian nursery context, stakeholders, environmental conditions, and current operational challenges.	Clear problem framing around water reliability, labour pressure, and operational continuity within nursery systems.	Selection and development of a modular gravity-fed nursery direction through stakeholder input, technical comparison, and feasibility evaluation.	Validated nursery toolkit with implementation guidance, calculations, operational planning, and scaling strategy for Vitara.

- literature review
- stakeholder mapping
- context analysis
- current state of the art

- Interviews with experts
- Literature review concluding
- Site visits in Ghana
- Focus Group Discussions
- Problem Framing

- Stakeholder interviews
- Participatory discussion
- Requirements synthesis
- Organisational mapping

- Technical analysis
- Irrigation comparison
- Location scouting
- Feasibility assessment

- Validate: hydraulic calucluations
- Sceneration evaluation
- System validation
- Operational planning

METHODOLOGY

The project followed a double diamond process adapted for a context-specific agroforestry design challenge. The process moved through four phases:

Phase 1 — Discover (Weeks 1–3)
- Literature review across environmental context, water management, nursery design, shade, irrigation, and seedling physiology
- Field visits to four nursery sites in Tamale and Wa
- Semi-structured interviews with E1–E11
- Participatory mapping with 20+ nursery workers
- Key output: identification of water reliability as the core design problem, replacing the original shade infrastructure focus

Phase 2 — Define (Week 4)
- Synthesis of field findings into six design insights
- Translation of insights into six design requirements (DR1–DR6)
- Reframe confirmed: individual nursery components → water management as system core
- Research question reformulated

Phase 3 — Develop (Weeks 5–8)
- Three irrigation pathway development and evaluation
- Hydraulic calculations to validate gravity-fed configuration
- Solar pump comparison against fuel pump
- Site selection process leading to Sankana Dam selection
- Four-role operational structure developed
- Cost model developed from Ghanaian supplier quotes

Phase 4 — Deliver (Weeks 9–10)
- Toolkit development: 24 pages across seven WWWWWH directions
- Validation interviews with E16 and E17
- Final validation against all six design requirements
- Recommendations developed for Vitara implementation

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C – RESEARCH DOCUMENTATION: SHADOW NETS

Shadownets

Why?

Internal protection

Protection from extreme solar radiation
- Reduce photosynthetic stress
- Prevent photoinhibition (shut down photosynthesis due to too much light)
- Reduce infrared load to prevent overheating
- Prevent UV damage

Control Root-Zone temperature
- Reduce radiation absorbed by soil and polybags
- Reduce water uptake

Reduce evaporation
- Shadow nets 'trap' moisture in the soil
- Can create 10-20% higher local humidity

Protection from UV damage
- Shadow nets 'trap' moisture in the soil
- Can create 10-20% higher local humidity

Protection from rain
- Acts like rain diffuser, and reduce raindrop intensity

External protection

Protection from Harmattan Winds
- Act as windbreak, prevent dust from settling
- reducing water, physical damage, soil drying, crusting, prevent moisture lost.

Bugs and animal protection
- Help keep out livestock that eat seedlings
- Reduce infestation from grasshoppers, bugs, etc

Improve working conditions
- Reduce heat stress on management

Plant shade trees on the nursery — https://www.unep-wcmc.org/en/news/mapping-the-potential-for-cocoa-agroforestry-in-ghana-for-climate-change-adaptation-and-mitigation

species that do not lose leaves easily?

how long should it take?

What else could work?

source

source

source

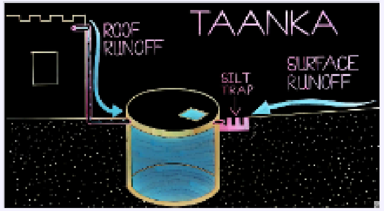
source

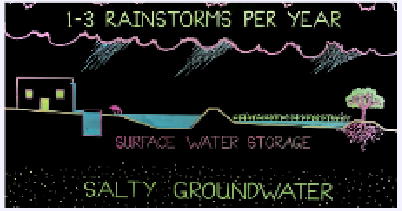
C – RESEARCH DOCUMENTATION: IRRIGATION

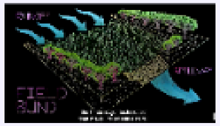
"the problem is not the lack of water, but the lack of water management"

Thar desert in India

- Build the perfect pond, areas that survive on 1,2 or 3 rainfall events in the year. Here bore holes do not work due to salty water. Based on where the water "flows" too, they created a permanent water pond.
- Water harvesting fields. The crops grow from all the moisture that is stored in the ground during the rain. Made by Gravis, purely rain fed water storing.
- this one is 60 years old and holds 300,000 liter of water.
- Home scale water harvesting: TAANKA, faro cement in the ground, the one in the picture is a 20,000L tank. There a diversion drains that collect rainwater from the sides. They have a zigzag silt trap to get the sediments out of the water.

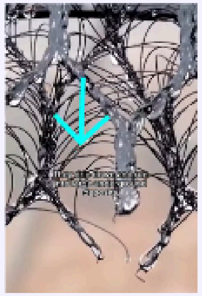






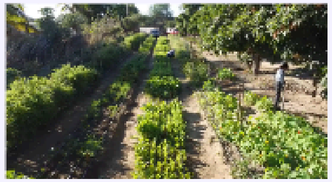
capture condensation or in peru

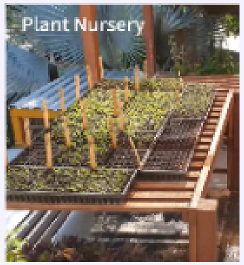
- harvest water from the air on large scale
- due to high temperature diffrerences between day and night
- in areas where there is a lot of fog, which are droplets in the air
- creating water foundation

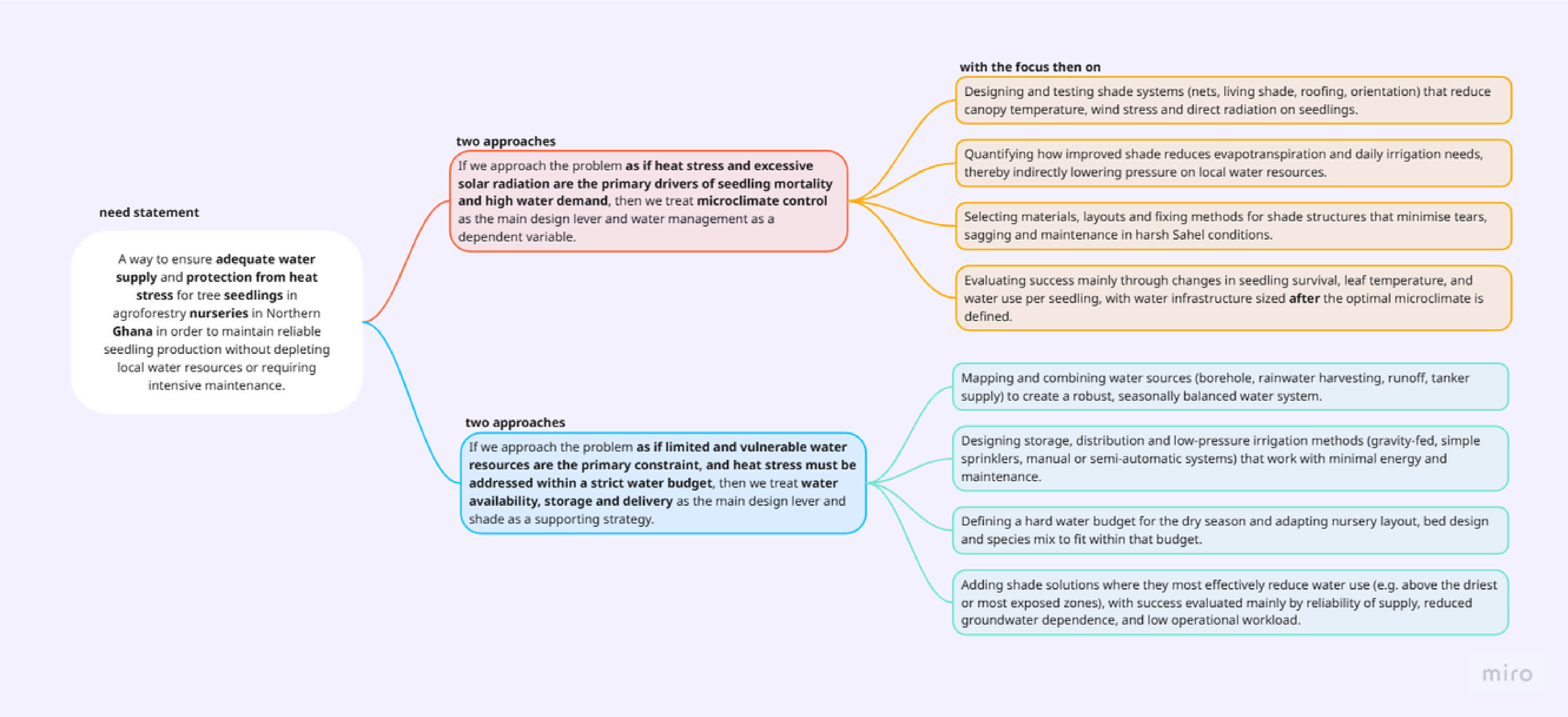


Conuco farm Mexico

- he irrigates +- 1 hectare of land and work with 5 people
- drip irrigation used
- minimzing pest problems by switching location of plants very much
- aromatic crops and bright yellow flowers migh distract / repel insects
- Alan Chadwick inspired; deep bed gardening
- charcoal for fertilizer and use if from their own campfires







need statement

A way to ensure **adequate water supply** and **protection from heat stress** for tree **seedlings** in agroforestry **nurseries** in Northern **Ghana** in order to maintain reliable seedling production without depleting local water resources or requiring intensive maintenance.

two approaches

If we approach the problem **as if heat stress and excessive solar radiation are the primary drivers of seedling mortality and high water demand**, then we treat **microclimate control** as the main design lever and water management as a dependent variable.

with the focus then on

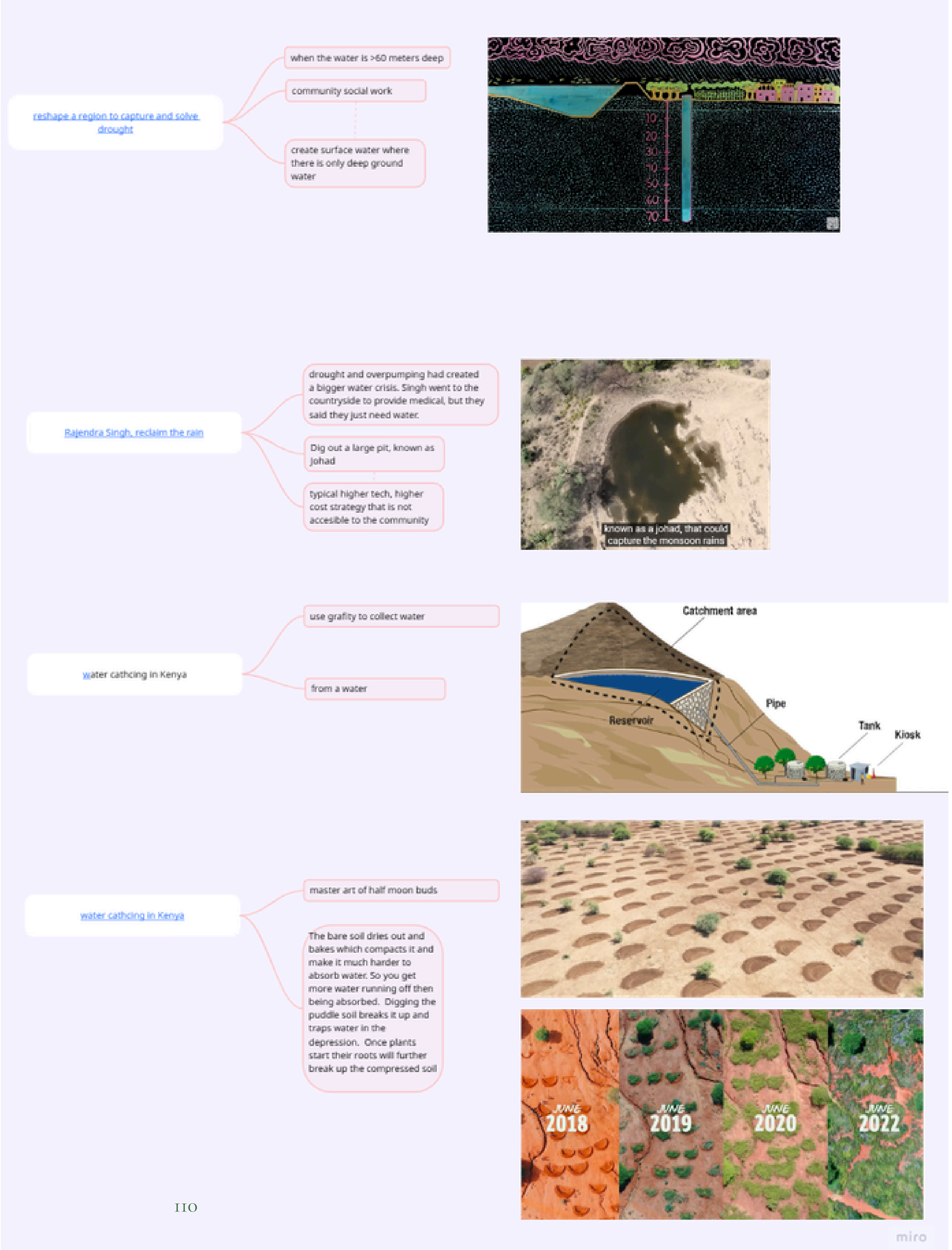
- Designing and testing shade systems (nets, living shade, roofing, orientation) that reduce canopy temperature, wind stress and direct radiation on seedlings.
- Quantifying how improved shade reduces evapotranspiration and daily irrigation needs, thereby indirectly lowering pressure on local water resources.
- Selecting materials, layouts and fixing methods for shade structures that minimise tears, sagging and maintenance in harsh Sahel conditions.
- Evaluating success mainly through changes in seedling survival, leaf temperature, and water use per seedling, with water infrastructure sized **after** the optimal microclimate is defined.

two approaches

If we approach the problem **as if limited and vulnerable water resources are the primary constraint, and heat stress must be addressed within a strict water budget**, then we treat **water availability, storage and delivery** as the main design lever and shade as a supporting strategy.

- Mapping and combining water sources (borehole, rainwater harvesting, runoff, tanker supply) to create a robust, seasonally balanced water system.
- Designing storage, distribution and low-pressure irrigation methods (gravity-fed, simple sprinklers, manual or semi-automatic systems) that work with minimal energy and maintenance.
- Defining a hard water budget for the dry season and adapting nursery layout, bed design and species mix to fit within that budget.
- Adding shade solutions where they most effectively reduce water use (e.g. above the driest or most exposed zones), with success evaluated mainly by reliability of supply, reduced groundwater dependence, and low operational workload.

C – RESEARCH DOCUMENTATION: IRRIGATION



reshape a region to capture and solve drought

- when the water is >60 meters deep
- community social work
- create surface water where there is only deep ground water

Rajendra Singh, reclaim the rain

- drought and overpumping had created a bigger water crisis. Singh went to the countryside to provide medical, but they said they just need water.
- Dig out a large pit, known as Johad
- typical higher tech, higher cost strategy that is not accesible to the community

water cathcing in Kenya

- use grafity to collect water
- from a water

water cathcing in Kenya

- master art of half moon buds
- The bare soil dries out and bakes which compacts it and make it much harder to absorb water. So you get more water running off then being absorbed. Digging the puddle soil breaks it up and traps water in the depression. Once plants start their roots will further break up the compressed soil

C – RESEARCH DOCUMENTATION: IRRIGATION PRESSURE MAP

WATER NEEDS

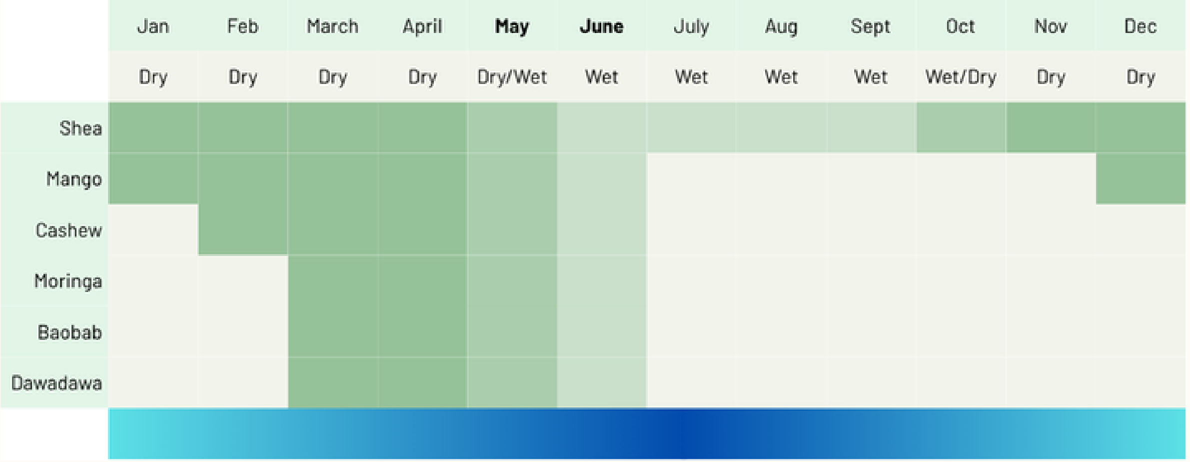
To understand the burden on the nursery, an overview of the water needs was created.

Research and stakeholder interviews have shown that seedlings are optimally watered with around 100 ml every three days.

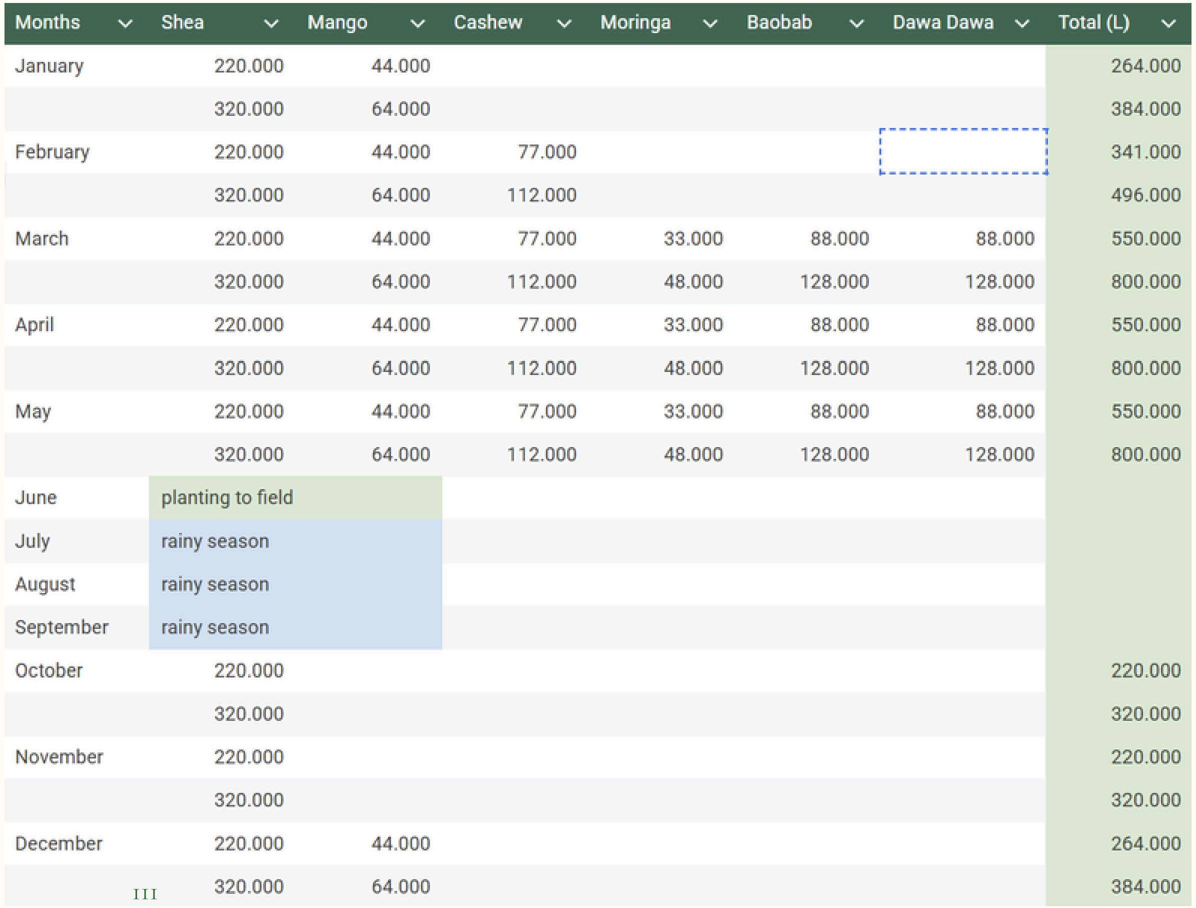
Seedlings remain in the nursery for varying periods, so irrigation pressure is not constant throughout the year. In Figure 30, the variation in irrigation demand over time is shown. Since all seedlings are transplanted to the field during the single rainy season (May/June), when survival chances are highest, the months of March, April, and May experience the highest irrigation pressure. During this period, all seedlings remain in the nursery and require watering. In the wet season, additional irrigation is minimal.

Based on this, the monthly water demand was calculated to better understand the required volumes. If seedlings are watered every three days, this corresponds to approximately 2.96 m³ per year; if watered every two days, this increases to around 3.50 m³ per year. Quantifying these values provides a concrete starting point for further design decisions.

IRRIGATION PRESSURE MAP



CAPACITY CALCULATIONS



Months	Shea	Mango	Cashew	Moringa	Baobab	Dawa Dawa	Total (L)
January	220.000	44.000					264.000
	320.000	64.000					384.000
February	220.000	44.000	77.000				341.000
	320.000	64.000	112.000				496.000
March	220.000	44.000	77.000	33.000	88.000	88.000	550.000
	320.000	64.000	112.000	48.000	128.000	128.000	800.000
April	220.000	44.000	77.000	33.000	88.000	88.000	550.000
	320.000	64.000	112.000	48.000	128.000	128.000	800.000
May	220.000	44.000	77.000	33.000	88.000	88.000	550.000
	320.000	64.000	112.000	48.000	128.000	128.000	800.000
June	planting to field						
July	rainy season						
August	rainy season						
September	rainy season						
October	220.000						220.000
	320.000						320.000
November	220.000						220.000
	320.000						320.000
December	220.000	44.000					264.000
	320.000	64.000					384.000

Figure 30
Capacity calculations

C – RESEARCH DOCUMENTATION: IRRIGATION PRESSURE MAP

BOREHOLE RESEARCH

This presents relevant research on borehole extraction, before moving towards dam irrigation.

Ways to prevent the cone of depression (collapsed hole due to extensive pumping).

With pumping:
1. 75% rule: limit pumping rate to 75% of the tested yield.
2. Constant: pumping at a slower level for longer periods of time is better than a large burst of water at once.

Not just the borehole:
1. Solar Filling: Use a low-flow solar pump to fill a 40,000 L storage tank slowly throughout the daylight hours.
2. Booster Irrigation: Use a separate surface pump to draw from the tank for your sprinklers. This decouples the high-pressure demand of the irrigation from the slow, steady extraction needed by the borehole.

Improve groundwater recharge:
1. Infiltration pits (like just Diggit) to manually assist the regolith.
2. Vegetative cover: maintain grass covers to prevent the soil from 'sealing'.

Monitor and adaptive management:
- You can not manage what you do not measure.

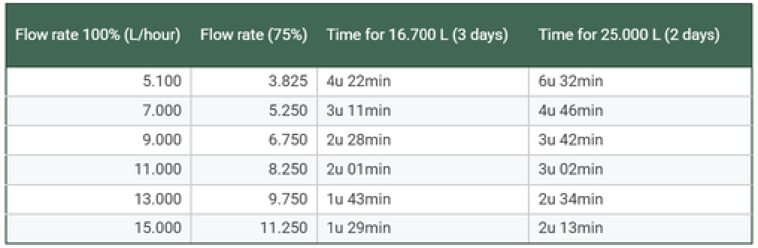
To help boost the recharge of your borehole and counteract the cone of depression, we design a simple Infiltration Pit (Recharge Pit) system. In North Ghana, where the regolith thickness acts as your primary water storage "sponge," these pits help bypass the hard,

Design for a Nursery Infiltration System
Layout plan for a large-scale nursery with filtration system:

1. Dimensions and Placement
- Size: Construct a pit approximately 2 meters long, 2 meters wide, and 2 to 3 meters deep.
- Location: Place the pit at least 15 to 20 meters away from your borehole. This distance ensures the water is filtered by the soil before reaching the pump and prevents the "short-circuiting" of contaminated surface water.
- Catchment: Position the pit at the lowest point of your nursery's natural slope to capture maximum runoff during the rainy season.

2. The Filter Layers (Bottom to Top)
Fill the pit with graded materials to prevent it from clogging with silt:
- Bottom Layer (50 cm): Large boulders or broken bricks to create large spaces for water storage.
- Middle Layer (50 cm): Coarse gravel (crushed stone).
- Top Layer (30 cm): Coarse sand, which acts as a final filter for debris.

A table for the period 2000–2005 indicates that Wa faces a severe water deficit, primarily due to a high potential evapotranspiration of 1,767 mm, which exceeds the lower precipitation of 1,040 mm. Consequently, only 19 mm (or a mere 1.8%) of annual rainfall actually recharges the groundwater system, which is the second-lowest recharge rate among all listed stations. This indicates that the aquifer in Wa is replenished extremely slowly, making it highly vulnerable to over-extraction (Bart, 2019).



Flow rate 100% (L/hour)	Flow rate (75%)	Time for 16.700 L (3 days)	Time for 25.000 L (2 days)
5.100	3.825	4u 22min	6u 32min
7.000	5.250	3u 11min	4u 46min
9.000	6.750	2u 28min	3u 42min
11.000	8.250	2u 01min	3u 02min
13.000	9.750	1u 43min	2u 34min
15.000	11.250	1u 29min	2u 13min

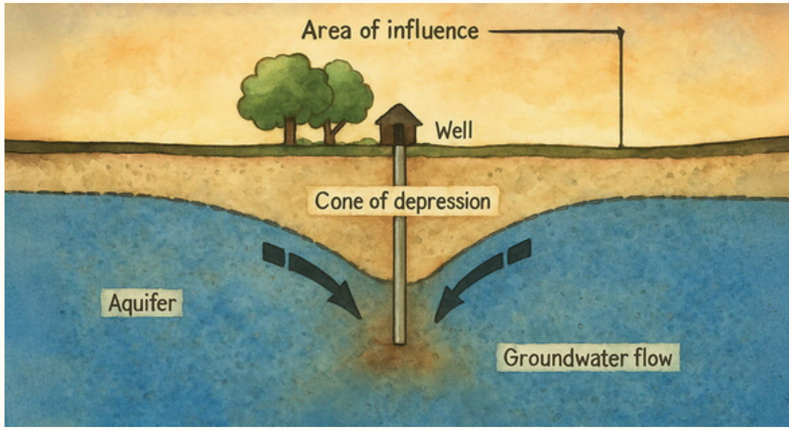


Figure – cone of influence

TWO STRATEGIC PATHWAYS

The reframe from shade to water fundamentally reshaped the design space. Two strategic directions were then explored in parallel, followed by three specific irrigation strategies within the low-tech pathway. The choice reflects a specific understanding of where reliability matters more than control in this context.

High-tech pathway

✔ High control and predictability when implemented correctly.
✔Remote monitoring capabilities, detailed system data.
– Nearest qualified technician: 5 hours from Wa by car.
– Installed systems reverted to manual usage. Users found automated output "too slow" and misaligned with working routines
– Harmattan wind and dust increase component wear, which results in higher maintenance frequency
– High dependency on the electricity supply and spare parts chains

$109,421

Full system: irrigation + net house + shade + installation (E12, 2026) for 0.6Ha (190.000 seedlings)

Low/mid-tech pathway

✔Proven in similar climates across West, East, and Southern Africa
✔ No electricity is required during irrigation, as gravity provides pressure
✔Repairable with tools and materials available in Wa
✔ Replicable at other places
✔ Start with one module before scaling, with lower upfront investment.
– Less precise automation at the individual plant level vs. full system

$13,117

Pilot CAPEX · One module (irrigation + net house + installation + worker fee· 25,000 seedlings

> The trade-off between control and resilience is real. In a context where maintenance infrastructure is limited, resilience is the more important .

As the project progressed, two irrigation pathways emerged: a highly automated, high-tech system and a more frugal, low-tech approach. While the high-tech pathway offered predictability and control, fieldwork revealed strong dependencies on maintenance, spare parts, electricity, and external technical expertise.

Based on the design requirements of reliability, scalability, low maintenance, affordability, and local adaptability, the project gradually shifted toward a mid- to low-tech approach. This direction is better aligned with the environmental and operational realities of Northern Ghana while allowing for phased implementation and long-term resilience.

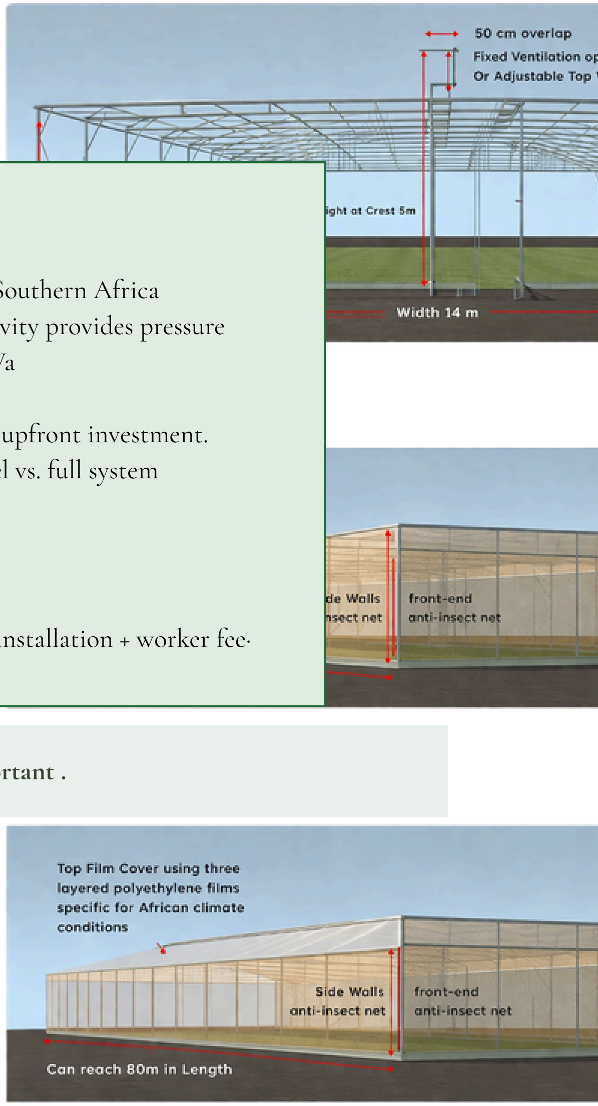


Figure 29 ▶
Shade nets, visual by expert E10

ECOLOGICAL DRIVERS

Groundwater constraints

Groundwater in Northern Ghana is governed by crystalline basement geology that restricts flow and limits aquifer storage capacity (Rambhunjun et al., 2024). Recharge during the rainy seasons is approximately 2% of annual rainfall. Extraction rates don't necessarily outnumber the recharge, with a recharge around 0.74%, the problem is the pressure is not even throughout the year. while groundwater abstraction and water demand increase during the long dry season, when recharge is nearly absent. (Lutz et al., 2014)

The main extraction manner is through a borehole, either manual (human-powered) or mechanical (pump). Manual boreholes require great energy to pump water, and a mechanical pump is very sensitive to breakdown and maintenance. Borehole yields vary substantially over short distances, meaning that a succesful borehole closeby does not mean that drilling the same one further will have the same results. This is because the Voltaian aquifers store water in slits in the earth. They account for about 60% of the water storage in the north. These aquifers have low yields and are highly vulnerable during the rainy season. Natural recharge is slow, and irrigation extraction causes depletion (Loh et al., 2020). Aquifers are sensitive to intensive pumping for prolonged hours per day, not because water is structurally absent, but because storage volumes are small and recharge is slow.

The practical consequence is that boreholes in this context are unreliable under sustained dry-season demand, exactly the period when nursery irrigation is needed most. Aquifers are sensitive to intensive pumping, not due to water shortages, but because of small rock storage volumes and the time required for water to reach the storage (Akurugu et al., 2019).

Powered by the insights from the research as shown above, a field insight in Ghana, the choice was made deliberately to step away from a reliance on boreholes and other mechanical extraction methods due to their high maintenance, low sustainability, and low reliability for supply in the dry season.

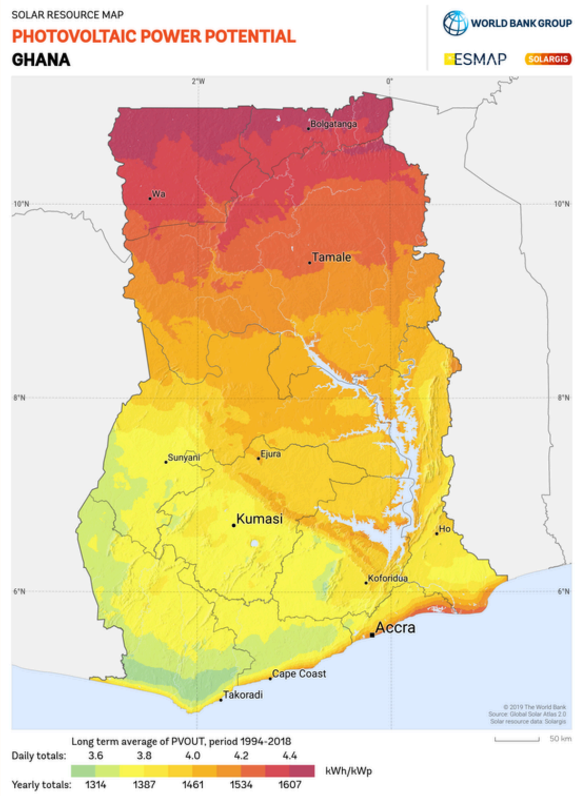


Figure 17
Photovoltaic Power Potential, Ghana
By World Bank Group et al., 2024b, Photograph

Surface Water Availability

The Upper West Basin receives approximately 7,673 million m^3 of annual runoff, of which only 0.74% is currently used for irrigation (Ghana Water Resources Commission, 2020). The challenge is not water scarcity; it is reliable, managed access to water that exists in the landscape.

ECONOMIC DRIVERS

The shea sector is estimated to be worth more than USD 2 billion annually, with West Africa supplying approximately 95% of the world's shea nuts. In Ghana alone, an estimated 600,000–900,000 women depend on shea collection and processing as an important source of seasonal income and financial independence (Shea Market Size, n.d.).

The importance of Shea

For decades, women in Northern Ghana have traditionally collected shea nuts and processed them into shea butter through roasting, grinding, and boiling. Shea butter is widely used for cooking, medicine, and cosmetics, and its growing international demand has made shea an important economic resource across West Africa.

Shea trees grow only within the African shea belt, making them both ecologically and economically significant to the region. However, despite rising global demand, shea tree densities are declining due to desertification, deforestation, agricultural expansion, and limited natural regeneration. This threatens not only local ecosystems but also an important source of income and financial independence for many women in Northern Ghana (Stopponi et al., 2025).

Despite the growing global demand for shea products, the long-term economic potential of the sector is increasingly under pressure. Declining tree densities, limited natural regeneration, and increasing land pressure have reduced the availability of productive shea trees across many landscapes. Since shea trees take many years to mature, the current decline in tree populations threatens the future stability of the sector and the income streams that depend on it.

Strengthening agroforestry nursery systems, therefore, becomes a key economic intervention. Nurseries provide a means to support the regeneration and cultivation of shea and other agroforestry species, helping to replenish declining tree populations while supporting the long-term productivity of parkland systems. For local communities, and particularly for women involved in the shea value chain, this creates opportunities to stabilise and potentially increase income while building resilience to environmental change. In this sense, nursery development is not only an ecological strategy for landscape restoration but also an economic mechanism for sustaining rural livelihoods and strengthening local value creation in northern Ghana.

Women's Gold

The shea tree is the region's most economically significant species. Its decline represents both an ecological and economic crisis for women who depend on it for income.

Figure 18 ▶
Shea belt (UNDP, 2025)

SOCIAL DRIVERS

Historically, women in Northern Ghana have been the backbone of daily nursery operations. They manage irrigation, cleanup, and seedling monitoring while taking responsibility for childcare, household management, and community roles. This dual burden thus makes it a central design condition.

Women in the nurseries

Throughout the fieldwork in Northern Ghana, women consistently formed the operational backbone of agroforestry nurseries. Daily nursery activities, such as irrigation, filling polybags, seedling monitoring, weeding, and maintenance, were primarily carried out by women, often alongside childcare, household management, and agricultural labour.

Within many community nurseries, nursery work is deeply intertwined with daily life. Nursery performance is therefore influenced not only by technical systems but also by labour intensity, travel distance to water sources, workload manageability, and infrastructure reliability. Field observations showed that when water systems become unreliable, physical effort increases significantly. Longer walking distances, manual watering, inconsistent irrigation, and maintenance failures create additional pressure on workers.

Over time, this often leads to fatigue, reduced motivation, inconsistent seedling care, and declining survival rates. In addition, labour structures and social dynamics influence how nurseries are maintained over the long term

Community ownership, payment structures, workload division, and social expectations all directly affect continuity and operational performance. The nursery, therefore, functions not only as a technical environment, but also as a social and operational ecosystem in which labour realities directly influence ecological outcomes.

Community ownership, payment structures, workload division, and social expectations all directly affect continuity and operational performance. The nursery, therefore, functions not only as a technical environment, but also as a social and operational ecosystem in which labour realities directly influence ecological outcomes.

Fieldwork finding

Seedling performance correlates directly with salary regularity, workload manageability, and system reliability. When the system fails, extra effort increases, motivation declines, and survival rates drop.

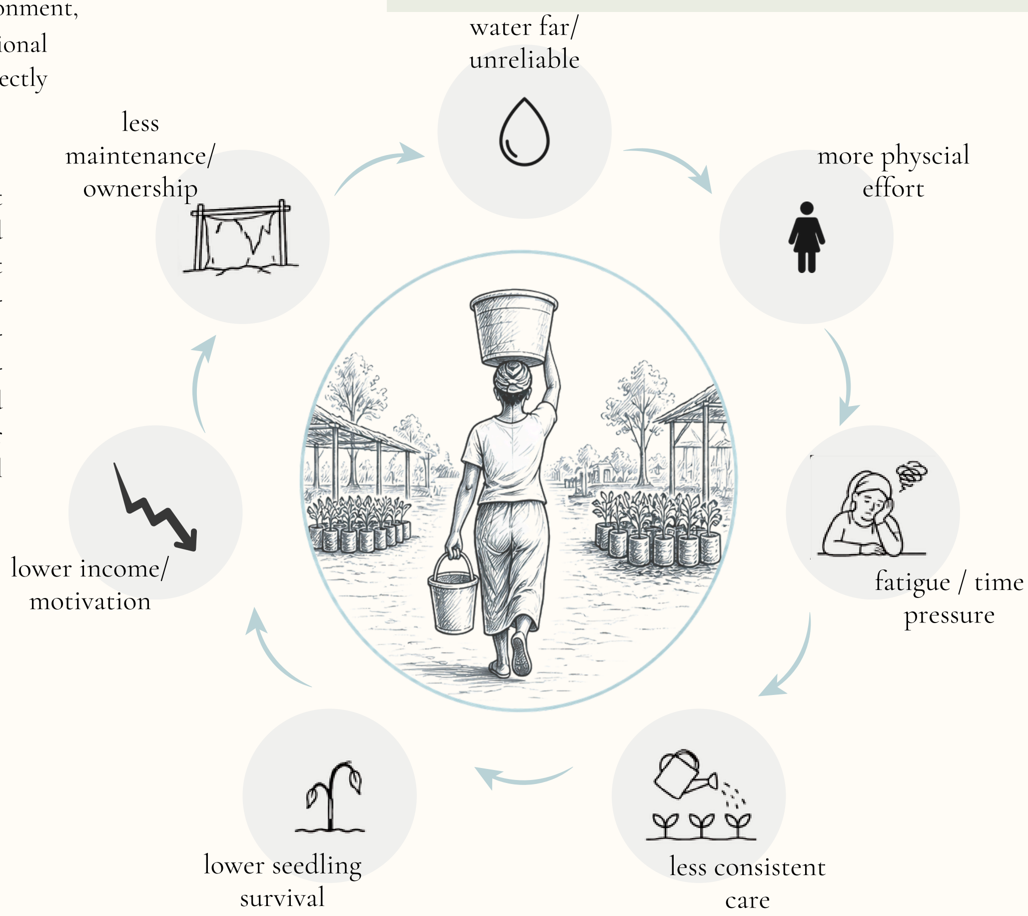


Figure 19 ▸
The nursery cycle, visual by me

C – EXPERT INTERVIEWS: E1 - E7

! At the start of the project, the company was called Sommalife, but it changed to Vitara. They can be used interchangeably.

E1 - CONSERVATION MANAGER

Q&A – Meeting with (Sommalife Conservation Manager)
Date: 24/11/2025
Q: Do you visit the nurseries often, or are you mostly based in Wa?
A: I do not directly visit the nurseries. I'm mainly in Wa. Field staff manage daily operations.
Q: What is the condition of the Bienye nursery and its water connection?
A: The road to Bienye is in poor shape, and the nursery is undergoing updates. It is not connected to power at the moment.
Q: What shade systems are currently used in Sommalife nurseries?
A: We use shade nets and also natural shade from trees. The nets are usually green and black.
Q: Do the color differences of shade nets matter?
A: According to our experience, the color differences don't seem to make much difference.
Q: How well do the shade nets perform in terms of durability?
A: They tear within a few months. Workers try to tie them back to the frame. They repair them almost every month.
Q: What fixing methods are used for shade nets?
A: We used to use tie-wraps, but they became too expensive and break easily. Now we use binding wire, which is stronger and reusable.
Q: Where do the shade nets typically tear?
A: Often in the middle, especially when winds are strong. The sides are tied to the poles, but the middle takes the stress and rips.
Q: Do you prefer flat-top or pitched shade structures?
A: I prefer the flat-top structures because of the wind exposure here.
Q: How does Harmattan affect shade and seedlings?
A: Harmattan is extremely dry and windy. Shade nets do not prevent the sun from heating the polybags; temperatures still rise significantly.
Q: What happens to the shade nets during Harmattan?
A: Strong winds cause tears. The exact timing of wind gusts is unpredictable, so it is difficult to prepare.
Q: Does dust or sand clog the shade nets?
A: No, dust and sand are not a major issue. The nets do not collect it significantly.
Q: Have alternative solutions been tried to reduce wind damage?
A: No other structural wind-protection solutions have been tested so far. The tension wire around the edges was not enough.
Q: How does irrigation work in the nurseries?
A: Water comes from boreholes. Workers use watering cans and hoses. Hose pressure changes all the time.
Q: What are the challenges with watering cans?
A: Workers must walk long distances back and forth for each load of water, which is tiring and time-consuming.
Q: Do you capture or store rainwater?
A: No, we do not currently store rainwater, but it could be a useful solution.
Q: How often are seedlings irrigated?
A: More than three times a week, but the amount of water is not measured.
Q: What makes irrigation difficult during Harmattan?
A: It is extremely dry and windy. Water availability drops, and the timing of strong winds is unpredictable.
Q: Is dust affecting irrigation or seedlings?
A: No, dust does not create major issues for the seedlings or the nets.
Q: Are workers satisfied with the current systems?
A: It depends on the location. In Kunfusi, workers have a good tap and hose and few complaints. In Domawa and Bienye, water access is limited and more labor is needed.
Q: What is the most urgent problem that could be solved with better shade or irrigation?
A: Water is the biggest issue. In Domawa, both shade and water are problematic, but water is the most critical.
Q: How often do women work in the nurseries, and for how long?
A: Women work 3–5 days a week. Watering takes 3–4 hours per day; seedling work can take the entire day.
Q: What are seasonal activities in the nurseries?
A:Shea nut collection: August–September
Germination: October–November
Grafting: Shea grafting happens at 1.5 years in the field; mango is grafted immediately; cashew hybrids do not need grafting, they produce nuts after 3 years. .
Q: How do you protect seedlings from animals?
A: Fencing is used; if well-maintained, animals do not enter.
Q: Do seedlings get diseases or pests often?
A: Not often. Occasional insects occur, but not significantly. Waterlogging can sometimes cause issues. Sometimes bugs can eat some of the seedlings but it it not a big issue.

E1, E2, E3 - FOCUS GROUP DISCUSSION AND GAME OUTCOMES

Focus Group Discussion Ghana
Contents:

- Problem Cards
- (Sun, water, Distance, Animals, Heavy Carrying, Wind)
    - additional problems: (mulching, grafting, removal of weeds, scorpions, snakes)
- Ranking Smilies (from red to green)
- Empty modifiable plot (A4, A3, A2)
- 3D objects
    - Trees (14 in different sizes)
    - Houses (User, ownership, distance)
    - Water containers + tanks (source, transport, storage)
    - Compost area

Expected Output:

1. Priority conflicts (what hurts the most vs. what matters the most)
2. Spatial logic (how people organise land mentally)
3. Trade-off reasoning (why is something placed close/far)
4. Mismatch detection (what they say vs. what they do)
5. Design constraints (for nursery, land, water systems)

GAME 1: Problem Severity Ranking
Step 1: Individual ranking
Each participant gets all problem cards and the smiley ranking strip. All must place each problem under one smiley.

Step 2: Group negotiation
All individual rankings are placed on the ground, and the group must create one shared ranking, so it is more in a group form.

This is to identify true pain points, reveal gender, age, role differences and identify deal breakers.

GAME 2: Land Reality Mapping
Step 1: Baseline placement
Lay down the A3 land plot, the 3d printed houses, the 3d printed trees, the water container, and the compost.

Prompt:
Explain the different layout, and ask for their preferred layout.
Introduce one problem card at a time (only suitable ones)
For example, sun, distance, heavy carrying, animals, wind, water.

C — EXPERT INTERVIEWS: E8

Theme	Summary of Insights	Most Important Insights & Design Implications
Programme Approach (SDF)	The Sustainable Development Forward programme embeds gender inclusion into business practices, focusing on entire value chains and	Insight: Inclusion is most effective when integrated into business models. Design implication: Align design solutions with economic incentives rather than standalone social
Value Chain Perspective	Gender inequality at the production level affects the entire value chain. Women are key actors in sourcing but remain undervalued.	Insight: Inequality at the source impacts system performance. Design implication: Address gender dynamics at the production level in system design.
Private Sector Role	CEOs and companies are engaged to recognise women as reliable suppliers and invest in inclusive systems.	Insight: Market demand can drive inclusion. Design implication: Design solutions that are attractive for private sector adoption.
Cultural Norms & Land Access	Women rarely own land and depend on husbands, often receiving less fertile plots.	Insight: Structural inequality limits productivity. Design implication: Design must function within unequal land access conditions.
Labour Division	Women are responsible for household work, childcare, and farming, often working on husbands' land before their own.	Insight: Women face severe time and labour constraints. Design implication: Reduce labour and time demands in system design.
Access to Mechanisation	Mechanisation is prioritised for men's land, causing delayed planting and lower yields for women.	Insight: Unequal resource access reduces output. Design implication: Improve access to tools or design low-tech alternatives.
Productivity of Women	Despite constraints, women often achieve higher yields than men.	Insight: Women are highly efficient producers. Design implication: Investing in women yields high returns.
Business Model Strategy	Instead of changing norms directly, the programme incentivises companies to work with women, creating indirect social change.	Insight: Economic incentives drive behavioural change. Design implication: Embed value for both users and businesses.
Age-Based Differences	Younger women focus on childcare and immediate needs; older women focus more on management and organisation.	Insight: Needs differ by life stage. Design implication: Design flexible systems for different user groups.
Migration Patterns	Young women often migrate to cities for work, leaving gaps in rural labour structures.	Insight: Labour availability is dynamic. Design implication: Design systems that can adapt to changing workforce availability.
Childcare Constraints	Lack of childcare limits women's participation in work activities.	Insight: Childcare is a major barrier to productivity. Design implication: Integrate childcare solutions into work environments.
Daycare Solutions	Simple, low-cost daycare setups at worksites improve productivity and retention. Cost-sharing models are often used.	Insight: Small interventions can have large impact. Design implication: Include low-cost, scalable childcare solutions.
Work Organisation	Women organise rotational schedules to balance work and caregiving.	Insight: Informal systems already exist. Design implication: Design should support and strengthen existing practices.
Safety & Safeguarding	Strong safeguarding policies are required, especially when children are present.	Insight: Safety is a critical requirement. Design implication: Integrate safeguarding into system design.
Gender Dynamics in Income Use	Women reinvest income into households, while men often invest in assets or non-household priorities.	Insight: Income distribution affects social outcomes. Design implication: Supporting women increases household resilience.
Role of Men	Including men can improve balance, but women perform most labour without equal benefit.	Insight: Gender balance is complex but necessary. Design implication: Design inclusive but women-focused systems.
Child Labour Context	Family labour is common but must not interfere with education. International standards often conflict with local realities.	Insight: Definitions of labour differ across contexts. Design implication: Ensure compliance while respecting local practices.

Field visits take-aways (E8)

- Frequently, there is no electricity, and when a part of the borehole breaks at a depth of +-50 meters, it is hard to repair.
- The main point of failure is the pump; during the dry season, it can suck in air and thus sediment, and break down. It proves unreliable to the locals.

Figure 34
All pictures by me

C – EXPERT INTERVIEWS: E9

Theme	Summary of Insights	Most Important Insights & Design Implications
Community Organisation (Unions)	Three unions represent multiple communities across districts. A central warehouse functions as storage, coordination point, and knowledge hub. After a 3-year project, communities operate independently.	Insight: Strong local structures enable long-term independence. Design implication: Design systems that can be transferred and managed locally without external support.
Cooperative Approach	Activities are organised through community groups rather than individuals, improving ownership, coordination, and knowledge sharing.	Insight: Collective systems increase sustainability. Design implication: Design for group use than individual optimisation.
Scale of Operations	~61 nurseries in Northern Ghana; production ranges from 60,000 to 250,000 seedlings. Tree Aid advises starting small and scaling gradually.	Insight: Scaling depends on system reliability. Design implication: Enable modular growth a phased scaling.
Water as Limiting Factor	Nursery expansion is constrained by water availability and borehole capacity.	Insight: Water determines system limits. Design implication: Design must be centred aroun availability and efficiency.
Water Sources	Combination of boreholes, rivers, dams, and reservoirs. Handpumps are labour-intensive and unreliable; mechanised systems and surface water preferred.	Insight: Not all water sources are equally viable. Design implication: Prioritise low-labour a reliable water systems.
Watering Regime	Seedlings are watered twice daily, with reduced frequency toward the end to harden plants before transplanting.	Insight: Water needs change over time. Design implication: Design adaptable irrigation strat based on growth stage.
Environmental Conditions	Harmattan winds increase evapotranspiration and water demand, especially during the dry season.	Insight: Climate strongly increases water stress. Design implication: Integrate wind and evaporation mitigation strategies.
Shade Use	Shade nets and natural shade reduce evapotranspiration and water use.	Insight: Shade directly reduces water demand. Design implication: Incorporate effective, po natural, shading systems.
Water Storage Systems	Some nurseries use underground reservoirs (~100m deep, plastic-lined) to reduce evaporation, though these are costly.	Insight: Water storage reduces losses but increases cost. Design implication: Balance cost w efficiency in storage solutions.
Labour Distribution	~25 workers per nursery, ~90% women. Work is often done in shifts due to competing responsibilities.	Insight: Labour availability is limited and fragmented. Design implication: Design for flexible time-efficient workflows.
Labour Constraints	Women often prioritise household and farm duties, leading to irregular or nighttime nursery work.	Insight: Time is a key constraint. Design implication: Reduce time and effort required for co tasks.
Physical Labour Bottlenecks	Water collection (especially with handpumps) and polybag filling are the most physically demanding tasks.	Insight: Physical strain limits productivity. Design implication: Focus on labour-reducing interventions.
Distance to Water	Distance between water source and nursery increases workload significantly.	Insight: Spatial layout impacts labour intensity. Design implication: Minimise transport dista design.

C – EXPERT INTERVIEWS: E9

Theme	Summary of Insights	Most Important Insights & Design Implications
Multifunctional Role of Nurseries	Nurseries also produce vegetables and multipurpose trees (e.g. moringa, baobab) for nutrition and income.	Insight: Nurseries serve broader livelihood goals. Design implication: Integrate multifunctio into design.
Species Selection	Focus on shea and fruit trees; multipurpose species are prioritised for added value.	Insight: Species choice is linked to livelihood benefits. Design implication: Support diverse p strategies.
Capacity building	Training includes nursery management, value addition (e.g. moringa products), and financial literacy.	Insight: Knowledge is key to sustainability. Design implication: Embed learning and knowledge transfer in design.

Field visits take-aways (E9)

- Reliant on a borehole for water supply increased the burden on the nursery.
- No formal irrigation system was in place, and because the hose was too slow, they used pans to irrigate.
- Shade nets frequently tear down and are expensive to maintain.

Figure 33
All pictures by me

C – EXPERT INTERVIEWS: E10

Theme	Summary of Insights	Most Important Insights & Design Implications
Grafting Strategy	Shea seedlings (~1 year old) are grafted directly in the nursery, reducing mortality compared to field grafting.	**Insight:** Early-stage control improves survival. **Design implication:** Include controlled zones for critical phases (grafting/germination).
Labour Organisation	~10 women manage daily tasks; additional workers are added during peak activities like grafting or transplanting.	**Insight:** Labour demand fluctuates. **Design implication:** Design for both routine and peak workloads.
Nursery Scale & Layout	One row contains ~4000 seedlings. Planting can be completed in 1–2 days. Filling and arranging polybags is the most labour-intensive task.	**Insight:** Polybag handling is the main bottleneck. **Design implication:** Focus on reducing labour in filling, transport, and arrangement.
Polybag Strategy	Black polybags (more expensive) are used for long-cycle crops like shea. Short-cycle crops use recycled water sachets with drainage holes.	**Insight:** Material choice depends on crop duration and cost. **Design implication:** Design flexible, low-cost container systems.
Water Use & Demand	A 6000L tank supports ~32,000 seedlings for ~2 days. Watering occurs every 2 days (~3 times per week).	**Insight:** Water demand is high and continuous. **Design implication:** Accurate storage sizing and water planning are essential.
Water Supply System	Water is supplied via canals from a man-made lake (6:00–18:00). Distribution is manual (buckets/gieters) or via underground taps from polytanks.	**Insight:** Hybrid system (gravity + manual labour). **Design implication:** Improve distribution efficiency without increasing complexity.
Shade Strategy	No shade nets needed in high-water conditions. Separate shaded areas are used for germination and grafting with double-layer nets.	**Insight:** Shade requirements depend on growth stage and water availability. **Design implication:** Use modular, phase-specific shading systems.
Shade Net Failures	Nets previously tore due to high tension. Now installed loosely with wire support to allow movement in wind.	**Insight:** Rigid systems fail under environmental stress. **Design implication:** Design flexible, wind-adaptive structures.
Water Infrastructure	Multiple 10,000L polytanks distribute water via underground taps within the nursery.	**Insight:** Central storage + distributed access improves usability. **Design implication:** Include decentralized water access points.
Scaling Across Nurseries	GSA operates ~70 nurseries: 60% boreholes, 40% dams.	**Insight:** Different water systems coexist. **Design implication:** Solutions must work across multiple infrastructure types.
Water Quality Risks	High salinity and acidic soils can lead to nursery abandonment. Water quality is only known after drilling a borehole.	**Insight:** High uncertainty in site viability. **Design implication:** Integrate early-stage water testing and risk mitigation.
Salt Damage Indicators	High salt levels cause visible red discoloration in polybag soil. Some boreholes have been abandoned due to salinity.	**Insight:** Salinity directly affects seedling survival. **Design implication:** Explore filtration or alternative water strategies.

C — EXPERT INTERVIEWS: E10

Theme	Summary of Insights	Most Important Insights & Design Implications
Potential Treatment Solutions	Options include filtration or aeration systems, though these increase cost.	**Insight:** Technical fixes exist but add complexity. **Design implication:** Balance low-tech resilience with high-tech solutions.
Windbreak & Ecology	Small forest areas are created around nurseries to act as windbreaks and seed banks.	**Insight:** Ecological integration improves system performance. **Design implication:** Incorporate trees as functional design elements.
Soil Composition	Mixture of topsoil and subsoil is used.	**Insight:** Soil is locally sourced and variable. **Design implication:** Design must allow flexibility in soil inputs.
Overproduction Strategy	Due to ~80% mortality, nurseries plant ~120% to reach targets.	**Insight:** Inefficiency is built into the system. **Design implication:** Improve survival rates to reduce waste.
Selection & Reuse	Non-germinated seedlings are sorted out. Polybags are reused if intact.	**Insight:** Circular practices already exist. **Design implication:** Design for reuse and easy sorting systems.

Key Takeaways

- Water availability and water quality are the primary drivers of nursery success, influencing layout, irrigation methods, and overall feasibility.
- Reliance on groundwater introduces significant risk, as salinity and depletion can lead to complete system failure and nursery abandonment.
- Labour-intensive processes, particularly polybag filling and manual watering, form the main operational bottlenecks, limiting scalability.
- Current systems rely on hybrid water distribution (manual + gravity-fed), indicating opportunities for improved efficiency without increasing technical complexity.
- Nursery performance is highly dependent on growth-stage-specific conditions, such as controlled environments for germination and grafting.
- Material and system flexibility are essential, as nurseries adapt resources (e.g. polybags, water sources) based on crop type, duration, and availability.
- Overproduction compensates for high mortality rates, revealing inefficiencies and the need for improved seedling survival strategies.
- Environmental conditions (wind, heat, salinity) directly impact infrastructure performance, requiring adaptive and resilient design solutions.
- Nature-based elements (windbreaks, soil management, shading) already play a key role in improving microclimate and should be integrated into design strategies.

Figure 32 ▸
All pictures by me

Field visits take-aways (E10)

- No place for children to rest, or women to breastfeed.
- A constant water supply eliminated the need for shade nets.
- When they had shade nets, they frequently broke down in under a year.

C — EXPERT INTERVIEWS: E11

Theme	Summary of Insights	Most Important Insights & Design Implications
System Overview (BAR System)	The BAR system filters borehole water using one external sediment filter and three internal filters before use.	Insight: Multi-stage filtration improves water quality. Design implication: Integrate layered filtration systems for reliability and safety.
Role of Borehole Monitoring	Boreholes are regularly checked to ensure proper functioning and water availability.	Insight: Continuous monitoring is required for system performance. Design implication: Include simple monitoring or diagnostic features in system
Pump Failures	Pumps are the most failure-prone component, often due to air intake or sediment.	Insight: Pumps are critical but vulnerable. Design implication: Reduce pump dependency or protect pumps from sediment and air intake.
Buffer System (Polytank)	Water is first filtered and then stored in a polytank, which acts as a buffer when pumps fail.	Insight: Storage increases system resilience. Design implication: Integrate buffer storage to ensure continuity of water supply.
Energy Constraints (Solar Power)	Solar-powered systems cannot pump water in early morning or evening, while evapotranspiration demand is highest during these times.	Insight: Energy supply does not align with water demand. Design implication: Design systems that decouple pumping from usage (e.g. storage, passive
Power Outages	Frequent electricity outages disrupt system reliability.	Insight: Energy instability affects system performance. Design implication: Prioritise low-energy or energy-independent solutions.
System Failures (BAR Housing)	The filter housing can fail due to pressure peaks (>5 bar), especially when air enters the system.	Insight: Pressure fluctuations cause structural failure. Design implication: Design pressure-tolerant or pressure-relief systems.
Environmental Constraints	Drought conditions and poorly constructed boreholes (e.g. insufficient depth) reduce system effectiveness.	Insight: System success depends on environmental and installation quality. Design implication: Account for variability in borehole quality and climate
Water Quality & Trust	Increased trust in filtered water has led to reduced boiling of household water.	Insight: Perceived water quality influences behaviour. Design implication: Design for both actual and perceived water quality improvements.
Behavioural Change	Increased geospatial awareness and improved understanding of water systems among users.	Insight: Technology influences user awareness and behaviour. Design implication: Support user understanding through clear system feedback.
Social Context (Hierarchy)	Approval from local chiefs is required before implementation. Working with respected local figures improves acceptance.	Insight: Social hierarchy strongly affects adoption. Design implication: Incorporate local governance and authority structures into implementation
User Acceptance	Systems are better understood and accepted when introduced through trusted community members.	Insight: Trust determines uptake. Design implication: Design deployment strategies that leverage local trust networks.
Supply Chain Dependency	Most system components are imported; only taps and pipes are locally sourced.	Insight: High dependency on external supply chains. Design implication: Explore local sourcing to improve resilience and reduce costs.

C — EXPERT INTERVIEWS: E12

Theme	Summary of Insights	Most Important Insights & Design Implications
Energy Requirements	No grid power available on site. Options include solar (with batteries) or generators. Diesel-powered pumps are recommended as reliable, low-	Insight: Energy availability is limited and unreliable. Design implication: Prioritise low-energy or fuel-based systems over complex electrical setups.
Power System Trade-offs	Solar systems require strong battery storage and are complex; generators require fuel but are more predictable.	Insight: Each energy system has trade-offs in cost, reliability, and complexity. Design implication: Design flexible systems that can operate under multiple
Pump Strategy	Manual or diesel-powered pumps reduce dependency on electricity and lower operational risk.	Insight: Simpler systems increase reliability. Design implication: Avoid over-reliance on high-tech pumping systems.
Maintenance & Inspection	Systems require limited maintenance; major servicing can occur every ~6 months. Local users can be trained to perform basic maintenance.	Insight: Systems can be low-maintenance if properly designed. Design implication: Design for easy, user-led maintenance.
Technical Support	External technicians (e.g. HGT) provide periodic support; service costs should be included in planning.	Insight: External expertise is still required occasionally. Design implication: Include service models in system design.
Water Filtration	Filters require regular cleaning but are manageable by trained users.	Insight: Filtration is critical but maintainable. Design implication: Design accessible and easy-to-clean filtration systems.
Irrigation Control	Manual valves are used to open/close sections of the nursery, allowing flexible water distribution.	Insight: Manual control enables adaptability. Design implication: Integrate simple, user-controlled distribution systems.
Water Consumption	Total water demand depends on system scale and pump selection; sizing must be aligned with capacity.	Insight: Water demand is system-dependent. Design implication: Design based on accurate water demand calculations.
System Scalability	Systems can be expanded by extending from the main pipeline.	Insight: Infrastructure can support scaling. Design implication: Design modular systems with expansion capacity.
Shade Net Strategy	Common approach uses black shade nets (for shading) combined with white insect nets (for protection). Multiple layers may be applied.	Insight: Different net types serve different functions. Design implication: Combine shading and protection layers strategically.
Wind Resistance of Nets	Shade nets must be properly fixed (locked and tensioned correctly) to prevent tearing in high-wind areas.	Insight: Installation quality determines durability. Design implication: Design wind-adaptive fastening systems.
Greenhouse Structures	Arched (rounded) structures perform better in wind, allowing airflow to pass over. Flat structures are less effective.	Insight: Geometry affects structural performance. Design implication: Use aerodynamic shapes for wind resistance.
UV & Crop Needs	UV protection is not essential for tree crops; focus is on drainage and structural stability.	Insight: Crop type determines design requirements. Design implication: Avoid overdesign; match structure to crop needs.
Drainage & Rainfall	Structures should allow water to run off easily to prevent accumulation and damage.	Insight: Water management includes both irrigation and drainage. Design implication: Integrate drainage into structural design.
Labour & Operations	Irrigation reduces manual water collection, but propagation still requires labour (e.g. seeding, transplanting).	Insight: Labour is reduced but not eliminated. Design implication: Target labour bottlenecks beyond irrigation.
Cost Considerations	Maintenance costs are relatively low; key costs include occasional part replacement and service visits.	Insight: Operational costs are manageable. Design implication: Focus on reducing upfront and failure-related costs.

C – EXPERT INTERVIEWS: E13

Theme	Summary of Insights	Most Important Insights & Design Implications
Scale of Operations	Large-scale nursery model targeting ~500,000 seedlings (e.g. mango, cashew).	Insight: High production volumes are required for commercial viability. Design implication: Design for scalability and high-throughput systems.
Tree Crop Challenges	Tree seedlings take ~2 years to grow and up to 10 years to become productive. Grafting is used to accelerate production.	Insight: Long timelines delay returns on investment. Design implication: Integrate strategies to shorten cycles (e.g. grafting, diversification).
Pricing & Revenue Model	Seedlings sold for ~5 Cedi each, generating potential revenue of ~2.5 million Cedi at scale.	Insight: Revenue depends on volume and efficiency. Design implication: Optimise cost-efficiency and survival rates.
Greenhouse vs Shade Hall	Instead of plastic greenhouses, steel-structured shade halls with replaceable nets are preferred for durability. Nets replaced every ~3 years.	Insight: Permanent structures with replaceable components are more robust. Design implication: Design durable, modular structures adapted to local
Water Dependency	Reliable water source (river/dam) is essential; low trust in boreholes. Large storage tanks (e.g. 3 × 30,000L) are recommended.	Insight: Water reliability is critical for business success. Design implication: Prioritise stable water sources and large buffer storage.
Water Storage & Buffering	Storage systems act as buffers to ensure continuous supply and match daily water demand.	Insight: Water buffering stabilises operations. Design implication: Design based on daily water demand and storage capacity.
Infrastructure Investment	Full system (hardware, trays, structure) for ~1000 m² can cost €400,000, but becomes profitable within ~3 years.	Insight: High upfront investment but viable business case. Design implication: Develop scalable, cost-sensitive alternatives for lower-budget contexts.
Hardware-Focused Approach	Truvalu provides hardware, infrastructure, and one lead operator; no direct management of nursery operations.	Insight: Clear separation between system provision and operation. Design implication: Design systems that can be independently operated.
Local Workforce Model	Implementation includes ~10 local workers and a local entrepreneur responsible for operations.	Insight: Local ownership drives success. Design implication: Design for local entrepreneurship and management.
Training & Long-Term Support	Training (3–5 years) is provided for vegetable systems; nurseries can become part of Growpact network.	Insight: Long-term engagement improves success rates. Design implication: Include long-term support structures where possible.
Business-Driven Approach	Nursery must function as a business, not a project. Success depends on a committed operator.	Insight: Commercial mindset is essential. Design implication: Design for financial viability and business ownership.
Phased Market Development	Production scales gradually (20% → 40% → 60%) to build market demand.	Insight: Market development must be gradual. Design implication: Enable phased scaling in design.
Crop Diversification	Vegetables (e.g. hydroponics or potted plants) can provide short-term revenue while trees mature.	Insight: Diversification reduces financial risk. Design implication: Integrate short-term revenue streams into system design.
Seasonality of Tree Crops	Tree planting occurs once per year; nursery cycles must align with seasonal demand.	Insight: Demand is seasonal and limited. Design implication: Design flexible systems that can adapt between cycles.
Quality of Materials	High-quality shade nets are essential; poor-quality nets lead to failure and higher long-term costs.	Insight: Material quality directly impacts system lifespan. Design implication: Prioritise durable materials over short-term cost savings.
Water Management (Rainfall)	Drainage trenches can be used to manage heavy rainfall and prevent flooding.	Insight: Both water scarcity and excess must be managed. Design implication: Integrate drainage alongside storage systems.
Business Model Validation	Initial validation phase (~€5000) before scaling to full implementation.	Insight: Testing reduces financial risk. Design implication: Include pilot phases before large-scale deployment.

C – EXPERT INTERVIEWS: E14 (S)

Theme	Summary of Insights	Most Important Insights & Design Implications
Two Perspectives on Water Use	Two main strategies: 1. Minimise groundwater pumping 2. Optimise water application to plants	Insight: Both supply and efficiency must be addressed simultaneously. Design implication: Combine water-saving irrigation with landscape water retention.
Challenges with Pumping Systems	Pumps can leak, reservoirs overflow, and systems fail, leading to water loss and reduced sustainability.	Insight: Mechanical systems introduce failure points. Design implication: Reduce reliance on pumps where possible.
Efficient Water Application	Drip irrigation is highly efficient; sprinklers less so. Soil should be covered with organic material (mulch) to reduce evaporation.	Insight: Water loss occurs mainly through evaporation and inefficiency. Design implication: Focus on root-targeted irrigation and soil protection.
Risk of Under-Irrigation	Too little water can cause salt accumulation in the soil, damaging plant growth. Slight over-irrigation is sometimes preferable.	Insight: Water quantity affects soil chemistry (salinity). Design implication: Design irrigation with minimum thresholds, not just efficiency.
Water Quality	Important factors: salinity of borehole water and required water for early-stage tree growth. A report on water quality is essential.	Insight: Water quality directly affects plant survival. Design implication: Include water testing and monitoring in system design.
Groundwater Compensation	Extracted water should be returned through infiltration (trenches, pits).	Insight: Water extraction must be balanced with recharge. Design implication: Integrate infiltration systems alongside water use.
Water Retention in Landscape	Use micro-basins, bunds, and trenches to slow runoff and increase infiltration.	Insight: Slowing water increases availability. Design implication: Design landscape features that retain water locally.
Groundwater Timescales	Groundwater can take days to thousands of years to recharge. Overuse can permanently deplete sources.	Insight: Groundwater is often non-renewable at human timescales. Design implication: Avoid designs that rely heavily on groundwater extraction.
Role of Trees in Water Balance	Trees both consume water and improve infiltration, reduce evaporation, and create microclimates.	Insight: Trees are part of the water system, not just consumers. Design implication: Integrate trees strategically for climate and water regulation.
Nursery Design Considerations	Avoid too many trees in nurseries to prevent excessive water use. Trees improve soil structure and cooling.	Insight: Density affects water demand and microclimate. Design implication: Optimise planting density for balance between growth and water use.
Windbreaks	Trees and shrubs are used around orchards to reduce wind and improve microclimate.	Insight: Wind significantly impacts evaporation and plant stress. Design implication: Include wind protection in nursery layout design.
Rainwater-Based Nurseries	Some nurseries operate without boreholes by storing rainwater (e.g., from roofs into tanks).	Insight: Rainwater harvesting can fully replace groundwater in some cases. Design implication: Explore roof catchment and storage systems for nurseries.
Need for Local Data	Requires detailed local information: site photos, GPS location, borehole position, and landscape context.	Insight: Design must be site-specific. Design implication: Collect detailed local data before finalising designs.

C — EXPERT INTERVIEWS: E14 (M)

Theme	Summary of Insights	Most Important Insights & Design Implications
Land Use & Project Setup	Land use varies depending on landscape type. Grasslands typically use bunds (earthen embankments). Projects are implemented together with local communities and follow a structured plan. After 2–3 years, ownership is transferred fully to the community.	**Insight:** Projects must be locally owned to be sustainable. **Design implication:** Systems should be simple, maintainable, and transferable without external dependency.
Community-Based Approach	Tree Aid works with technical experts and M&E teams, but projects are designed to be community-led and community-owned.	**Insight:** Long-term success depends on local capacity, not external control. **Design implication:** Design should focus on usability, low complexity, and knowledge transfer.
Water Constraints in Planting	A major challenge in tree planting is water scarcity. Direct planting often fails due to insufficient water availability.	**Insight:** Water availability is the main limiting factor. **Design implication:** Nursery and planting systems must reduce dependency on constant watering.
Farmer Managed Natural Regeneration (FMNR)	Many tree root systems remain alive underground after deforestation. These produce multiple shoots (50–60). Farmers prune these down to 1–2 strong shoots, allowing rapid regrowth due to established root systems.	**Insight:** Existing root systems drastically increase survival and growth. **Design implication:** Prioritise regeneration strategies over full replanting where possible.
Impact of FMNR	Trees improve water retention, microclimate, and crop yields. Farmers often see yield improvements within ~2 years. Pruned biomass provides sustainable firewood.	**Insight:** Trees provide both ecological and economic benefits quickly. **Design implication:** Integrate tree systems with agricultural productivity to ensure adoption.
Water Retention Techniques	Trenches around farmland improve water infiltration and retention. These are often more effective than half-moon bunds in practice.	**Insight:** Simple earthworks can outperform more complex interventions. **Design implication:** Focus on low-tech, landscape-based water retention solutions.
Landscape-Dependent Interventions	Land use strategies depend on rainfall and landscape type: – Farmland → trenches – Grassland → half-moons	**Insight:** No universal solution; context determines intervention. **Design implication:** Design must be adaptable to landscape conditions.
Grass Seed Banks (Kenya & Tanzania)	Grass plots are used for seed production: planted with local species, fenced, and maintained. Seeds are sold; remaining grass used as fodder.	**Insight:** Ecological restoration can generate income streams. **Design implication:** Integrate economic incentives into ecological systems.
Water Management Philosophy	Open soil structures allow water infiltration and reduce erosion. Pumps are considered unsustainable for agriculture but necessary for drinking water. Long-term strategies focus on rainwater harvesting.	**Insight:** Pump-based irrigation is fragile and unsustainable. **Design implication:** Prioritise passive water systems over mechanical solutions.
Examples of Water Harvesting	Includes water basins, sand dams, and Charco dams. These store runoff and reduce evaporation. Trees are planted around them as windbreaks.	**Insight:** Water storage must minimise evaporation losses. **Design implication:** Combine storage with microclimate design (e.g., windbreaks, shading).
Knowledge Transfer	Training is initially provided by experts, then transferred locally. Digital tools like the Kijani app support farmers with offline education modules.[3]	**Insight:** Knowledge is the most valuable long-term resource. **Design implication:** Include educational and intuitive elements in design outputs.

KEY TAKE-AWAYS

- Water availability is the primary limiting factor in both nursery performance and tree establishment, but reliance on groundwater pumping introduces significant technical and long-term sustainability risks.
- Landscape-based water retention strategies (e.g. trenches, bunds, micro-basins) are more robust and sustainable than pump-dependent irrigation systems, as they increase infiltration and reduce water loss.
- Working with existing ecological systems, such as Farmer Managed Natural Regeneration (FMNR), significantly improves survival rates by leveraging established root networks instead of relying solely on new planting.
- Trees function as part of the water system, improving infiltration, reducing evaporation, and creating favourable microclimates, but require careful balance to avoid excessive water demand.
- Efficiency in water application is crucial, with targeted methods (e.g. drip irrigation, mulching) reducing evaporation losses, while avoiding under-irrigation that may lead to soil salinisation.
- Simplicity and robustness in system design are essential, as technical failures (e.g. pumps, infrastructure) are common and directly impact nursery performance.
- Community ownership and knowledge transfer determine long-term success, requiring solutions that are intuitive, low-maintenance, and adaptable to local conditions.
- Design solutions must be context-specific, responding to local rainfall patterns, soil conditions, and landscape types rather than applying a single universal approach.

E15 – SMALL SCALE NURSERY OWNER

Connections & Culture

- Recommends connecting with local Ghanaian organizations working on similar systems.
- Important that local communities accept ecological interventions.
- She highlights the importance of understanding: Creation stories, Local culture, Cultural meaning of land and water, And connecting interventions to those cultural narratives.

Panorama perspective

- Suggests presenting a holistic panorama of all interconnected elements (shade, water, community, ecology).
- Your thesis can focus on one component, but acknowledge the broader system.
- Essential to recognise the limits of a graduation project.

Large-scale water solutions

Some commercial water-harvesting techniques exist in Africa, but:

- They may be quick fixes
- They may be a “necessary evil”
- Their long-term impact and cultural fit need evaluation (requires deeper research)

Ownership & empowerment

- Interventions should empower locals to start their own regenerative projects, not merely serve external organizations.

8. Final Reflections Relevant to Your Thesis

- Everything is interconnected; shade and irrigation cannot be designed in isolation.
- Your project should enter “the reality of Ghana,” including cultural and practical constraints.
- Not everything needs to be executed — focus on one part done well within the broader regenerative landscape.

Additional Insights

- Wind in her context dries plants more quickly than the sun. Vertical shade structures function more effectively than horizontal ones, as they block lateral winds and help regulate temperature. This reflects the continuous interaction between sun, wind, water, and soil, which is essential for understanding regeneration.

E15 – SMALL SCALE NURSERY OWNER

1. About her
- Lives and works in the southwest of Portugal.
- Runs a farm focused on agroforestry and beekeeping.
- Website: https://beewisdom.earth/
- Background in Industrial Design, currently 59 years old.
- Has a strong focus on permaculture, regeneration, and the idea of the "symphony of life" — understanding how life manifests in interconnected ways.
- Researching sound and frequency; believes everything is influenced by frequency patterns (requires further research).
- She maintains an olive tree nursery and works with other production trees such as cork oak (kurkeik) and strawberry tree (aardbeienboom).
- Connected to multiple community regeneration projects in the area.
- Her farm has become a place for connection, learning, and healing.

Terms needing further exploration:
Syntripie
Permaculture
Abstinence agriculture

2. About Her Nursery
A relatively small nursery with a core team of five workers.
- Initially started as a place to welcome people with personal challenges, helping them shift habits and perspectives.
- The nursery functions as a meeting place — especially around the grafting ("stekjes") area.
- The goal is to work without stress, without bureaucracy, and to focus on sharing knowledge and supporting regeneration.

They also give workshops on: Selective cleaning of natural areas to improve regeneration success.

3. Local Knowledge & Ecological Questions
Questions she considers important:
- How did nature look before it was empty?
- What is the local knowledge?
- What does the landscape want to do by itself?

4. Water Harvesting & Water Management
- Recommends studying Indian water-harvesting specialist Rajendra Singh (spelling uncertain → requires verification).
- Stresses the importance of understanding the entire water cycle.
- Believes: "There is not a shortage of water, but a shortage of water management."

Key questions she raises:
- How does water flow?
- How can water be collected?

- How can water be kept in place?
- The real challenge is creating time and resources ("middelen") to execute such systems.

Water issues in dry regions
- In the rainy season of dry regions, water often flows out of the landscape immediately, washes nutrients away, and moves toward the sea.
- Water should remain locally available near the surface, promoting regeneration.
- Deep groundwater should stay deep so ecological cycles can restore themselves (why this matters needs further research).

View on scale
- She does not believe in large-scale interventions.
- Big areas have low responsibility, more opportunities for mistakes, and require huge energy inputs.

Nature functions through small, resilient systems, not mega-structures.

5. Shade, Local Mindset & Spatial Design
- She strongly advises not cutting trees ("kappen") to create space for nurseries.
- Encourages avoiding a Northern European mindset, and instead understanding local Ghanaian ecological and cultural logic.

In Portugal she uses: Reed andRecycled fencing (e.g., old tennis court mesh)

Temperature differences in arid/semi-desert landscapes are large; design must consider this.

Vertical Structures
Suggests looking into vertical structures that:
- Capture condensation
- Provide water passively
- Act as windbreaks

(→ requires further technical research)

6. Irrigation & System Failures
Tried drip irrigation, but it failed because:
- Trees were in different pot sizes, causing uneven distribution.
- Taller trees captured drip water on leaves, preventing smaller pots from receiving water.
- For drip irrigation to work, each pot needs an individual water connection.

Shifted to hand watering, which:
- Increased control
- Improved workers' awareness of plant health
- Notes that wind dries plants more than the sun in her context.

7. Regeneration, Landscape & Ecosystem Interactions
- Emphasises the interplay between sun, water, wind, and soil.
- On south-facing slopes in her region:
- She advises not planting trees immediately,

Instead, start with water harvesting, pioneer plants, and biomass building to restore soil.

KEY OBSERVATIONS INTERVIEWEE'S

Besides the site visits, I conducted several unstructured interviews with experts, including an large organisation focused on landscape restoration through rainwater harvesting and re-greening, two technical companies working on irrigation systems in West Africa, and an experienced small-scale nursery owner. The key insights, and its opportunities are summarised here, with full interviews in Appendix A–D, forming the basis for the initial design requirements.

E14

- Water availability is the primary limiting factor for nursery performance and tree growth.
- Current systems rely heavily on groundwater pumping, which is prone to technical failure and not sustainable long-term.
- Many nurseries operate independently from the surrounding landscape and natural water flows.
- Landscape processes such as infiltration and water retention are underutilised.
- Trees and seedlings place additional demand on already limited water resources.
- Water application is often inefficient, with high evaporation losses.
- Under-irrigation occurs and can contribute to poor plant performance and soil degradation (e.g. salinisation).
- Technical systems (pumps, infrastructure) frequently fail and directly disrupt nursery operations.
- Knowledge on system use and maintenance is inconsistent across communities.
- Community ownership varies, affecting long-term continuity and care.
- Local conditions (rainfall, soil, landscape) differ significantly between sites.

E13

- Long timelines delay return on investment.
- Stable water sources and buffer storage are often lacking or insufficient.
- Local ownership strongly influences success and continuity.
- Financial viability and business structures are not always embedded in current systems.
- Short-term revenue streams are often missing.
- Systems are often rigid and do not adapt well over time or across seasons.
- Lower-cost materials are used, leading to faster degradation.
- Both water excess and water scarcity occur and are not consistently managed.
- Large-scale implementations are often done without prior testing or validation.

E12

- Electrical systems are often unreliable or difficult to maintain in this context.
- High-tech pumping systems create dependency and are prone to failure.
- Water demand varies depending on system setup and seasonal cycles.
- Current systems are often fixed and lack scalability.
- Structures are exposed to strong winds and are not always designed accordingly.
- Water accumulation on structures leads to damage over time.

E15

- There is no shortage of water, but a shortage of water management.
- Local knowledge and the natural landscape are often underutilised.
- Water is not retained locally near the surface, limiting regeneration.
- Large-scale interventions reduce responsibility, increase risk of mistakes, and require high energy input.
- Natural systems function through small, resilient structures rather than large, centralised ones.
- A Northern European mindset is often applied without fully understanding local Ghanaian ecological and cultural systems.
- Drip irrigation failed due to uneven distribution in pots and the need for large, complex systems.
- Hand watering increased control and improved awareness of plant health.
- Existing local organisations working on similar systems are not always connected or integrated.
- Ecological interventions are not always aligned with community acceptance.
- Cultural meaning of land and water is often not fully understood or integrated.
- Systems are often designed in isolation, while in reality everything is interconnected.

CO-CREATION SESSION NURSERY

Objective
To identify and prioritise operational challenges within existing community nurseries and explore worker preferences for future nursery development.

Participants
The session was conducted with nursery workers in Northern Ghana and facilitated by the author. Translation and contextual support were provided by a Vitara Conservation Agent.

Method
Custom-designed 3D-printed tools and visual cards were used to facilitate participatory mapping and co-creation activities. Participants first ranked challenges encountered during nursery operations and subsequently co-created their ideal nursery layout. The visual and tangible format was selected to reduce literacy barriers and encourage active participation.

Data Collection
Data consisted of challenge rankings, participant discussions, observational notes, and the resulting nursery layouts.

Outcome
Water access consistently emerged as the highest-priority challenge and was repeatedly linked to labour intensity, nursery maintenance, and seedling survival. These findings directly informed the project's focus on water management.

FIELD FINDINGS

Expert interviews and site visits across Tamale, Wa, and Accra confirmed that water scarcity was rarely the only issue. The larger challenge was the reliability, distribution, and long-term management of water systems. Many nurseries relied on boreholes, pumps, or inconsistent manual watering, leading to breakdowns, uneven distribution, and evaporation losses.

At the same time, local solutions, canals, rainwater harvesting, and storage systems revealed a strong understanding of water management embedded within the landscape itself.

The same finding appeared across all three methods: literature (surface water governance), expert interviews (social system dependency), and fieldwork (worker priority rankings). When three methods produce the same signal, the finding is reliable. Among the interviews with nursery workers (E1-3), the key findings were:

Water access, ranked #1 by all groups
20+ workers across multiple groups independently ranked water access as their highest daily priority, confirming the reframe from shade to water.

Heavy lifting as top physical burden
Carrying water over a distance was identified as the most exhausting and least rewarding task.

Multiple distributed points preferred
Workers strongly preferred several water access points across the nursery to a single central tap. Modularity validates this preference.

Children
Workers with young children reported having to take their children to work because they had no one else to look after them during the day.

Figure 20
Different ways of pumping, visuals by me

D — TECHNICAL VALIDATION: EMISSION UNIFORMITY

EMISSION UNIFORMITY

Emission uniformity (EU) measures how consistently water is distributed across all emitters. The target EU for drip irrigation is ≥80% (Bakker et al., 2015; Martinez et al., 2024).

- Calculated EU for proposed configuration: 85–98% (Martinez et al., 2024, comparable low-head gravity systems in West Africa)

- Field validation benchmark: Darimani et al. (2021) gravity-fed drip system in Upper West Region, Ghana: 90% EU, 0.57 L/h average emitter discharge

Uniformity coefficient (CU) target: ≥78% achieved in comparable systems (Darimani et al., 2021)

The proposed 30 m lateral length at 2.0 m head falls within the validated range for high-uniformity distribution. Longer laterals (>40 m) would require increased head or reduced flow rates to maintain uniformity.

0.1 L PER SEEDLING

- Expert recommendation: 100 ml per seedling every 3 days under Harmattan conditions (E9, January 2026)

- Literature validation: effective delivery range of 0.08–0.12 ml per seedling per day under semi-arid ambient conditions (Darimani et al., 2021; Bakker et al., 2015)

- At 3-day intervals: 0.1 L every 3 days = 0.033 L/day — within validated range •Total per module per event: 25,000 × 0.1 L = 2,500 L
- Tank capacity: 3,000 L witgh 500 L buffer for evaporation, cleaning, and flow variation

- Workers can adjust frequency (every 2, 3, or 5 days) based on growth stage and weather, delivery per event stays constant at 0.1 L

SOLAR PUMP SIZING

- Daily irrigation demand per module: 2,500 L per event (every 2–3 days)

- Daily pump requirement: 2,500 L refill in daylight hours, approximately 3,000 L/day including losses

- Pump flow rate required: 3,000 L / 8 solar hours = 375 L/hour = 6.25 L/minute

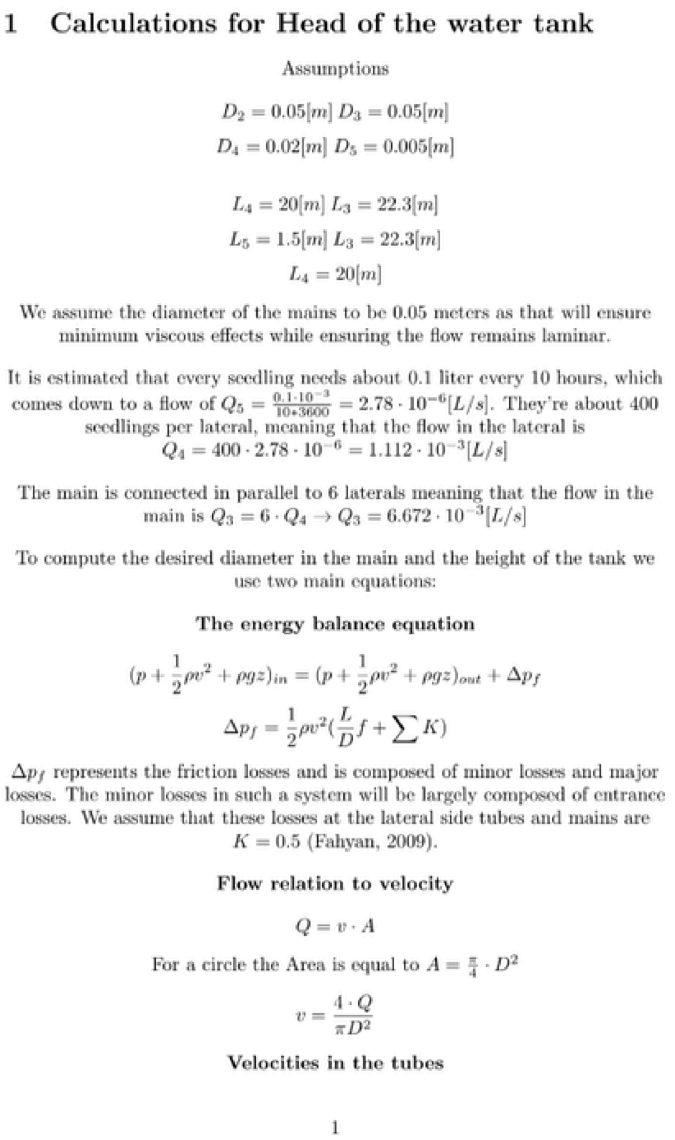
- Solar irradiance near Wa: 5.4 kWh/m^2/day (Solargis, 2021) — peak during dry season

- Recommended pump specification: 120–370W DC solar pump; 3,000 L/h capacity

- One pump can fill up to 6 modules of 3,000 L during a single daylight cycle

- Battery storage not required, the polytank itself serves as a storage buffer for night distribution

D – TECHNICAL VALIDATION: HYDRAULIC HEAD OF THE TANK



1 Calculations for Head of the water tank

Assumptions

$$D_2 = 0.05[m] \; D_3 = 0.05[m]$$

$$D_4 = 0.02[m] \; D_5 = 0.005[m]$$

$$L_4 = 20[m] \; L_3 = 22.3[m]$$

$$L_5 = 1.5[m] \; L_3 = 22.3[m]$$

$$L_4 = 20[m]$$

We assume the diameter of the mains to be 0.05 meters as that will ensure minimum viscous effects while ensuring the flow remains laminar.

It is estimated that every seedling needs about 0.1 liter every 10 hours, which comes down to a flow of $Q_5 = \frac{0.1 \cdot 10^{-3}}{10 * 3600} = 2.78 \cdot 10^{-6}[L/s]$. They're about 400 seedlings per lateral, meaning that the flow in the lateral is $Q_4 = 400 \cdot 2.78 \cdot 10^{-6} = 1.112 \cdot 10^{-3}[L/s]$

The main is connected in parallel to 6 laterals meaning that the flow in the main is $Q_3 = 6 \cdot Q_4 \rightarrow Q_3 = 6.672 \cdot 10^{-3}[L/s]$

To compute the desired diameter in the main and the height of the tank we use two main equations:

The energy balance equation

$$(p + \frac{1}{2}\rho v^2 + \rho g z)_{in} = (p + \frac{1}{2}\rho v^2 + \rho g z)_{out} + \Delta p_f$$

$$\Delta p_f = \frac{1}{2}\rho v^2(\frac{L}{D}f + \sum K)$$

Δp_f represents the friction losses and is composed of minor losses and major losses. The minor losses in such a system will be largely composed of entrance losses. We assume that these losses at the lateral side tubes and mains are $K = 0.5$ (Fahyan, 2009).

Flow relation to velocity

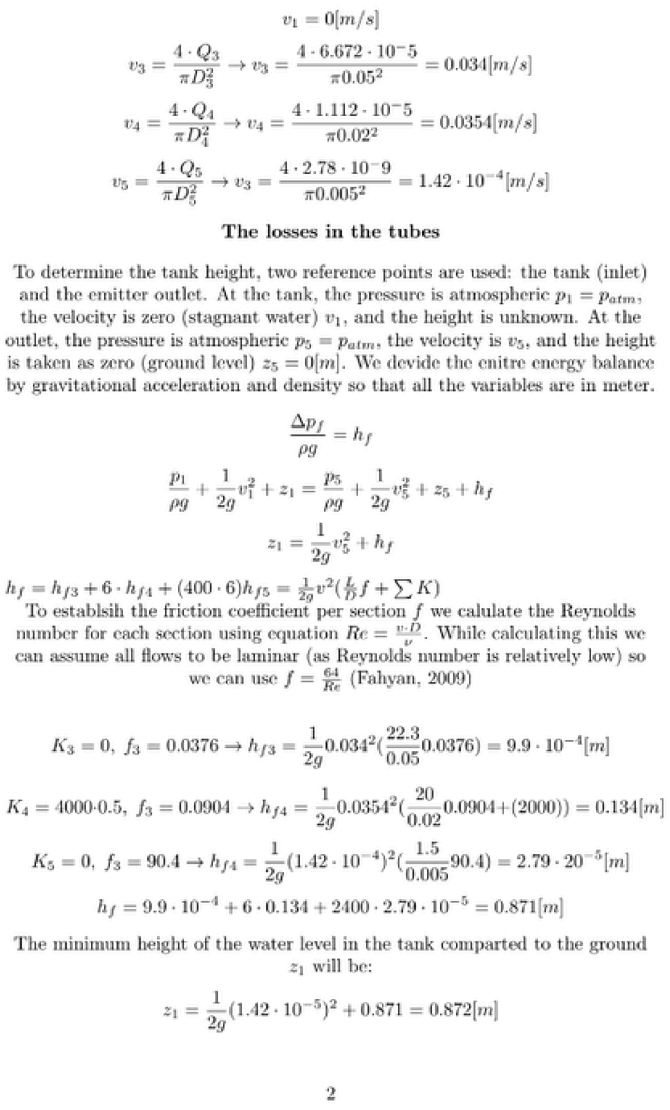
$$Q = v \cdot A$$

For a circle the Area is equal to $A = \frac{\pi}{4} \cdot D^2$

$$v = \frac{4 \cdot Q}{\pi D^2}$$

Velocities in the tubes

1



$$v_1 = 0[m/s]$$

$$v_3 = \frac{4 \cdot Q_3}{\pi D_3^2} \rightarrow v_3 = \frac{4 \cdot 6.672 \cdot 10^-5}{\pi 0.05^2} = 0.034[m/s]$$

$$v_4 = \frac{4 \cdot Q_4}{\pi D_4^2} \rightarrow v_4 = \frac{4 \cdot 1.112 \cdot 10^-5}{\pi 0.02^2} = 0.0354[m/s]$$

$$v_5 = \frac{4 \cdot Q_5}{\pi D_5^2} \rightarrow v_3 = \frac{4 \cdot 2.78 \cdot 10^-9}{\pi 0.005^2} = 1.42 \cdot 10^{-4}[m/s]$$

The losses in the tubes

To determine the tank height, two reference points are used: the tank (inlet) and the emitter outlet. At the tank, the pressure is atmospheric $p_1 = p_{atm}$, the velocity is zero (stagnant water) v_1, and the height is unknown. At the outlet, the pressure is atmospheric $p_5 = p_{atm}$, the velocity is v_5, and the height is taken as zero (ground level) $z_5 = 0[m]$. We devide the enitre energy balance by gravitational acceleration and density so that all the variables are in meter.

$$\frac{\Delta p_f}{\rho g} = h_f$$

$$\frac{p_1}{\rho g} + \frac{1}{2g}v_1^2 + z_1 = \frac{p_5}{\rho g} + \frac{1}{2g}v_5^2 + z_5 + h_f$$

$$z_1 = \frac{1}{2g}v_5^2 + h_f$$

$h_f = h_{f3} + 6 \cdot h_{f4} + (400 \cdot 6)h_{f5} = \frac{1}{2g}v^2(\frac{L}{D}f + \sum K)$

To establsih the friction coefficient per section f we calulate the Reynolds number for each section using equation $Re = \frac{v \cdot D}{\nu}$. While calculating this we can assume all flows to be laminar (as Reynolds number is relatively low) so we can use $f = \frac{64}{Re}$ (Fahyan, 2009)

$$K_3 = 0, \; f_3 = 0.0376 \rightarrow h_{f3} = \frac{1}{2g}0.034^2(\frac{22.3}{0.05}0.0376) = 9.9 \cdot 10^{-4}[m]$$

$$K_4 = 4000 \cdot 0.5, \; f_3 = 0.0904 \rightarrow h_{f4} = \frac{1}{2g}0.0354^2(\frac{20}{0.02}0.0904 + (2000)) = 0.134[m]$$

$$K_5 = 0, \; f_3 = 90.4 \rightarrow h_{f4} = \frac{1}{2g}(1.42 \cdot 10^{-4})^2(\frac{1.5}{0.005}90.4) = 2.79 \cdot 20^{-5}[m]$$

$$h_f = 9.9 \cdot 10^{-4} + 6 \cdot 0.134 + 2400 \cdot 2.79 \cdot 10^{-5} = 0.871[m]$$

The minimum height of the water level in the tank comparted to the ground z_1 will be:

$$z_1 = \frac{1}{2g}(1.42 \cdot 10^{-5})^2 + 0.871 = 0.872[m]$$

2

D — TECHNICAL VALIDATION: SOLAR VS. FUEL PUMP

Criteria	Solar DC Pump	Fuel Pump (Petrol/Diesel)
Initial investment (CAPEX)	High: €700–1,800	Low: €250–650
Annual running cost (OPEX)	Near zero: €20–80/year for cleaning	Very high: €380–950/year for fuel/oil
5-year total cost (TCO)	€1,100–2,800	€2,550–6,600
Breakeven point	8–14 months	Never — costs compound permanently
Hydraulic suitability	Ideal — slow steady pumping matches system requirement	Poor — overpowered; short run-times damage engine
System lifespan	5–8 years (pump); 20+ years (panels)	1–2 years (dust/heat damage to engine)
Labour and maintenance	Passive — turns on/off automatically with sun	High — requires daily manual refuelling and starting
Supply chain risk	Zero — independent energy source	High — vulnerable to local fuel shortages and price spikes

Field evidence	Near Wa: 300 GH₵ per gallon (~$27); lasts 2 weeks for 2 acres = ~$700/year in fuel (E6, Feb 2026)	Same field evidence confirms fuel dependency is operational risk, not just financial

The selection of a solar-powered pumping system was based on a broader evaluation than capital costs alone. Previous research has shown that water infrastructure in Northern Ghana is frequently affected by maintenance challenges, breakdowns, and dependence on external inputs, making operational reliability a critical design criterion (Chegbeleh et al., 2020). Combined with the high solar irradiance levels available in Wa throughout the dry season (Solargis, 2021), solar pumping offers a technically suitable and operationally resilient alternative to fuel-dependent systems.

Validation Interview 2 – Systems & Sustainability Perspective

Set up: the toolkit was presented in its entirety, after which discussion was facilitated naturally. The key topics are as follows:

Role of expert: big-scale nursery manager for over 15years on an arid island.

Irrigation & Water Management

- Overhead irrigation can increase the risk of rot and disease development.
- Hand watering can be effective, but it becomes labour-intensive as nursery size increases.
- Drip irrigation is one of the most efficient irrigation methods because water is delivered directly to the root zone.
- Sub-irrigation systems may provide an effective alternative depending on context.
- Reliable water access is one of the most important conditions for successful nursery operation.
- Rainwater harvesting should be considered as a supplementary or backup water source.
- Relatively simple rainwater collection systems can contribute meaningful amounts of water.

Biodiversity & Restoration

- Restoration efforts should contribute beyond economic objectives alone.
- Nurseries should support ecological restoration and food security simultaneously.
- Indigenous species should be prioritised where possible.
- Species diversity should be actively promoted within restoration programmes.
- Similar climatic regions can be used to identify suitable restoration species.
- Healthy nurseries should contain a diversity of species rather than focus on a single species.
- Indigenous reforestation is important for restoring ecological resilience.

Windbreaks & Shade

- Trees should be viewed as multifunctional landscape elements.
- Windbreaks should provide multiple benefits beyond wind protection alone.
- Natural shade may offer advantages over artificial shade nets.
- Non-invasive nitrogen-fixing species may provide valuable shade while improving ecosystem functioning.

Nursery Operations

- Healthy microbial activity within polybag growing media is important for seedling development.
- Nursery soils should contain a diverse microbial community.
- Genetic diversity within planting stock should be maintained.
- Excessive genetic uniformity should be avoided.
- Drip irrigation can be beneficial for grafted seedlings because stems and graft unions remain drier.
- Nursery modules should be cleaned between production cycles.
- Regular cleaning reduces disease pressure and improves nursery health.

Scaling & Risk Management

- Small-scale implementation allows learning before expansion.
- Modular systems increase resilience because failures remain isolated.
- Systems should be allowed to evolve through gradual adaptation.
- Community collaboration should remain central during implementation.

Key Takeaways

- Drip irrigation was validated as an efficient irrigation strategy.
- Reliable access to water remains fundamental to nursery success.
- Biodiversity should remain central to restoration efforts.
- Multifunctional windbreaks and natural shade systems are preferred.
- Healthy soils, genetic diversity, and maintenance practices strongly influence seedling quality.
- Modular implementation reduces risk and supports adaptation.

Validation Interview 2 – Systems & Sustainability Perspective

Set up: the toolkit was presented in its entirety, after which discussion was facilitated naturally. The key topics are as follows:
Role of expert: private small-scale nursery owner in arid circumstances for over ten years of experience.

Ownership & Responsibility
- Long-term success depends strongly on local ownership.
- People are more likely to maintain systems when they directly benefit from outcomes.
- Responsibility increases commitment and care.
- Organisational structures influence maintenance quality.
- Systems based on self-organisation are often more resilient than systems dependent on external control.
- Local capacity building should be prioritised where possible.

Community Resilience
- Restoration projects should strengthen communities as well as ecosystems.
- Social resilience is as important as technical resilience.
- Community participation influences long-term success.
- Large interventions should consider how they affect local self-reliance.
- Sustainable restoration requires attention to organisational and social structures.

Water Systems & Sustainability
- Rainwater harvesting generally creates greater local resilience than dependence on centralised infrastructure.
- Local water systems are often easier to manage and maintain.
- Dependence on large infrastructure can create vulnerabilities.
- Water systems should be evaluated based on their contribution to long-term resilience.
- Restoration interventions should avoid creating unnecessary dependency.

Nursery Environment
- Raised nursery tables may reduce physical strain on workers.
- Raised nursery tables may improve ergonomics.
- Raised nursery tables may improve attention given to seedlings.
- Raised nursery tables may influence root development positively.
- Raised nursery tables may reduce temperature stress around root systems.
- Elevated nursery systems warrant further investigation.

Key Takeaways
- Ownership and responsibility are critical drivers of long-term success.
- Social resilience should be considered alongside technical performance.
- Rainwater harvesting remains an important long-term resilience strategy.
- Restoration systems should strengthen local capacity rather than create dependency.
- Raised nursery systems may offer operational and horticultural benefits.

Validation Interview 3 – Seedling Development & Irrigation Management

Set up: the toolkit was presented in its entirety, after which discussion was facilitated naturally. The key topics are as follows:

Role of expert: private small-scale nursery owner in arid circumstances for over ten years of experience.

Seedling Development

- Seedlings pass through different developmental stages with different requirements.
- Establishment, rapid growth, and hardening each require different management approaches.
- Irrigation requirements change throughout the seedling lifecycle.
- Seedling quality is influenced by how water is managed throughout these stages.
- Hardening is an important preparation stage before outplanting.
- Controlled stress can improve resilience before field planting.
- Strong seedlings are more important than simply maximising growth speed.

Irrigation Strategy

- Water management should be adapted to the developmental stage of the seedling.
- Irrigation should support biological development rather than simply maximise water delivery.
- Excessive irrigation can produce weaker seedlings.
- Precision irrigation can improve control over seedling development.
- Consistency in water delivery contributes to more uniform seedling quality.
- Human monitoring remains important even when irrigation systems are automated.
- Irrigation systems should be evaluated based on seedling quality outcomes.

Nursery Production

- Customer-linked production can strengthen accountability.
- Knowing the destination of seedlings may increase care and responsibility.
- Clear production targets improve nursery management.
- Linking production to planned outplanting destinations may reduce waste.
- Accountability mechanisms can improve nursery performance.

Workforce & Maintenance

- Irrigation systems require regular monitoring.
- Clogged emitters remain a key operational risk.
- Technical maintenance should not be overlooked.
- Training remains essential regardless of the irrigation technology used.
- Human attention remains an important component of nursery success.

Key Takeaways

- Water management should be centred around seedling development rather than water delivery alone.
- Different growth stages require different irrigation approaches.
- Hardening is essential for preparing seedlings for field conditions.
- Seedling quality should be prioritised over irrigation efficiency alone.
- Accountability and planned production can improve nursery performance.
- Technical systems remain dependent on training, monitoring, and maintenance.

Toolkit Validation – Research Setup

Objective

The objective of this validation was to evaluate whether the toolkit could be independently understood by external stakeholders without prior explanation of its intended structure. Particular attention was given to the clarity of the content, logical flow, ease of navigation, and overall comprehensibility of the implementation process.

Participants

Five external participants with out relevant background.

Method

An unstructured interview format was used. Participants received the toolkit and were asked to review it independently. No explanation of the intended structure, navigation, or content hierarchy was provided beforehand.

Instead of asking participants whether they liked the toolkit, they were encouraged to explain in their own words:

- What they believed the toolkit contained.
- How they interpreted the structure.
- How they would navigate through the document.
- Which elements stood out to them.
- Whether anything was unclear or missing.
-

This approach was selected to evaluate whether the intended logic of the toolkit was communicated through the design itself rather than through additional explanation by the author.

Results

Across all interviews, participants were able to describe the toolkit structure with limited additional guidance. The sequence of information, implementation logic, and intended purpose was generally interpreted as intended.

Representative statements included:

“It feels very structured. I immediately understand where to start and how the information builds on itself.”

“The toolkit guides you through the process step by step. I never felt lost while going through it.”

“I can clearly see the logic behind the sections and how they connect to each other.”
“The visual layout makes it easy to understand what is important and where information can be found.”

“Even without an explanation, I understand what needs to happen first and what follows afterwards.”

Several participants also highlighted the visual nature of the toolkit as a strength:
“The visuals make complex information much easier to understand.”

“I normally would not read a technical report like this, but the toolkit format keeps my attention.”

Conclusion

The validation suggests that the toolkit communicates its intended structure and implementation logic effectively. Participants were generally able to understand the content, sequence, and purpose of the toolkit without prior instruction, indicating that the visual and organisational structure successfully supports independent use.

F — BOM, AND BUDGET

Assumptions made for calculations:

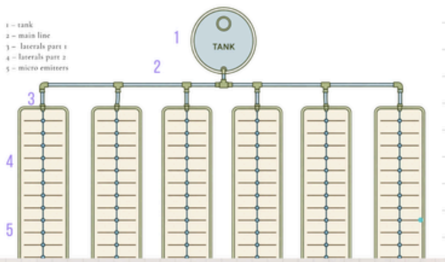
- Maximum polybag width is 0.15m
- Six rows of each 4-5000 seedlings, of around 90m2 (with said 0.15m2)
- Two meters around the edge of all seedlings for fencing to allow place for tractors or cars if needed
- Area of pure seedlings = 540 m2
- Walking area = 75 m2
- Total length: 34m, total width = 24.5 m. Total area (with fencing as outer part is 833 m2)
- Poles for metal fencing are spaced 2.5 meters apart for sturdiness

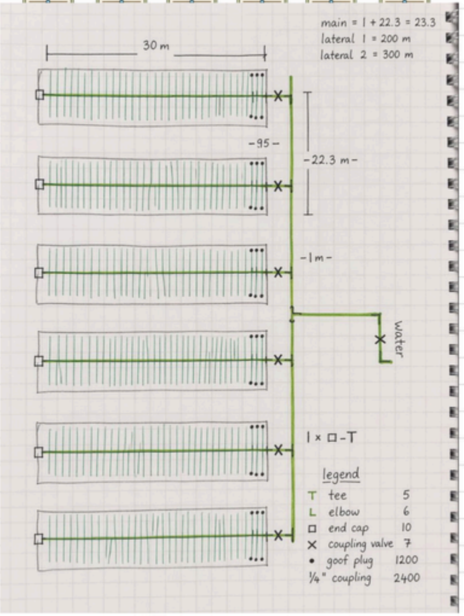
-Each polybag (Ø 0.15 m, height 0.15 m) is assumed to hold approximately 2.5 liters of soil, accounting for settling

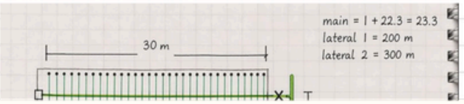
Exchange rate 1 GHC = 0.076 EUR = 0.089 USD (03/05/2026)

except for expert is daily worker rate 35 CEDI (Ghana, 2025)

Contingency is set at 15% (IFAD, 2025)

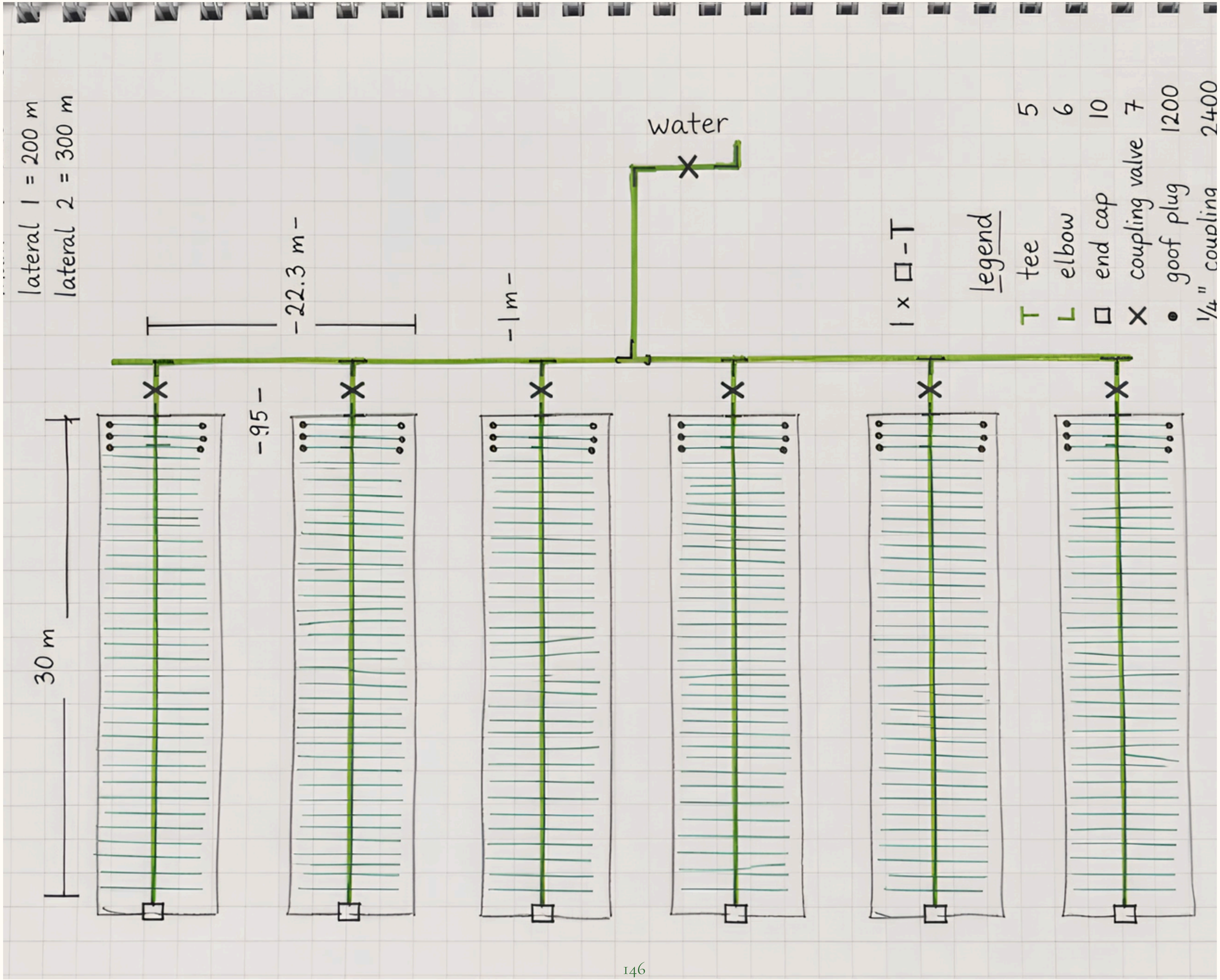






Part of Nursery	Item	Quantity	Unit	Unit or 1m Cost (GHS)	Unit Cost (USD)	Unit Cost (Euro)	Total Cost (USD)	Link	Contact
Irrigation	Polytank 3000L (nr 1 in picture)	1	tank	4360	393.46	336.84	393.46	https://polytankgh.com/	
	Stand polytank 2meters	1	stand	5000	820.43	380.74	446.43	https://www.youtube.com/watch?v=A_xYf2gWeCk	
	Solar pump unit (1.5 -- 2 HP)	1	pump	4000	357.14	304.59	357.14	https://www.dengltd.com/our-products/water-pum	info@dengltd.com
	MPPT controller and wiring	1	controller	5000	820.43	380.74	446.43		
	Solar panel array (6 x 300 W panels)	6	unit	1000	535.71	456.88	3214.26		
	Main line (0.05m) 22,3 meter (nr 2 in picture)	23.3	m	40	3.57	3.05	83.181		
	laters part 1 (0.02m) (nr 3 in picture)	200	m	8	0.71	0.61	141		
	laterals part 2 (0.02m) (nr 4 in picture)	3600	m	8	0.71	0.61	2556		
	Micro emitters 0.1L (nr 5 in picture)	4000	pcs	1.4	0.17	0.11	680	https://jiji.com.gh/ashaiman-municipal/farm-mach	
	Tee	5	pcs	15	1.34	1.14	6.7	https://www.irrigationglobal.com/index.html	
	Elbows	10	pcs	12	1.07	0.91	10.7	https://www.irrigationglobal.com/index.html	
	End caps	6	pcs	3	0.27	0.23	1.62	https://www.irrigationglobal.com/index.html	
	Coupling valves	7	pcs	10	0.89	0.76	6.23	https://www.irrigationglobal.com/index.html	
	Goof plugs	1200	pcs	0.5	0.045	0.038	54	https://www.irrigationglobal.com/index.html	
	1/4 inch coupling	2400	pcs	0.5	0.045	0.038	108	https://www.irrigationglobal.com/index.html	
	Transportation	1	working days	1000	89.29	76.15	89.29	https://www.irrigationglobal.com/index.html	
	Construction time/labour (three people)	4	working days	120	10.71	9.14	67.89		
							8662.331		
Total irrigation							350		8505.151
Seedlings	Polybags	25,000	pcs	0.15	0.014	0.012	278.75	https://jiji.com.gh/ahafo-ano-south/feeds-supplem	
	Filling material	62.5	m³	50	4.46	3.81	0		
	Shea seedlings	25,000	pcs	0	0.00	0	8.93		
	Transportation	1	working days	100	8.93	7.61	125		
	Construction time/labour (eight people)	5	working days	35	3.13	2.67			
	including: collection and preparing filling materia		fill 25.000 polybag						
Total Seedlings							762.68		628.75
Fencing	Galvanized chain link fence	117	m	49.2	4.39	3.75	513.96	https://jiji.com.gh/accra-metropolitan/building-and	
	Metal Gate	1	gate						
	Metal Poles	47	pcs	80	7.14	6.09	335.58	https://jiji.com.gh/tema-metropolitan/building-mate	
	Cement	14	bags (of 1m³)	91	8.13	6.93	1274	https://jiji.com.gh/north-industrial-area/165-cemen	
	Ballast (gravel)	30	wheelbarrows (0.0	25	2.23	1.9	750	https://jiji.com.gh/165-gravel	
	Nails	1	kg	20	1.79	1.52	20		
	Sand	15	wheelbarrows	15	1.34	1.14	225		
	Transportation	1	working days	700	62.50	53.3	62.5		
	Construction time/labour (five people)	2	working days	35	3.13	2.67	31.3		
	including: digging, mixing cement, fixing fence								
Total fencing							3212.34		3118.54
Land	Land cost	833	m²	616	55.00	46.91	55		
	Clearing/ levelling land	833	m²	73	6.52	5.56	6.52		
	Layin paths	117	m²	30	2.68	2.28	2.68		
	Transportation	1	working days	100	8.93	7.61	8.93		
	Construction time/labour (four people)	2	working days	35	3.13	2.67	25.04		
Total land							98.17		64.2
Shed working	Round metal poles for shed	12	pcs	100	8.93	7.61	107.16	https://jiji.com.gh/tema-metropolitan/building-mate	
	Angle bars	60	m	25	2.23	1.9	133.8	https://jiji.com.gh/tema-metropolitan/building-mate	
	Cement	6	bags	91	8.13	6.93	48.78	https://jiji.com.gh/accra-metropolitan/hardware-an	
	Sand	12	wheelbarrows	15	1.34	1.14	16.08		
	Ballast (gravel)	18	wheelbarrows	20	1.79	1.52	32.22	https://jiji.com.gh/165-gravel	
	Binding wire	5	kg/box	14	1.25	1.07	6.25	https://jiji.com.gh/accra-metropolitan/repair-and-co	
	Nails and screws	3	kg/box	25	2.23	1.9	6.69		
	Transportation	1	working days	100	8.93	7.61	8.93		
	Construction time/labour (2 people)	2	working days	35	3.13	2.67	12.52		
							372.43		
Total shed									350.98

F — TECHNICAL LAYOUT DRAWING



F — ADDITIONAL INTERVENTIONS COST ANALYSIS

The six complementary interventions presented in toolkit page 23/24 are each low-cost and locally implementable. The following overview provides indicative cost ranges based on Ghanaian supplier quotes (Wa and Tamale, February 2026), comparable project data from the region, and published implementation guides.

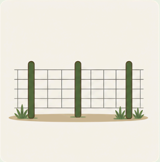
1. **Windbreaks (Neem trees)** Neem (Azadirachta indica) seedlings are widely available across Northern Ghana at approximately GH₵2–5 per seedling ($0.18–0.45). A perimeter row of 60–80 trees for one module is estimated at GH₵120–400 ($11–36). No irrigation infrastructure is required beyond the first establishment month. Labour for planting is included in the coordinator's existing role. Source: FAO Agroforestry Field Manual (2008); field observation, Tamale nursery (E10, February 2026).

2. **Waterbunds and earth ridges** require no materials beyond local soil and manual labour. Construction of simple bunds around an 820 m^2 plot is estimated at 2–3 working days for two workers at GH₵50/day each, totalling GH₵200–300 ($18–27). No maintenance cost unless damaged by heavy rainfall. Source: Tree Aid implementation documentation (E9, January 2026); Westerberg (2019).

3. **Perimeter Fencing** Already included in the main CAPEX at $3,212 for the pilot module (117 m of galvanised chain-link fencing, metal poles, cement). Included here for completeness. Maintenance cost is minimal — estimated GH₵150–200/year ($13–18) for wire repairs. Source: Jiji.com.gh supplier quotes, Wa (February 2026).

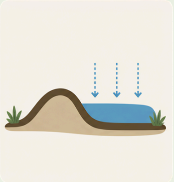
WINDBREAKS

Fast-growing, locally adapted trees, like the Neem, are planted from day one. Reduces Harmattan wind velocity, limits evaporation, and provides partial shade, reducing dependency on shade nets, which frequently fail.



PERIMETER FENCING

Defines and protects the nursery from animals and external disturbance. Creates a clear maintenance boundary. Low-cost wire fencing with wooden posts is standard and effective in this context.



WATERBUNDS

Simple earth ridges that slow surface runoff and increase soil infiltration. Allows water to remain in the landscape longer, supporting both the nursery and surrounding farmland during dry season.

F – ADDITIONAL INTERVENTIONS COST ANALYSIS

4. **Childcare Space**
A shaded, safe area under or adjacent to the elevated polytank stand. One-time setup cost of GH₵3,600–7,600 ($325–680), covering basic shade structure using locally sourced timber and shade cloth, one mat or groundsheet, and simple boundary markers. No dedicated staff required, integrated into the coordinator role. Source: WHO Early Childhood Development guidelines (2018); Bardasi and Wodon (2010); field observation focus group Wa (February 2026).

5. **Recordkeeping Physical logbooks**
cost approximately GH₵15–30 ($1.34–2.68) each per season. QR-linked digital reporting requires a smartphone (assumed already available within Vitara's field agent structure) and a free platform such as KoboToolbox or Google Forms. Total annual cost: under GH₵100 ($9). Source: Field observation Tamale (E6, February 2026); Vitara operational documentation (2026).

6. **Maintenance Budget**
A dedicated maintenance reserve of GH₵1,100–1,650/year ($100–150) is recommended, covering emitter replacements, pipe fittings, filter cleaning materials, and minor structural repairs. This is already partially included in the OPEX figure of $678 for materials, transport, and contingency. Isolating a named maintenance sub-budget prevents it from being absorbed into general operating costs. Source: Irrigation component pricing, irrigationglobal.com (February 2026); E4 and E8 field interviews.

Total indicative cost of all six interventions (excluding fencing, already in CAPEX): GH₵5,000–10,000 per pilot year ($450–890), representing approximately 3.4–6.8% of total pilot CAPEX. All materials are locally sourceable within the Wa–Tamale corridor.

RECORDKEEPING

Simple logbooks and QR-linked reports track daily observations, maintenance requests, and seedling performance. This data helps us improve and supports our management's scale-up decisions.

CHILDCARE SPACE

A shaded, safe area near the nursery allows children to be close while mothers work. With coordinated scheduling, this supports both productivity and community trust, a practical, human-centred detail.

MAINTENANCE BUDGET

A small, dedicated budget for routine maintenance and quick repairs. Covers leaks, fittings, filter cleaning, and minor replacements. Allocated upfront, it enables immediate fixes without delays, preventing downtime and seedling loss.

Sankana dam

Site selection was treated as a design decision. The following four criteria were applied:

- •Water reliability: a surface water source maintaining sufficient levels throughout the dry season eliminates borehole-dependent sites
- •Existing infrastructure: on-site water infrastructure to reduce setup cost during pilot year
- •Operational proximity: within 30 minutes of Vitara's base in Wa for practical oversight and rapid response
- •Governance: existing community governance structure (WUA or equivalent) with local chief acceptance

Rainwater harvesting was explored as an alternative, but requires infrastructure, septic tanks and large collection surfaces that fall outside the scope and budget of a pilot nursery.

Coordinates	10°11'08.35"N, 2°36'13.68"W
Year built	1961
Primary purpose	Irrigation reservoir
Estimated total capacity	>30 million litres
Annual scheme water use	1.50 Mm^3
Developed irrigated area	40 hectares
Current capacity utilisation	Approximately 20%
Nursery demand (25,000 seedlings)	5.4–7.2 million litres per dry season
Nursery demand as % of annual scheme usage	<0.5%
Available farmland near dam	2 acres confirmed (Google Earth + field stakeholder)
Distance to Vitara HQ, Wa	<30 minutes by motorbike
Governance	Water User Association (WUA) in operation
Community acceptance	Local chiefs indicated acceptance of new irrigation initiatives (E10, February 2026)
Existing infrastructure	Water infrastructure present on-site — reduces setup cost
Field evidence	Existing nursery at Sankana: seedlings thriving despite broken shade nets due to stable dam water supply (E10)

H – OVERVIEW OF DESIGN REQUIREMENTS

IMPLICATION FOR DESIGN

The following requirements list was derived from field observations, expert interviews (E-codes), and literature research. Requirements are classified as Must, Should, or Could and are traceable to the six design priorities above.

Although elevated storage enables gravity-fed irrigation independent of the pumping source, the toolkit prioritises solar-powered pumping over fuel-based systems. This decision was made to strengthen long-term water reliability, reduce fuel dependency and operational labour, and support modular scaling under remote dry-season conditions. By combining solar pumping with elevated buffer storage sized for multiple days of irrigation demand, the system remains functional during temporary low-sun periods while reducing reliance on fuel logistics, combustion maintenance, and external operational inputs.

FOCUS AREAS	REQUIREMENTS
WATER MANAGEMENT The system must improve water availability, retention, and efficiency without increasing dependency on external inputs.	• Prioritise water management over water extraction • Reduce reliance on groundwater pumping systems • Integrate landscape-based water retention (infiltration, storage, runoff control) • Ensure water remains locally near the surface to support regeneration • Design for both water scarcity and excess • Include sufficient buffer storage capacity • Adapt the water supply to fluctuating seasonal and system demand
SYSTEM ROBUSTNESS The system must function reliably under local conditions with minimal failure risk.	• Prioritise simple, low-tech, and low-energy solutions • Avoid dependency on complex or high-tech pumping systems • Ensure systems remain functional under technical failure scenarios • Use durable materials over short-term cost savings • Design structures to withstand strong winds (aerodynamic shaping) • Ensure effective water runoff to prevent structural damage
ECOLOGICAL INTEGRATION The system must work with natural processes rather than against them.	• Build on existing ecological systems and landscape dynamics • Avoid large-scale, high-energy interventions • Design small, distributed, and resilient systems • Balance the tree water demand with available resources • Retain and reuse water within the local system • Support regenerative processes in soil and vegetation
USABILITY AND LOCAL INTEGRATION The system must be understandable, accepted, and maintained by local communities.	• Enable strong local ownership and responsibility • Ensure systems are intuitive and low-maintenance • Build on local knowledge and practices • Integrate cultural understanding of land and water • Increase user control and awareness (e.g. manual or semi-manual systems) • Connect with existing local organisations and initiatives
EFFICIENCY AND PERFORMACE The system must improve nursery output while reducing losses.	• Increase efficiency in water application (e.g. targeted irrigation, mulching) • Reduce evaporation losses • Avoid under-irrigation and soil degradation (e.g. salinisation) • Improve the consistency and survival rate of seedlings • Integrate shade and water systems as interconnected components
SCALABILITY The system must function reliably under local conditions with minimal failure risk.	• Design modular systems with expansion capacity • Allow adaptation to seasonal cycles and changing conditions • Ensure solutions are site-specific (rainfall, soil, landscape) • Avoid one-size-fits-all approaches • Enable phased implementation and scaling
FINANCIAL VIABILITY The system must function reliably under local conditions with minimal failure risk.	• Shorten return-on-investment timelines • Integrate short-term revenue streams • Ensure business ownership and financial structures are embedded • Balance initial investment with long-term durability • Reduce dependency on continuous external funding

H — OVERVIEW OF DESIGN REQUIREMENTS

DR1 — Not a lack of water, but a lack of water management

#	Requirement	M/S/C	Specification & Source
11	System must supply minimum water per seedling per irrigation event	Must	≥ 100 ml per seedling per event (Bakker et al., 2015)
12	Water distribution must be uniform across all seedlings in a block	Must	Coefficient of Uniformity ≥ 80%; emitter CV < 5% (Bakker et al., 2015)
13	System must include sufficient buffer storage per module	Must	5,000 L polytank per 25,000 seedlings (Vitara, 2026)
14	System must minimise evaporation losses during irrigation	Must	Night irrigation scheduled; ≥ 8–26% evaporation reduction vs surface irrigation (Bakker et al., 2015)
15	System must prioritise surface water over groundwater extraction	Must	Dam or seasonal surface water as primary source (E14)
16	Runoff and evaporation losses per event must be controlled	Should	≤ 10% of applied water lost per irrigation event (Bakker et al., 2015)
17	System should include soil moisture monitoring to trigger irrigation	Should	Moisture sensor or visual indicator to avoid over- and under-irrigation (Bakker et al., 2015)
18	System could integrate rainwater harvesting during wet season	Could	Supplementary storage to reduce dry season pump dependency

DR2 — A resilient nursery starts with understanding the needs of the seedling

#	Requirement	M/S/C	Specification & Source
21	Irrigation must adapt to seedling growth stage	Must	Differentiated regime for establishment, rapid growth, and hardening phases (E5; E9; E13)
22	Irrigation interval must reflect seedling water demand under Harmattan	Must	Every 2–3 days at 0.1 L per seedling under dry season conditions (Bakker et al., 2015)
23	Shade must reduce heat stress without blocking essential light	Must	50–75% shade factor; knitted HDPE preferred over woven (Ghana Shade-Net Standard; Freire et al., 2024)
24	System must support a hardening phase before transplantation	Must	Gradual reduction of irrigation and shade in final nursery weeks to improve field survival (E5; E9)
25	Seedling survival rate through dry season must meet minimum target	Must	≥ 80% survival rate through dry season (E9; E13)
26	Polybag bed should maintain capillary continuity to root zone	Should	Loamy sand or loam bed material ensuring lateral water movement into polybags (Bakker et al., 2015)
27	System could integrate root thermal protection	Could	Avoid dark polybags in direct sun to prevent root heat stress (E6; E7)

H — OVERVIEW OF DESIGN REQUIREMENTS

DR3 — The nursery system is connected to the landscape

#	Requirement	M/S/C	Specification & Source
31	Site must be selected based on water availability throughout dry season	Must	Access to seasonal surface water source for full dry season coverage (E14)
32	System must work with natural landscape processes rather than against them	Must	Integrate infiltration, runoff reduction, and soil moisture retention into nursery layout (E14; E15)
33	System must avoid large-scale land intervention at pilot stage	Must	Modular pilot on existing site before major earthworks or infrastructure investment (E14)
34	System should support ecological regeneration beyond the nursery boundary	Should	Avoid salinisation; reuse water where possible; support soil biological activity (E15; FAO, 2008)
35	Water-use efficiency should improve on traditional flood irrigation	Should	Target WUE improvement of 12–17% over flood irrigation (Bakker et al., 2015)
36	System could incorporate shade trees as long-term structural shade	Could	Transitioning from shade nets to established trees over time (E15)

DR4 — To design for a woman is to design for all responsibilities

#	**Requirement**	**M/S/C**	**Specification & Source**
41	System must eliminate heavy manual lifting during daily operations	**Must**	No single action requiring > 20 kg lift; gravity-fed replaces manual watering rounds (E3; E7; E12)
42	System must be operable by a small local team	**Must**	2–5 workers per module without specialised training (E3; E7)
43	Watering process must be intuitive and visible without technical knowledge	**Must**	Visual water level indicators; self-explanatory operation (E3; E7; FAO, 2008)
44	Nursery layout should integrate shaded rest and childcare space	**Should**	Dedicated shaded area within nursery boundary accommodating young children (E3; E7; E12; FAO, 2008)
45	Task organisation should reduce repetitive and physically demanding routines	**Should**	Scheduled gravity-fed irrigation reduces daily labour burden (E3; E7; E12)
46	System could incorporate simple task scheduling tools	**Could**	Visual planner or calendar for irrigation and maintenance cycles accessible to low-literacy users (E3)

DR5 — High-tech systems create dependency and maintenance risks

#	Requirement	M/S/C	Specification & Source
51	System must function without specialised imported components	Must	All parts locally sourceable and repairable on-site (E4; E8; E14)
52	System must operate at low or no pressure without continuous pumping	Must	Gravity-fed; tank elevated 3–5 m generating 0.03–0.05 bar (Bakker et al., 2015)
53	Pipe and emitter specifications must suit low-head conditions	Must	Laterals ≤ 13 mm diameter; lateral length ≤ 20–40 m for EU ≥ 85–95% (Bakker et al., 2015)
54	System must resist clogging and allow simple maintenance	Must	Sediment filter at inlet; emitters flushed at least once per season (E4; E8)
55	Materials must withstand UV exposure and sediment ingress	Must	Rated for minimum 2–5 years under field conditions (E4; E8)
56	Shade structure must withstand Harmattan wind loads	Must	Structure rated for wind speeds > 5 m/s; retractable or roll-up mechanism preferred (Ghana Shade-Net Standard; Omay et al., 2023)
57	Local and natural materials should be used where structurally appropriate	Should	Bamboo and raffia poles acceptable as structural material (E10; E11)
58	System should avoid single points of failure	Should	Modular layout so one failed unit does not interrupt full nursery operation (E8)
59	Routine maintenance should be completable on-site without external support	Should	Cleaning, flushing, and basic repair possible with local skills and tools (E4; E8; E14)
510	System could incorporate solar pumping to replace fuel-based pumps	Could	Solar-powered pump for tank refill reduces fuel dependency and operational cost (E4; E8)

DR6 — Modularity enables resilient scaling

#	Requirement	M/S/C	Specification & Source
61	System must be designed as a modular pilot first	Must	Pilot module of 25,000 seedlings validated before full-scale expansion (Vitara, 2026)
62	Full-scale system must reach annual production target	Must	300,000–400,000 seedlings annually at full scale (Vitara, 2026)
63	System must be buildable with local labour and basic skills	Must	No heavy machinery or specialised construction required (E8; E10; E11)
64	Total setup cost must remain within budget ceiling	Must	≤ €120,000–130,000 for full-scale nursery (Vitara, 2026)
65	Modules should be independently operable	Should	Performance of one module not dependent on another (E8)
66	System should be adaptable to seasonal variation	Should	Adjustable for wet and dry season without structural changes (E14)
67	System should be site-specific in logic but repeatable in structure	Should	Not one-size-fits-all; modular components reproducible across sites (E14; Westerberg, 2019)
68	System could enable phased investment	Could	Each module independently investable; reduces upfront financial risk for Vitara (Vitara, 2026)