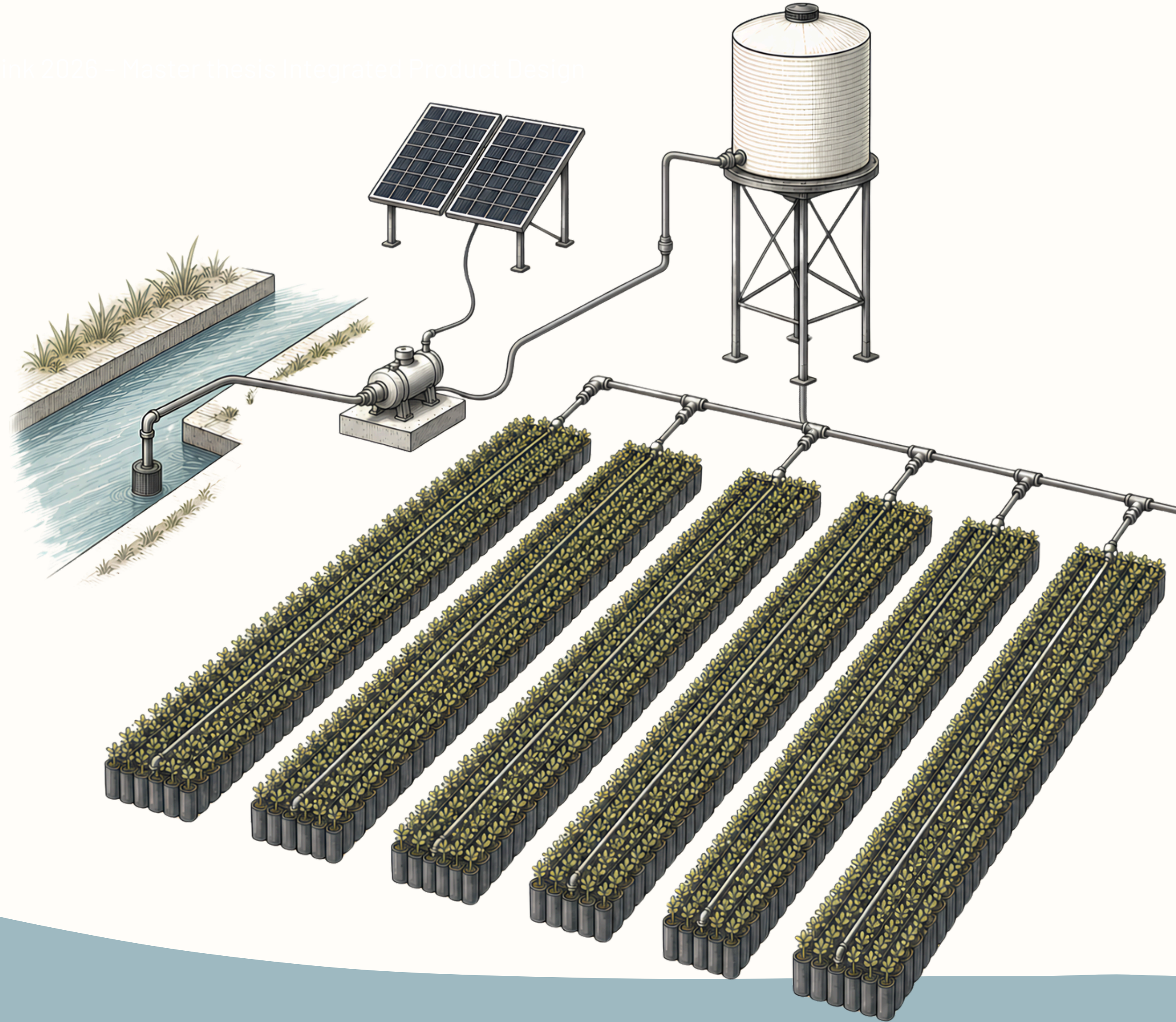
VITARA

IRRIGATING TREE NURSERIES IN NORTHERN GHANA

A toolkit for growing tree seedlings with less water and zero fuel using solar power and gravity.



Includes:

- Set-up to gravity irrigation system
- Nursery roles, management
- OpEx and CapEx estimations
- Timeline to plan a pilot

Vera Dubbink 2026 – Master thesis Integrated Product Design

MASTER GRADUATION PROJECT

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TUDelft VITARA

Water

The essence of all living things is the ability to grow.
The essence of this design is rooted in creating certainty in water access.
Without water, there is no life, and no growth.

AT A GLANCE

This thesis presents the design of a gravity-fed, modular agroforestry nursery system for Vitara in Northern Ghana.

Water shortages are often caused not by an absolute lack of water, but by ineffective management of the available water resources. By knowing how to manage water in a dry area, this limiting factor can be mostly avoided. When supply becomes unreliable, a chain reaction ensues: the effort to maintain the nursery increases, worker motivation declines, overall care diminishes, and ultimately, seedling survival rates decline.

The design presented in this project addresses this problem by using a solar pump to lift water from the irrigation canals fed by Sankana Dam. Water is stored in an elevated polytank, from which gravity distributes it through a fixed pipe network at night, delivering 0.1 L per seedling every three days to a total of 25,000 seedlings.

The final deliverable is a practical nursery toolkit that Vitara can act on immediately. The proposed design is for a new nursery and does not build on existing infrastructure.

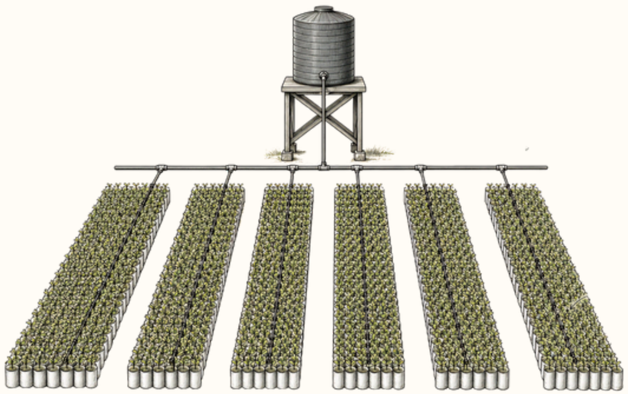

Figure 1
The Irrigation Layout, visual by author

0.1 L

per seedling • every 3 days

delivered through precise, gravity irrigation at night

> 85%

target seedling survival

after one full planting season, including dry season

3,000L

water storage in per module

gravity-fed polytank at 2.0 m head (height)

25,000

seedlings per pilot module

six seedling beds with approx, 4200 each

4 WORKERS

to operate the module

a technician, keeper, coordinator and field agent

820 M^2

per module • scalable

modular in design enables replication, not redesign

PREFACE

I want to thank my coaches, JC Diehl and Wim Schermer, for their efforts, insight, and understanding of the context, as well as their flexibility in adapting to the project's inherent requirements. A project of this nature demands sensitivity and a willingness to be vulnerable to truly see the system behind the problem.

I also want to thank Nanouk de Leng, my mentor at Vitara, for her constant input, willingness to serve as a brainstorming partner, and the best support from the company I could have wished for.

Finally, I would like to thank everyone in Ghana who shared their knowledge, time, and perspectives during this project. Their openness and generosity were invaluable in understanding the broader system behind the problem.

> ## "ZIENA A TEƐ NANG GƆNG GAA BE KA A TEƐ NA LE GAA"
>
> "Where the branches of the tree bend towards, it is that direction that the tree will eventually fall."
>
> – DAGAARE PROVERB, UPPER WEST REGION, GHANA

This proverb guided the entire project. The care given at the beginning of a system determines what it will eventually become. In this nursery, that principle shaped everything, from the system design to the team structure to the financial planning behind it. This graduation project marks the completion of the master's in Integrated Product Design. By fully immersing myself in both the design process and Ghana's context, I gained a deeper understanding of and respect for the culture, landscape, and way of life. My hope is that this project and the accompanying toolkit, even in a small way, can contribute to a greener, more resilient nursery. Not only by supporting the development, but also by facilitating conversations on water management and long-term resilience, helping hardworking farmers who form the backbone of the country. The project's layers, along with stakeholder, expert, and mentor involvement, shaped its direction and outcomes. Much like the proverb suggests, the orientation and care given in the early stages of a system determine what it will eventually become.

I hope you enjoy reading this thesis as much as I have enjoyed writing it.


Figure 2
Nursery field visit, picture by author

EXECUTIVE SUMMARY

Northern Ghana faces increasing pressure from climate change, prolonged dry seasons, and environmental degradation. Agroforestry plays an important role in improving biodiversity, soil health, and farmer livelihoods, yet many nursery systems struggle under local environmental and operational conditions. Existing nurseries often depend on unreliable boreholes, manual watering, or inconsistent infrastructure. During the Harmattan season, unreliable water management, evaporation losses, and system failures frequently lead to declining seedling survival and inconsistent production.

This graduation project was conducted in collaboration with Vitara, a Ghanaian-Dutch social enterprise focused on agroforestry, women's economic empowerment, and landscape restoration in Northern Ghana. Vitara aims to expand beyond community-led nurseries towards a more resilient and scalable nursery model. This thesis aims to design a scalable and context-appropriate nursery system that improves seedling quality, operational reliability, and production capacity under local environmental and operational conditions.

The deliverables of this project are:

- A gravity-fed modular nursery system for resilient seedling production.
- An in-depth overview of nursery components, including material selection, sourcing, and implementation.
- A network of manufacturers, experts, and local stakeholders was established to support future implementation of the toolkit.
- A practical operational toolkit for implementation and scaling.

Research process and outcome

The project combined literature research, stakeholder interviews, fieldwork in Ghana, technical analysis, and iterative design development. The research focused on: water management and irrigation; climate resilience and dry-season operations; labour and operational workflows; scalability and maintenance; and nursery organisation. Multiple irrigation approaches were explored and evaluated, resulting in the development of a gravity-fed modular nursery system.

Description of the final design

The final design proposes a gravity-fed agroforestry nursery system located near the Sankana Dam in Northern Ghana. A solar pump lifts water into elevated polytanks, after which gravity slowly distributes it through a fixed pipe network.

The proposed pilot module supports approximately 25,000 seedlings and is designed to reduce evaporation losses, simplify maintenance, and improve operational reliability during prolonged dry seasons. The final deliverable is a practical nursery toolkit translating the research and design into an accessible implementation guide for Vitara.

Reflection

This project positions design not only as the creation of a technical solution, but as a process of understanding systems, people, and local realities simultaneously. Fieldwork in Ghana highlighted the importance of water reliability, operational simplicity, local ownership, workforce organisation, and long-term adaptability. The project, therefore, focused on creating a system that remains functional, understandable, maintainable, and scalable within the realities of Northern Ghana.

PERSONAL MOTIVATION

I did not want my graduation project to become another design exercise. I wanted it to place me in a situation that was unfamiliar, uncomfortable at times, and completely different from the environments I had designed before. Over the years at TU Delft, I learned that design can be aesthetic, functional, and technically strong, but that it only becomes truly meaningful when it resonates with people and creates impact.

The projects that stayed with me most were not necessarily the most polished, but the ones connected to real situations, real people, and real challenges. Because of this, I consciously searched for a project that would push me outside my comfort zone as a designer and force me to look beyond the systems and assumptions I had grown up with.

I wanted to learn outside the Netherlands, outside TU Delft, and outside the environment I had become familiar with over the years. I wanted to speak to people directly, hear their experiences, observe daily life, and carefully navigate the complexity of designing within another cultural context.

Throughout the project, I became increasingly aware of how strongly my own perspective had been shaped by the infrastructure, culture, and systems surrounding me. Working in Ghana challenged many of those assumptions and forced me to approach design with more humility, openness, and adaptability.

The supervisors aligned strongly with this perspective, each offering different ways of thinking that continuously pushed me beyond my familiar design process. Together with Vitara, this transformed the project into something much deeper than simply developing a final design outcome.

More than anything, I wanted this graduation project to be a meaningful learning experience that would shape how I think about people, systems, and design long after graduation.

After speaking with several great companies, Vitara offered to take on this project. Communication from the get-go was enthusiastic, and the mindset was *what can we do next?* A driver to go further, and look broader than I had. This enthusiasm made the project easy to pick up and full of energy, and I could drive it forward.

This project dealt with extensive complexity by moving through different scales from climate conditions to organisational levels. The complexity was addressed by identifying the relationships among these layers and how they influenced one another.

Figure 3
Farmer field visit, picture by author

GLOSSARY

Agroforestry	An integrated land-use system combining trees with crops or livestock, designed to improve ecological/economic productivity.
CAPEX	Capital Expenditure. One-time investment costs that are required to build infrastructure.
Gravity-fed	Water stored at height contains gravitational potential energy that can be used for irrigation throughout the day without pumping.
Grafting	Joining a part of one plant (the scion) to a mature root system (the rootstock). This causes the tree to bear fruits earlier.
Harmattan	A dry, dusty north-easterly wind from the Sahara affecting West Africa Nov–March. Humidity (air) can fall below 20%.
Head (hydraulic)	Vertical height of a water column determining pressure. 1 m of head ≈ 0.098 bar.
Lateral	A distribution pipe branching from the mainline, delivering water along a seedling row (20 mm, 30 m).
Module	Name of the entire unit, 1 module proposed for pilot year. Contains: the system of 1 polytank and 6 seedling beds holding ~25000 seedlings in total.
OPEX	Operational Expenditure. Recurring annual costs to run the system.
Parkland	Traditional agroforestry landscape with scattered trees in cultivated fields. Densities have declined 95% since 1940 in Northern Ghana.
Polybag	Low-density polyethylene bag used to grow tree seedlings before transplanting.
Polytank	Large plastic water storage tank. In this system, elevated to 2.0 m to generate gravity pressure.
Sahel	A vast semi-arid transitional region in North-Central Africa that stretches south of the Sahara Desert.
Shea	Vitellaria paradoxa. A tree whose nuts are processed into shea butter. Critical livelihood crop for women in Northern Ghana.
SSNIT	Ghana's mandatory social insurance. Employer contribution: 13% of wage.

All definitions gathered from Oxford Languages (2022).

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01 INTRODUCTION

01 – INTRODUCTION

Goal of this chapter

This chapter introduces the project. Where it started, how it changed, and what it proposes. By the end of this chapter, the initial project assignment, Vitara's vision for scaling its nursery operations, and the research questions that guided the exploratory phase of the project have been introduced.

Key takeaways

- Vitara's original brief focused on shade infrastructure and other components that could be enhanced in the nursery.
- The initial research question asks how to define which parts are most in need of upgrading. a scalable, context-appropriate nursery system for Northern Ghana.
- The answer this thesis proposes: a gravity-fed, modular pilot nursery before any large-scale implementation.
- The toolkit in Chapter 5 turns the answer into action.

1.1 THE PROJECT

Bordering the Atlantic Ocean on its southern coast, the Republic of Ghana lies in West Africa. Its neighbouring countries are Burkina Faso, Côte d'Ivoire, and Togo. With over 35 million inhabitants, it is the twelfth most populous country in Africa (Haynes, 2024). The country is diverse in many ways, both in its people and in its ecosystems, from the ocean lapping against the beaches in the south to the humid environments of jungles in the middle, and further north to the far edges of the Sahel, where hot, dry seasons typify the landscape.

Research within Ghana
It is within these arid circumstances of the north that this research is situated. Several key cities are relevant to this research: Accra, the capital of Ghana; Tamale, where many agroforestry nurseries are located; and Wa, the capital of the Upper West Region and the location of the headquarters of Vitara.

Vitara
Vitara is a Ghanaian-Dutch social enterprise that works with farmers and communities in Northern Ghana to strengthen agroforestry value chains, particularly the shea value chain. They focus on improving farmer livelihoods by combining tree planting, nursery development, and market access with long-term community partnerships. With their nursery work, they mostly focus on female farmers. Upon arriving at Vitara, it quickly became apparent that the organisation has a strong ambition to expand its impact and reach. Within the conservation section of Vitara, this placed increasing pressure on the tree nurseries and their daily operations.

The original assignment
Agroforestry nurseries are a measure to restore tree cover in Northern Ghana, yet the existing nurseries are not performing as hoped. To understand why, it's first important to understand what's at stake.

Traditional parkland systems have declined from approximately 230 trees per hectare in 1940 to around 11 per hectare today, largely due to agricultural expansion, land clearing, and fuelwood use (Westerberg, 2019). This represents a loss of more than 95% of native tree cover within less than a century. Without trees, the landscape becomes increasingly vulnerable to the Harmattan, the dry north-easterly wind dominating November to March, pushing temperatures above 35°C and humidity below 20% (Omay et al., 2023). Natural regeneration cannot keep pace; an agroforestry nursery helps to restore this imbalance (Anyedina et al., 2025).

Nurseries raise tree seedlings under controlled conditions until they are strong enough for field transplantation. The shea tree, *Vitellaria paradoxa*, is one of the most common seedlings raised and requires up to eleven months of nursery care before transplanting, making a stable nursery environment crucial. Important for reforestation, as a single shea tree lives 200–300 years and captures an estimated 300–400 kg of CO_2 over its lifetime (IPCC, 2022).

However, Vitara's community nurseries are currently not achieving their full potential. Shade nets, which protect seedlings from UV and full sun exposure, break under heavy winds and poor tensioning, and seedling quality and survival rates vary widely across sites. The assignment initially focused on improving these factors in the nursery, with the failing shade infrastructure as the central design problem.

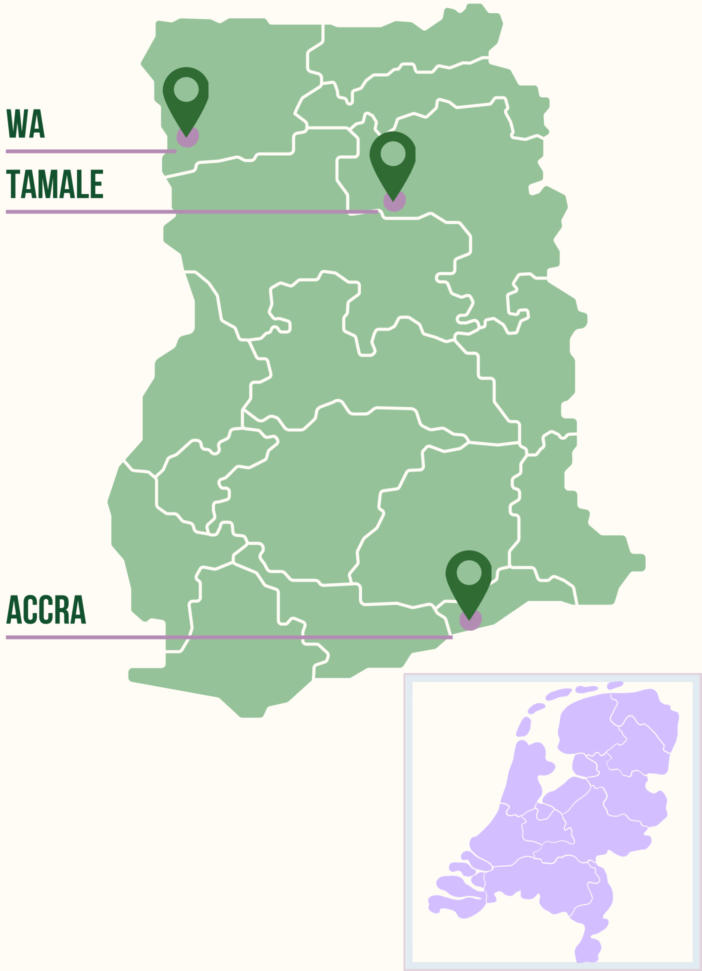


Figure 4
Netherlands in comparison to Ghana, map by author

1.2 VITARA'S FUTURE VISION

To correctly frame the project, it's important to understand Vitara's future vision, which acts as the timeline for this project. Vitara aims to rebuild Northern Ghana's tree cover by supporting smallholder farmers, primarily women, through the full value chain: seedling production, tree planting, ecosystem restoration, and market access for products from seedlings, like shea butter.

Vitara's current nursery model

Their current model relies on decentralised, community-led nurseries spread across the Upper West Region. Vitara provides training, coordination, and technical support. This model has proven effective at the community scale: it builds local capacity and distributes the work of seedling production across multiple sites. However, it produces highly variable outputs. Survival rates, seedling quality, and production volumes differ greatly among sites (Vitara, 2026).

The 2030 ambition

Within five years, Vitara wishes to scale up from its current model of decentralised community-led nurseries towards a more centralised, Vitara-owned nursery capable of producing 300,000–500,000 seedlings per year. This target is based on Vitara's landscape restoration ambitions, anticipated farmer demand, and the transition from distributed community nurseries to a managed nursery system that fits a large scale better. As visualised in Figure 5.

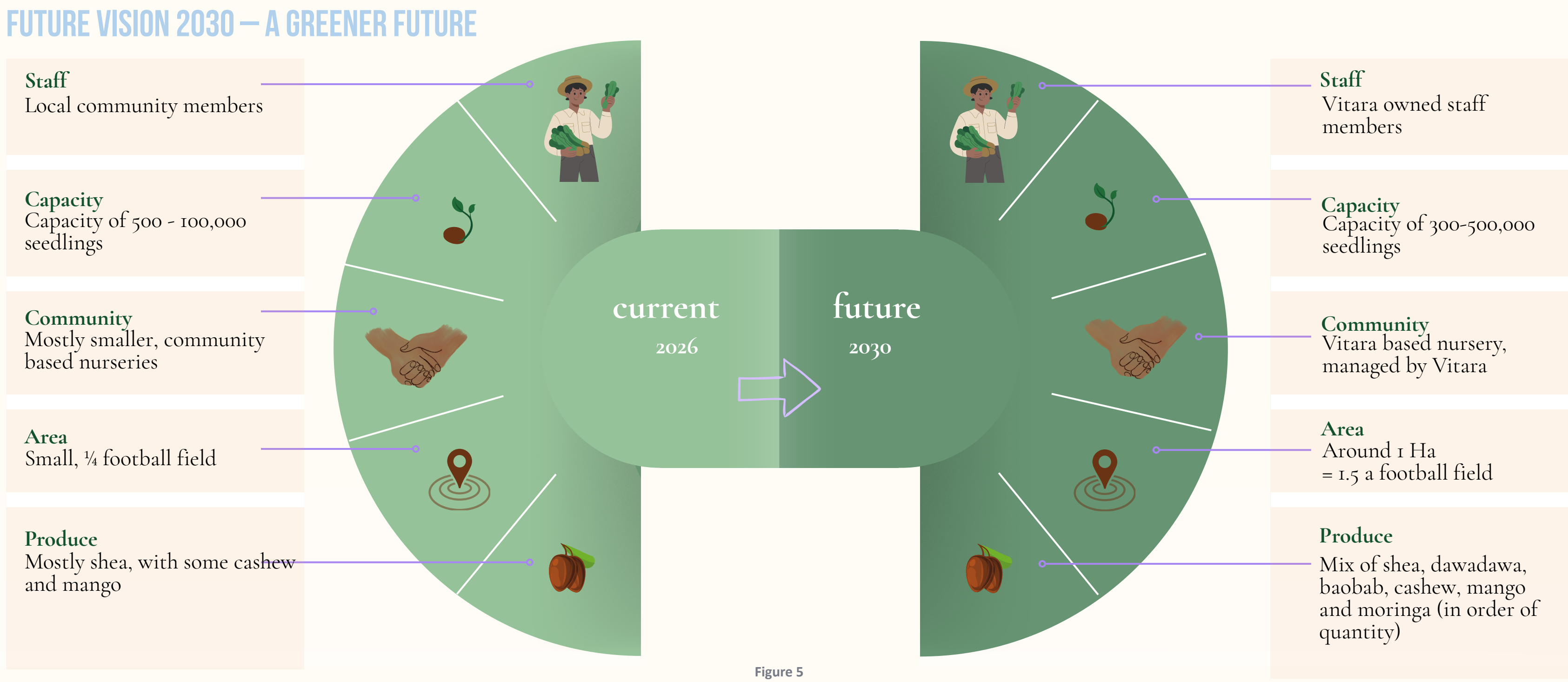


Figure 5
Future vision of Vitara

1.3 INITIAL RESEARCH QUESTIONS

Upon receiving the initial brief, the following research question was formulated to guide the discovery phase, with the main goal of understanding the local context and the factors influencing the nursery workings in Ghana. The indepth brief can be found in Appendix A.

As the focus lay on understanding why the community nurseries were not performing as hoped, and what could be implemented in their new Vitara-owned nursery, the following research questions (RQ) were formulated.

Initial Research Questions

"How can the structural and operational design of agroforestry nurseries in Northern Ghana be improved to increase seedling survival rates and production consistency?"

Two sub-questions structured the initial research:

SQ1 — Discover

What are the current technical, environmental, and organisational challenges affecting nursery performance in Northern Ghana?

SQ2 — Analyse

What factors influence water management, shading performance, maintenance, and day-to-day operational feasibility in agroforestry nurseries under local conditions?

These questions guided six weeks of fieldwork across Tamale, Wa, and Accra, and fifteen expert interviews across Ghana and the Netherlands. The following pages highlight the data collection methods and approach, with the full extended description in Appendix B.

The findings of these research questions changed the direction of the problem. Through this research, the main findings were bundled into the six insights presented on the following pages. These helped guide a problem re-frame, and thus guided the final research question and scope. These insights will serve as the guide for design decisions in the final toolkit and irrigation design.

Figure 6
Natural Tree Nursery, picture by Author

02 APPROACH

02 — APPROACH

Goal of this chapter

This chapter introduces the positionality and the two core design principles which centre the design. It provides the methodology and data collection, both of which are explained in depth in Appendix B. It lays the framework that forms the project and the final research question, derived from the six insights that will guide the final design.

Key takeaways

- The project was approached as a collaborative, context-sensitive process, treating local workers and practitioners as experts, not design subjects.
- Data collected through literature review, fifteen semi-structured expert interviews, and six weeks of fieldwork across Tamale, Wa, and Accra.
- Six insights that summarise the environmental, operational, social, and technical realities of nurseries in Northern Ghana.
- These insights translated into six design requirements that guided every decision in the toolkit.
- The reframe: the core problem is not shade infrastructure but water management.

2.1 POSITIONALITY AS DESIGNER

This chapter takes a moment to reflect on positionality within the context of this project and research. It highlights the differences between a Dutch design background and the context of Northern Ghana.

Designing within a Western African context from a Northern European background introduces an asymmetry that is important to acknowledge. Cross-cultural design research requires awareness of positionality and the limitations of externally developed assumptions, which can overlook locally embedded knowledge, operational realities, and socio-cultural dynamics.

Rather than positioning design as an externally imposed intervention, this project approaches design as a collaborative and context-sensitive process. Through interviews, observations, fieldwork, and engagement with local stakeholders in Ghana, the aim was not to develop a universal solution, but to better understand the realities, constraints, and knowledge already present within the nursery systems.

As a result, the project's focus lies on understanding the broader socio-technical system in which the nursery operates, and identifying where interventions could create the greatest long-term impact and resilience. This took shape through the toolkit and final design.

Design is therefore positioned not as the solution itself, but as a connecting mechanism: one that creates dialogue between stakeholders, translates insights into practical systems, and supports context-aware implementation strategies.

The project is guided by two core design principles:

Frugal design
The project aligns with principles of frugal innovation, which focus on solutions developed under resource constraints while remaining affordable, adaptable, robust, and maintainable over time (Radjou & Prabhu, 2015). In Northern Ghana, this was relevant due to limitations in infrastructure, maintenance capacity, and financial resources. The design prioritised simplicity, repairability, and modular systems that can realistically function in the local context.

Local knowledge first
Escobar (2018) argues that development-oriented design should treat communities as experts in their own lived experience rather than passive design subjects. This strongly shaped the research approach. Rather than only testing ideas from literature, the fieldwork focused on learning from the local context itself. Nursery workers, farmers, technicians, and practitioners were approached as experts with knowledge about daily operations, environmental conditions, and long-term system performance that could not be fully understood through literature alone.

The project was further guided by the Sustainable Development Goals (2025) (SDGs), which aligned strongly with the ambitions of Vitara (SDGs, 2026).

Figure 7
Farmer holding shea plant (Vitara, 2026)

KEY SDG CONTRIBUTIONS

- SDG 1 · No Poverty — income stability
- SDG 5 · Gender Equality — women's work
- SDG 9 · Innovation — frugal design
- SDG 13 · Climate Action — adaptation
- SDG 15 · Life on Land — restoration

2.2 METHODOLOGY

This project followed a context-driven and iterative methodology, combining field research, technical analysis, and stakeholder input. The project moved between environmental, operational, social, and technical scales to shape the design.

This project is positioned within impact-driven design: design as a practical, responsible tool for addressing real-world challenges. The stakes are not abstract; nursery failures mean fewer trees planted, less income for women, and continued landscape degradation in Northern Ghana. As mentioned before, the asymmetry in designer background and design application was addressed by prioritising local information, validating findings with local experts, and treating the design findings as interventions which have to be tested in the local context. Design is not a linear process, but the general flow of the phases of this process over the last six months is shown below. An in-depth project planning can be found in Appendix A.

Often, short 'trips' to other phases are made to broaden understanding or to validate and narrow down. It was constantly zooming in, zooming out to get a good grip on the context and situation. The phases were great at identifying core deliverables and at providing the understanding needed of the current state to move forward in the design process while staying relevant with knowledge and validation. This methodology aligns with Donald Schön's concept of the 'reflective practitioner' (1983), where knowledge emerges through doing and reflection-in-action rather than through the application of pre-existing theory. The full in-depth double diamond approach and phase timeline can be found in Appendix B.

Impact Design

Design is approached as a practical and responsible tool for addressing real-world challenges.

PROCESS OVERVIEW

1 Context immersions
Environmental, social, and economic conditions. Literature research. Stakeholder mapping, forming initial assumptions.

2 System framing
Field visits in Ghana and 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 in the end to select location for the pilot.

5 Refinement and integration
Final concept calculated and validated. A practical nursery toolkit produced as the primary deliverable.

Phase 1:
The first phase focused on understanding the environmental, social, and economic conditions shaping agroforestry systems in Northern Ghana through literature, reports, and contextual analysis.

Phase 2:
The broad problem space was narrowed into key themes and design criteria, identifying where intervention would be most relevant.

Phase 3:
Interviews, field visits, and stakeholder interactions provided insight into local practices, challenges, and operational realities.

Phase 4:
Research findings were synthesised into clusters, concepts, and design directions exploring resilient nursery strategies.

Phase 5;
Design outcomes were refined and evaluated based on feasibility, local relevance, and long-term implementation potential.

2.3 DATA COLLECTION

Fundamental to the design process was understanding the nursery system from multiple perspectives. The data collection methods were therefore structured around the three research phases: discovering current challenges, analysing interacting system factors, and synthesising these insights into a feasible nursery proposal.

Three main data collection methods:

1 — **Literature review** across environmental context, water management in arid agriculture, and nursery design, including shade, irrigation, and seedling physiology. Full research is found in Appendix C.

2 — **Semi-structured interviews** with 15 key informants: nursery workers, professors, gender experts, irrigation specialists, and NGO implementers. Semi-structured, the most useful insights emerged from following the interviewee's experience rather than a fixed questionnaire. Full research is found in Appendix C.

3 — **Six weeks of fieldwork in Ghana**: Tamale (Week 1), Wa at Vitara (Weeks 2–5), Accra (Week 6). Site visits, a participatory mapping game with 20+ workers, field observations, and focus group discussions. Full in Appendix C.

For **SQ1 – Discover the context**, operational challenges and nursery routines were explored through field observations, participatory mapping, and semi-structured interviews.

For **SQ2 – Analyse the findings,** technical and environmental factors influencing irrigation and seedling survival were analysed through literature research, expert interviews, and hydraulic calculations.

EXPERT OVERVIEW

E1–E3 · Nursery workers — Field
Active and former workers in community nurseries in Wa and Tamale. Provided operational ground truth: irrigation routines, workload, and daily challenges.

E4–E5 · Irrigation specialists — Tech
Engineers with experience in drip and gravity-fed systems in West Africa. Validated hydraulic approach and component sourcing.

E6–E7 · Agronomy professors — Academic
Faculty at University for Development Studies (UDS), Tamale. Provided scientific grounding on seedling physiology and root thermal stress.

E8–E9 · NGO implementers — Org
Experienced in agroforestry project implementation. Confirmed that complex systems revert to manual and that the social system determines long-term continuity.

E10–E11 · Landscape experts — Context
Specialists in land degradation and watershed management in the Upper West Region. Confirmed surface water as the appropriate long-term source.

E12 · Commercial supplier — Commercial
Provided a detailed cost quote for a high-tech commercial system. This formed the baseline for the strategic pathway comparison.

E13–E14 · Gender experts — Social
Specialists in women's economic empowerment in Northern Ghana. Confirmed the dual burden (nursery + household) as a structural design condition.

E15 · Ecological systems — Systems
Expert in natural water systems and ecological restoration. Small distributed systems are more resilient.

The process evolved through continuously shifting between system scales, from environmental realities and organisational structures to operational workflows and technical aspects. Supporting research included 15 semi-structured interviews across Ghana and the Netherlands. Full transcripts, key actors, and takeaways can be found in Appendix C.

2.4 SIX INSIGHTS

The following pages present the six insights that emerged from the research. They are the result of six weeks of fieldwork across Tamale and Wa, fifteen expert interviews, and a participatory mapping session and co-creation session with over twenty nursery workers. The full research documentation and setup are in Appendix C.

Fieldwork was structured around direct observation and participatory tools, including 3D printed nursery objects and problem cards used during sessions to allow workers to physically rank and map their daily challenges without language barriers. Combined with site visits across over six nurseries and expert conversations around irrigation engineering, agronomy, gender, hydrology, and ecology, a consistent pattern emerged across every source.

These six insights summarise what important insights shifted, the moments where the evidence contradicted the original assumptions and redirected the design. Together, they form the foundation for the reframe that follows, and these six design requirements structure the entire toolkit.

The insights answer SQ1 – discover the technical, environmental and organisational challenges that influence nursery performance.

1 — A RESILIENT NURSERY STARTS WITH UNDERSTANDING THE NEEDS OF THE SEEDLING

"A plant undergoes three main growth phases."
— E13

CHALLENGE
Field observations and expert interviews showed that nursery systems often focus primarily on keeping seedlings alive through watering and shade, while the changing physiological needs of the seedling throughout its growth stages receive less attention (E5, E9, E13). As a result, seedlings may survive inside the nursery, but remain vulnerable during transplantation and early field establishment.

INSIGHT
These findings revealed that creating resilient seedlings requires more than a resilient nursery alone. Seedling irrigation needs change throughout establishment, rapid growth, and hardening stages, meaning water delivery must adapt over time (E5, E9, E13).

OPPORTUNITY
This created an opportunity to design the nursery around the development stages of the seedling itself. The grafting-fed irrigation thus integrates stage-specific irrigation, controlled stress reduction, and gradual hardening: all strategies to improve seedling resilience beyond the nursery and increase survival after transplantation (E5, E9, E13).

Figure 8
Thriving Mango Seedling, picture by author

2 — MODULARITY ENABLES RESILIENT SCALING

"Start small to build understanding of the context." — E7

CHALLENGE

Many nursery systems are designed around maximising production output, while failure prevention and operational resilience are often treated as secondary concerns. In Northern Ghana, however, environmental variability, maintenance limitations, and seasonal uncertainty make small failures escalate quickly into system-wide breakdowns.

INSIGHT

These findings revealed that resilience in this context is not created by maximising scale or efficiency immediately, but by reducing vulnerability and dependency step by step. A stable system first needs to survive uncertainty before it can successfully scale (E7).

OPPORTUNITY

This created an opportunity to design the nursery as a modular pilot system first, where risks, maintenance routines, water reliability, and operational workflows can be tested and adjusted before major expansion. The toolkit, therefore, proposes scaling through repetition of validated modules rather than through one large investment.

Figure 9
Failing Shadow Nets, picture by author

3 – THE NURSERY SYSTEM IS CONNECTED TO THE LANDSCAPE

"We try to get the water as close as possible; we always look locally before moving further away."
— E15

CHALLENGE

Expert interviews (E14) and field visits observed that many nurseries currently operate as isolated systems, disconnected from surrounding ecological and hydrological processes. Landscape mechanisms such as infiltration, runoff reduction, soil moisture retention, and seasonal water storage are often underutilised within nursery design.

INSIGHT

These findings revealed that nursery design in Northern Ghana cannot follow a one-size-fits-all approach. Site location itself becomes a key design driver, directly determining water reliability, operational resilience, and long-term feasibility (E14).

OPPORTUNITY

This resulted in the selection of Sankana Dam as the pilot location, due to its season-wide water availability and existing water infrastructure. Rather than investing immediately at a large scale, the toolkit proposes a small modular pilot first, allowing the site suitability, water reliability, and operational setup to be tested and adjusted before major investment (E14).

Figure 10
Grafted Shea Seedlings, picture by author

4 – TO DESIGN FOR A WOMAN IS TO DESIGN FOR ALL RESPONSIBILITIES

“The whole family helps in the nursery.” — E7

CHALLENGE

Expert interviews and field observations showed that women form the operational backbone of many nurseries, while simultaneously carrying responsibilities beyond nursery work, including childcare, household labour, water collection, and food preparation (E3, E7, E12). Current nursery layouts and workflows often assume workers can fully dedicate themselves to the labour without accounting for these overlapping responsibilities.

INSIGHT

These findings revealed that designing only for the “average worker” ignores the real operational context of the nursery. Designing for women, therefore, means designing for the full system of responsibilities surrounding nursery work, including physical workload, flexibility, safety, accessibility, and social realities (E3, E7, E12).

OPPORTUNITY

An opportunity to design the nursery as a more supportive working environment through increased water access, reduced heavy lifting, clearer task organisation, shaded childcare space, which accommodates the realities of daily life. By designing for their responsibilities, the system becomes more usable, resilient, and accessible for everyone (E3, E7, E12).

Figure 11
Family at the Nursery, visual by author

5 — NOT A LACK OF WATER, BUT A LACK OF WATER MANAGEMENT

"Natural systems function through small, resilient structures rather than large, centralised ones."
— E15

CHALLENGE
Experts (E14, E15) explained that water scarcity is often incorrectly framed. The main challenge is not the absence of water, but the inability to store, distribute, and manage it throughout the dry season. Current nurseries depend heavily on groundwater extraction, fuel pumps, and manual watering methods that become least reliable during periods of highest demand. Under Harmattan conditions, hand watering also leads to major evaporative losses.

INSIGHT
Field observations and expert interviews revealed that irregular watering triggers a chain reaction inside the nursery: seedling stress increases, survival rates decrease, worker motivation declines, and nurseries become trapped in reactive maintenance instead of stable production (E14, E15). It shifted to how to manage water more predictably and efficiently.

OPPORTUNITY
These findings created an opportunity to redesign the nursery as a controlled water management system. The toolkit, therefore, focuses on storage, gravity-fed distribution, night irrigation, and controlled root-zone application to reduce dependence on constant pumping while improving reliability, labour conditions, and water efficiency (E14, E15).

Figure 12
Canal irrigation, visual by author

6 — HIGH-TECH SYSTEMS CREATE DEPENDENCY AND MAINTENANCE RISKS

“If a borehole fails, water supply becomes uncertain.” — E4

CHALLENGE

Expert interviews and field observations showed that many irrigation systems in Northern Ghana become difficult to maintain once they depend on specialised technology, imported parts, fuel, or external technicians (E4, E8, E14). During the dry season, breakdowns in pumps, generators, or electrical systems can immediately interrupt watering, while repair capacity and replacement parts are often limited locally.

INSIGHT

These findings revealed that increasing technological complexity can also increase operational vulnerability. In contexts where maintenance capacity, spare parts, and technical support are limited, system reliability often depends more on simplicity and repairability than on technological sophistication (E4, E8, E14).

OPPORTUNITY

An opportunity to design for low-dependency infrastructure. The toolkit therefore prioritises gravity-fed distribution, modular layouts, locally available components, visible water storage, and systems that can be understood, repaired, and managed directly on-site with minimal external dependency (E4, E8, E14).

Figure 12
Dam in Wa, visual by author

2.4 INSIGHTS TO DESIGN REQUIREMENTS

Mapping all factors influencing nursery performance revealed a clear core notion: without reliable water, improving any other system element has a limited effect. But water management alone is not enough: seedling resilience, site selection, maintenance simplicity, gender-inclusive design, and modular scaling each emerged as equally necessary conditions.

The six insights translated directly into six guiding design priorities. Rather than functioning as isolated requirements, these priorities together define what a resilient nursery system must achieve under Northern Ghanaian conditions. Every design decision in Chapter 5 traces back to one or more of these priorities. The full requirements list containing 15 requirements classified as Must, Should, or Could can be found in Appendix H.

	Priority	Rationale	Design Implication
DR1	**Water management**	Irregular water access triggers system-wide failure	Design for storage, distribution and reliability
DR2	**Seedling-centred design**	Seedling needs change across growth stages	Adapt irrigation to development stage
DR3	**Maintenance simplicity**	Complex systems break down without local repair capacity	Prioritise gravity-fed, locally repairable systems
DR4	**Labour and gender**	Women carry overlapping responsibilities beyond nursery work	Reduce physical workload and increase flexibility
DR5	**Site and landscape**	Location determines water reliability and feasibility	Select + design sites based on hydrological context
DR6	**Modular scaling**	Large systems escalate risk in uncertain conditions	Pilot small, scale through repetition

Figure 13
Shea Seedlings, picture by author

2.5 THE REFRAME

~~INDIVIDUAL NURSERY COMPONENTS~~ → WATER MANAGEMENT

The original project brief identified shade structures as the primary design focus, which allowed a strong starting point. Shade net failure is well documented and directly linked to inconsistent seedling growth (Asare et al., 2016).

However, fieldwork told a different story. Across every struggling nursery visited, the shared characteristic was not broken shade nets but unreliable water access. The pattern was shown at every site. A nursery with functioning shade but no reliable water loses seedlings. A nursery with damaged nets but consistent irrigation survives, leading back to the core of water management.

Improving shade infrastructure without addressing water would not solve the core problem. The reframe shifted the central question from component-level to system-level design:

Final research questions:

How can a scalable and context-appropriate nursery system be designed to improve seedling survival, consistency, and production capacity in Northern Ghana, while remaining robust under local environmental and operational conditions?

→ *Answer in the toolkit, Chapter 05.*

A third sub-question emerged from the reframe:

SQ3 — Synthesise:

How can water distribution, climate control, modularity, and operational workflows be integrated into a resilient and context-appropriate nursery system design?

→ *Answer in Chapter 05, full research Appendix C.*

For SQ3 – Synthesise, the feasibility of an integrated nursery system was developed through stakeholder discussions, iterative concept development, and alignment with Vitara's scaling ambitions. The next chapter will introduce the contextual facts about the system in Ghana and lay the foundation for fully comprehending the problem.

Scope: Nursery System

The term nursery system refers to the set of physical, operational, and social components that determine nursery performance. This includes irrigation infrastructure, shade structures, site layout, water storage and distribution, and the operational workflows that connect them. It focuses on creating the most resilient seedling possible in the nursery and on water management.

It does not cover activities beyond the nursery, such as tree planting, field monitoring, or market access. The boundary is the nursery itself, from the water source until the hardened seedling is ready for transplantation.

Figure 14
Water Bassin, picture by author

When is the project a success?

Design Goal: To design a modular nursery system where reliable water access supports the seedlings, the workers, and the landscape it is restoring.

This project is considered successful when the nursery system is complete and validated to recommend implementation. Success is assessed across three dimensions.

FEASIBILITY

Can it be built and operated? The system must be constructible using locally available materials, operable by a trained team, and maintainable without external technicians.
The feasibility is fully evaluated in Chapter 06.

DESIRABILITY

Does it serve the people who use it? The system must reduce physical labour burden on workers, particularly women, who form the operational backbone of nurseries in Northern Ghana, while also carrying childcare and household responsibilities.
The desirability is fully evaluated in Chapter 06.

VIABILITY

Will it sustain itself over time? The system must be financially realistic for Vitara to invest in, with a reasonable path from pilot to full scale.
Viability is assessed in Chapter 6.

03 THE CONTEXT

03 – CONTEXT

Goal of this chapter

Goal of this chapter: establish the context needed to understand the environment in which this project operates. It covers the climate of Northern Ghana, what an agroforestry nursery is and how it functions, why shea is the central species, and who the key actors are. These set the foundation of the toolkit that follows.

Key takeaways

- Northern Ghana's Harmattan season creates extreme pressure on nurseries during the exact months when seedlings are most vulnerable
- Shea seedlings require up to eleven months in the nursery, the longest of any species, meaning they must survive an entire dry season
- The nursery is not just a technical system. It is ecological, social, and organisational simultaneously
- Vitara operates from both the Netherlands and Ghana.
- One size fits all does not work; context is a key design driver.

3.1 NORTHERN GHANA

Northern Ghana's climate creates four conditions that determine how a nursery must be designed: a concentrated rainy season that leaves seedlings dry for seven months, a Harmattan wind that peaks precisely when water demand is highest, an unreliable water source as boreholes, and solar irradiance strong enough to power the entire irrigation system.

These four climatic conditions are explained here and will be referred to throughout the thesis. They give an appropriate idea of the context in which a nursery operates. The complete ecological drivers research can be found in Appendix C.

Northern Ghana
Northern Ghana sits within the Guinea Savanna zone, a climatic belt characterised by a single rainy season from June to October, followed by a long dry season from November to May. Annual rainfall reaches approximately 1,000–1,200mm, but nearly all of it falls within a concentrated four-month window (Dakurah et al., 2024). Once the rains stop, the landscape enters a prolonged period of heat, wind, and declining moisture that lasts more than half the year. For context: the Netherlands receives approximately 900mm of rainfall annually, spread evenly across all seasons and at significantly lower temperatures (Kavi, 2026). Northern Ghana receives more rain, but nearly none of it is available or retained when seedlings need it most in the dry season.

The Harmattan
The dry season is defined by the Harmattan, a dusty north-easterly wind from the Sahara that dominates from November to March. As stated in the introduction, relative humidity regularly falls below 20%, daytime temperatures exceed 35°C, and evapotranspiration, the way plants lose moisture, rates are among the highest of the year, putting immense stress on both seedlings and workers alike (Omay et al., 2023).

Groundwater
Groundwater in Northern Ghana is stored in Voltaian aquifers typified by a crystalline basement geology that captures water in narrow rock fractures rather than porous layers (Rambhunjun et al., 2024). Recharge during the rainy season is limited to approximately 2% of annual rainfall, meaning aquifers cannot recover at the same rate they are depleted during the dry season. Borehole yields vary significantly over distances as short as fifty metres, meaning a well-running borehole has no guarantee of a successful one somewhere close by. Intensive extraction during dry months can cause pumps to begin drawing air and sediment instead of water, damaging the infrastructure permanently and requiring high maintenance (Loh et al., 2020). Under these conditions, boreholes fail at rates reaching 67% within two years of operation (Chegbeleh et al., 2020). They fail precisely when demand is highest.

Solar energy
What the climate removes in water availability, it returns in solar irradiance. Near Wa, average solar irradiance reaches 5.4 kWh/m²/day, well above the global average of 3–4 kWh/m²/day and within the operational range for solar-powered pumping (Solargis, 2021). Peak solar availability aligns directly with peak water demand: both are highest during the dry season. This is the climatic condition the design is built around, not resisting the environment, but working with it.

Figure 16
Dust because of Harmattan, picture by Author

3.2 AN AGROFORESTRY NURSERY AS AN ECOSYSTEM

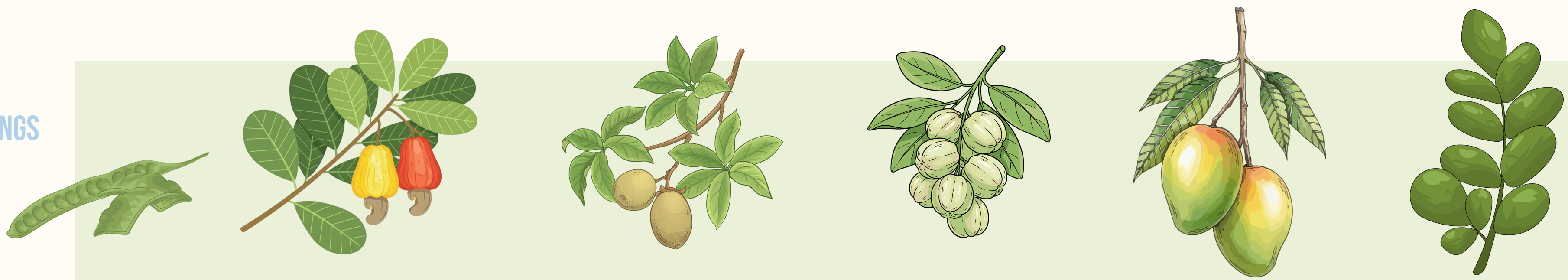
To understand the context, it is first fundamental to comprehend the function of an agroforestry nursery. Just like a real nursery for humans, it essentially raises tree seedlings until they are mature enough to be planted in the field and to survive in the wild or protected parklands.

Species in an agroforestry nursery
Agroforestry nurseries in Northern Ghana raise multiple tree species simultaneously, each with different growth durations and irrigation demands. Vitara's most common seedlings, including dawadawa and baobab (Figure 17), each require different nursery periods and watering frequencies, making management variable throughout the year. The shea tree is particularly significant as it requires the longest nursery period, up to eleven months and has a great value beyond the ecological restoration through creating value for the women, which is elaborated on in the next Chapter 3.3. Others, like cashew and mango, are identified as cash crops, grown mainly for farmer income generation with the bonus of ecological restoration.

The three main growth stages of a seedling
A seedling passes through three physiological stages that determine water needs: establishment, where consistent delivery is critical for root development; rapid growth, where water determines a huge part of the plant's height and survival; and hardening, where the stem hardens with less water to control its stress to prepare the seedling for field conditions (Wilkinson et al., 2014). Irrigation that ignores these stages produces weaker seedlings regardless of how much water is available. Fruit-bearing seedlings, such as mango, cashew and shea, can be grafted by merging a young stem with a mature rootstock. This promotes earlier fruiting and thus increases farmer income. Grafted seedlings are more sensitive to sun exposure and overwatering, making targeted, stage-adapted irrigation important.

The importance of species diversity
The Tropical Agroforestry Manual highlights that successful reforestation depends on a diverse system of local species with different ecological and cultural functions, such as medicinal value or nitrogen fixation. A diverse agroforestry system creates a more resilient landscape that is less vulnerable to disease and environmental stress, highlighting the importance of raising a variety of seedlings in a nursery with all different strengths for both the community and the environment (Wilkinson et al., 2014).

OVERVIEW OF COMMON SEEDLINGS IN NURSERY



	Parkia biglobosa	*Anacardium occidentale*	*Adansonia digitata*	*Vitellaria paradoxa*	*Mangifera indica*	*Moringa oleifera*
Sort	Dawadawa tree	Cashew tree	Baobab tree	Shea tree	Mango tree	Moringa tree
Fruiting period	1x a year, in Mar - April	1x a year, in Nov- May	1x a year, in Dec - Mar	1x a year, in Dec - Mar	2x a year, Apr - Aug, Nov - Jan	1x a year, in April - June
Nursery time	3	4	3	12	6	3

Figure 17
Common seedlings, by author

3.3 THE VALUE OF SHEA

Shea is not one of the most economically important species in the nursery; it is the most operationally demanding. Understanding its value and its vulnerability directly shaped the irrigation requirements, the pilot timeline, and the maintenance routines proposed in the toolkit.

The shea tree is the species on which a large part of Vitara's value chain is built. Its nuts are processed into shea butter and traded locally and globally for use in food, cosmetics, and pharmaceuticals. In Ghana, it's a household staple; used for skincare, cooking and home medicinal reasons. Beyond Ghana, its popularity is expanding as well. The global shea market was valued at approximately $1.9 billion in 2022 and is projected to grow significantly through 2030, driven by demand from the cosmetics and food industries (Grand View Research, 2023).

Women's Gold

In Northern Ghana, shea butter is collected, processed, and sold almost exclusively by women, making it not just an agricultural product but a primary livelihood system for rural households. Women in the Upper West Region derive an estimated 20–30% of their annual household income from shea (Yussif et al., 2025). The health of the nursery is therefore directly connected to household income stability across the region.

Of all the species raised in Vitara's nurseries, shea is the most demanding to keep alive. Its root system is slow to establish, highly sensitive to irregular watering, and dependent on consistent moisture throughout its development. A single missed irrigation cycle during the establishment phase can cause irreversible stress. This stresses the importance of creating a resilient species that survives both the nursery and transplanting for years to come.

Shea trees also play an ecological role beyond their economic value. They are a keystone species in Northern Ghana's parkland systems, providing shade, wind protection, and soil stability for surrounding crops. Their long lifespan makes each successfully transplanted seedling a multi-generational investment in landscape resilience (Brandt et al., 2019).

At the scale Vitara is targeting in their future vision, a functional nursery system is not just an operational tool but a strong way to enhance a long-term livelihood and landscape intervention.

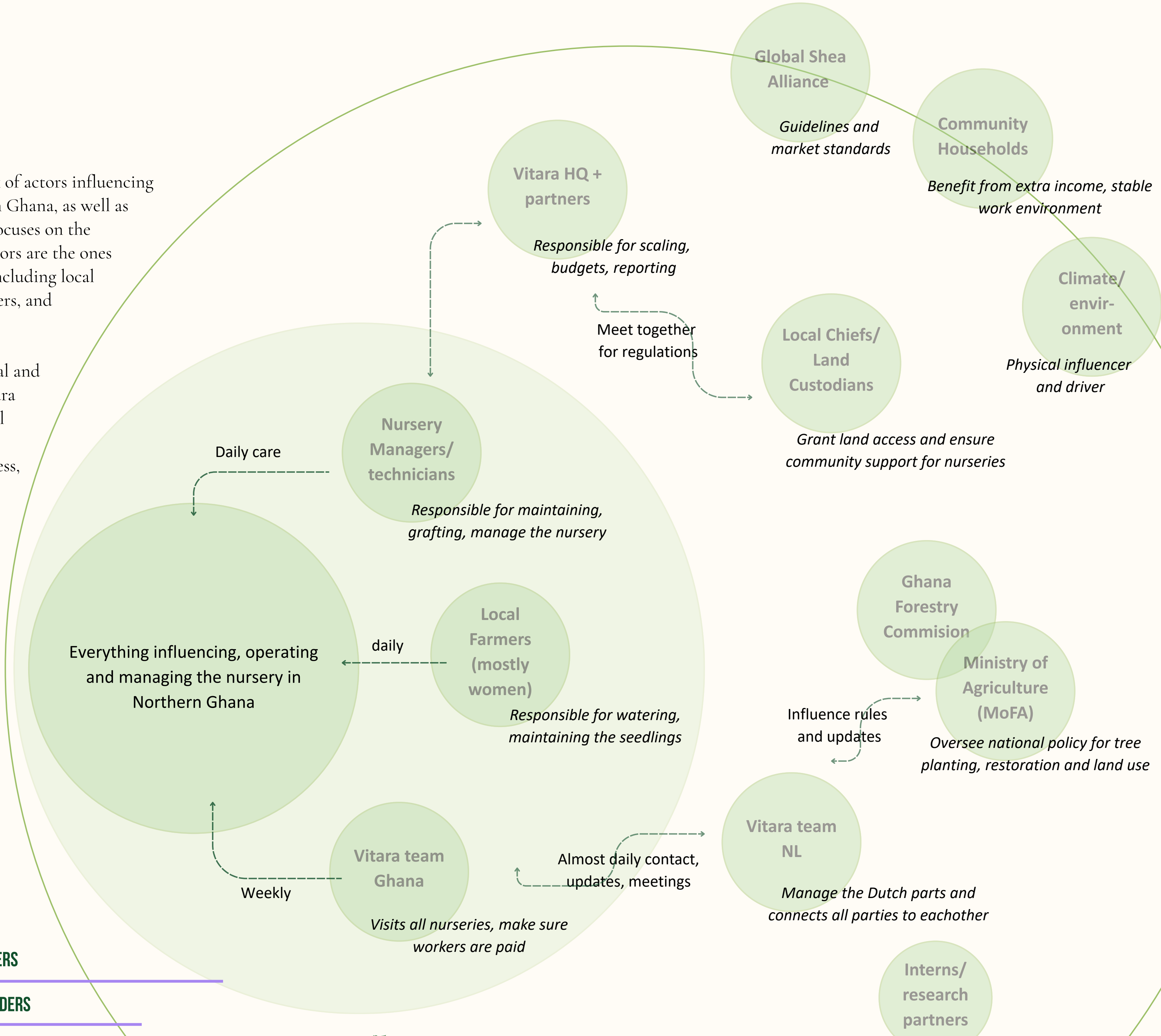
Figure 18
Shea plant and nuts (Vitara, 2026)

3.4 KEY ACTORS

This stakeholder map shows the network of actors influencing agroforestry nursery systems in Northern Ghana, as well as Vitara's operations. This key actor map focuses on the conservation team. At the centre, key actors are the ones responsible for daily nursery activities, including local farmers, women's groups, nursery managers, and Vitara's Ghana team.

Supporting these actors are organisational and institutional stakeholders, including Vitara Netherlands, traditional authorities, local communities, and governmental bodies. Together, these actors influence land access, operations, maintenance, funding, and long-term implementation.

It shows that nursery performance depends not only on technical systems, but also on the alignment between social structures, governance, labour, and environmental conditions.



DIRECT STAKEHOLDERS

INDIRECT STAKEHOLDERS

Figure 19
Stakeholders of Vitara

04 VISION

4.1 VISION: THE NURSERY AS A CONNECTED SYSTEM

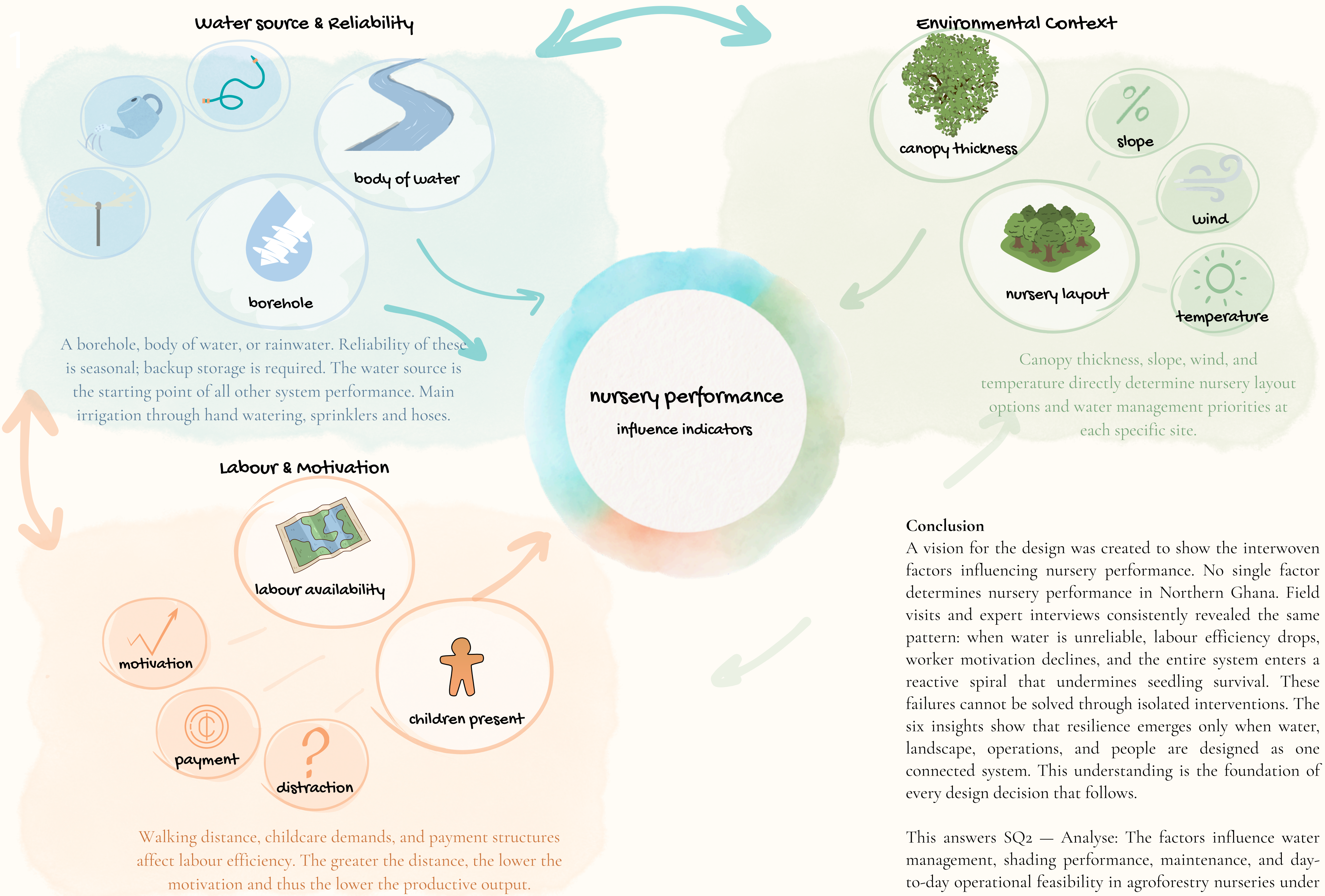


Figure 20
Influence structure, visual by author

Conclusion
A vision for the design was created to show the interwoven factors influencing nursery performance. No single factor determines nursery performance in Northern Ghana. Field visits and expert interviews consistently revealed the same pattern: when water is unreliable, labour efficiency drops, worker motivation declines, and the entire system enters a reactive spiral that undermines seedling survival. These failures cannot be solved through isolated interventions. The six insights show that resilience emerges only when water, landscape, operations, and people are designed as one connected system. This understanding is the foundation of every design decision that follows.

This answers SQ2 — Analyse: The factors influence water management, shading performance, maintenance, and day-to-day operational feasibility in agroforestry nurseries under local conditions.

05

OVERVIEW:

THE TOOLKIT

05 – THE TOOLKIT

Goal of this chapter
The goal of this chapter is to establish why the design has been formed through the method of a toolkit and why a pilot is proposed. It follows the WWWWWH method to explain the design decisions made.

4.1 Why: water as the guiding principle
4.2 What: three pathways, one solution
4.3 How: utilising low pressure
4.4 Where: Sankana Dam
4.5 Who: four roles in one nursery
4.6 When: timeline nursery
4.7 Costs: financial resilience with the pilot

Key takeaways
- The toolkit proposes a pilot year, with its own design irrigation set up for 25,000 seedlings. This is to understand the local context better and scale on proven data.
- One size fits all does not work; context is a key design driver.
- Drip target irrigation suits all design requirements well.
- Work with the women's daily life and integrate it into parts of the nursery.
- Use a dam over a borehole because of sustainability and lower maintenance.

5. PILOT IN A TOOLKIT

Throughout the project, the focus shifted from enhancing individual nursery components towards understanding the nursery as a system. The outcome is a practical toolkit for setting up and managing a gravity-fed agroforestry nursery in Northern Ghana.

The reason for a pilot

Rather than proposing a large-scale implementation, the project is structured around a modular pilot approach. The pilot functions as the first real-world validation step of the proposed nursery system, allowing proven irrigation logic, operational workflows, maintenance, and organisational feasibility to be tested under local conditions before scaling further. In this way, the pilot reduces implementation risks while creating a foundation for future expansion based on real factual data.

The toolkit

The toolkit functions as both a strategic and operational guide for setting up and managing a gravity-fed nursery system. It combines system layouts, operational structures, irrigation logic, maintenance principles, scaling strategies, and implementation guidance into one document. This report will elaborate on the pages of the toolkit.

Project outcome

The goal of the toolkit is to support Vitara in making informed decisions around nursery development while reducing uncertainty in implementation, maintenance, and operational planning.

Intended audience

The toolkit is intended for:

- Vitara management
- conservation teams
- nursery workers
- implementation partners

Validation

The toolkit was iteratively reviewed and discussed with stakeholders, nursery practitioners, and experts throughout the project. These discussions were used to evaluate the clarity, feasibility, and operational relevance of the proposed system under local conditions. Feedback from Vitara and external experts continuously informed adjustments to both the toolkit structure and the proposed pilot setup, which will be made clear in the chapters.

It uses the WWWWWH (who, why, what, where, when, how) design method to explain the toolkit clearly and make it easier to understand. The cost analysis was added, as this is an important point of viability and understanding for Vitara as a company, for reasons of investment. Besides going into the core of the design: water management, it elaborates on all the aspects mentioned in the vision of people, environment, and business to create a coherent design that ensures resilience and sustainability in all aspects.

Iterations

Throughout the project, the toolkit evolved through continuous feedback, visual communication, and stakeholder discussions.

Priorities of the toolkit are to have clear and accessible visualisations that help different stakeholders understand, discuss, and evaluate the proposed nursery system.

Figure 21
The toolkit overview

TOOLKIT PREVIEW

Now, let's dive into the toolkit. Throughout the chapters, the toolkit pages will be highlighted in purple, and they explain the design. The green-highlighted justification page explains how the decisions came to be.

Figure 22 ▶
Preview of the toolkit, by author

THE PLANT AT A GLANCE

Although water supports plant growth, creating a truly resilient plant is far more challenging than simply applying irrigation to a seedling. The ultimate goal of a seedling in a nursery is to be raised to become mature and strong enough to survive transplantation into the field, a stressful and often traumatic moment in its growth.

During the growing process, the way the plant receives water is essential. Water is not only the most important factor within the nursery itself, but also within the broader resilience of the surrounding environment. The needs of a seedling change throughout its different growth stages, and the way water is delivered must change with it.

This pilot allows irrigation to be adjusted to these different stages and their corresponding water needs. By delivering targeted irrigation directly to the seedling root zone, the system supports healthier growth. It increases resilience beyond the nursery by reducing unnecessary water extraction, minimising losses from less efficient irrigation, and easing labour effort.

On a large scale, it promotes healthy water management in an arid climate, but on a small scale, it follows the three phases of the plant, defined as: (1) Establishment requires predictable water delivery for root establishment. (2) Rapid growth requires water to grow strong and tall. (3) Hardening reduces total water demand before transplanting and prepares a seedling for drought (Wilkinson et al., 2014).

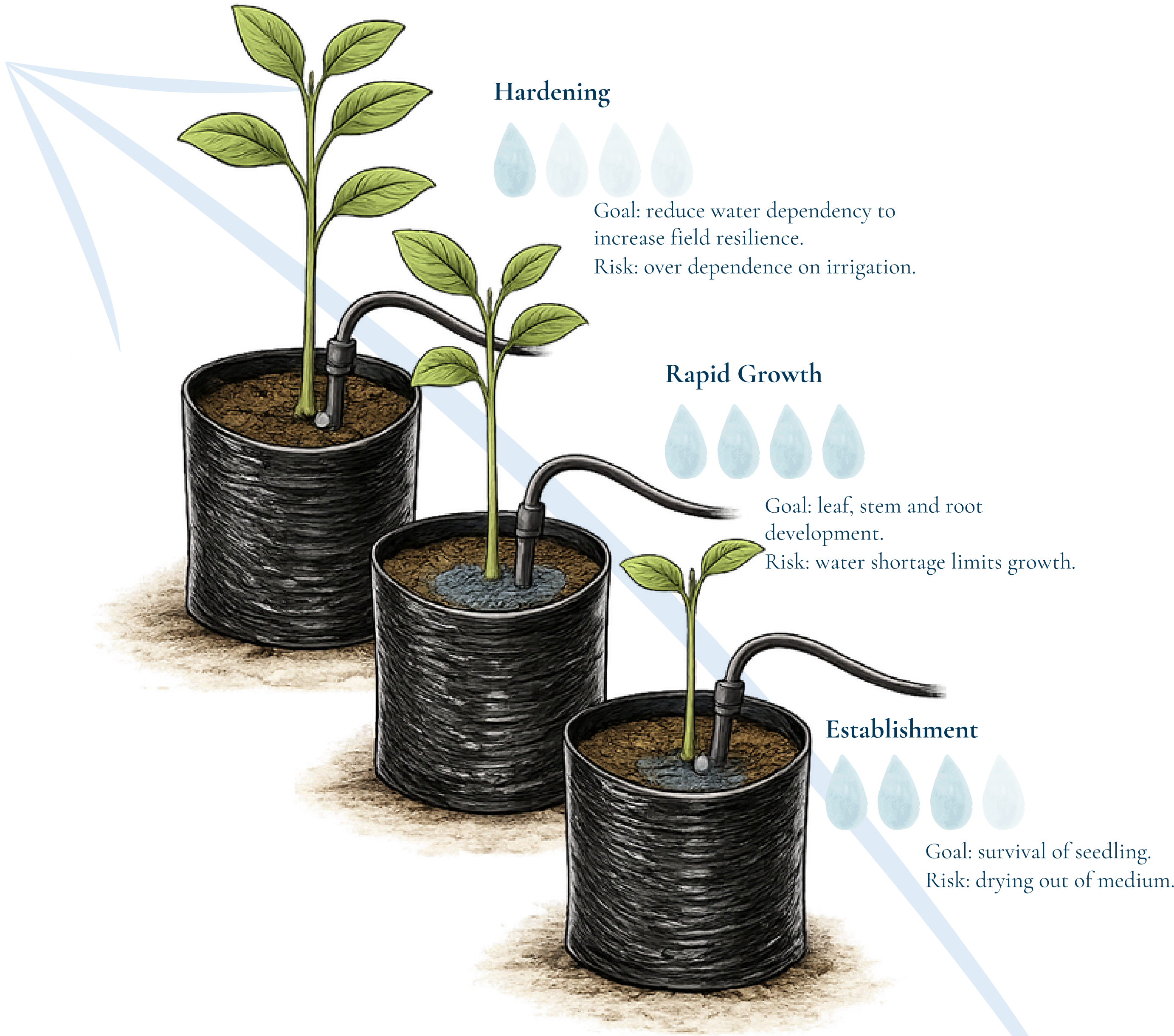
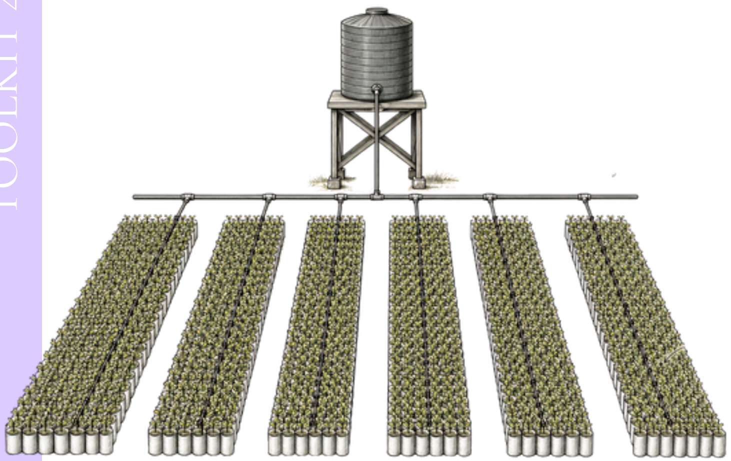


Figure 23 ▶
Plant growth phases, visuals by author enhanced with AI

THE PILOT AT A GLANCE

25,000 seedlings. One modular nursery. One pilot year to validate water use, seedling survival, labour, maintenance, and daily operations under real dry-season conditions. Prove the system works at manageable scale first, then scale step-by-step towards 300,000 seedlings.



Sankana Dam • Wa, Northern Ghana

Figure 24
Proposed gravity irrigation, visualy by author

0.1L
per seedling • every 3 days

delivered through precise, gravity irrigation at night

> 85%
target seedling survival

after one full planting season, including dry season

3,000L
water storage in per module

gravity-fed polytank at 2.0m head (height)

25,000
seedlings per pilot module

six seedling beds with approx, 4200 each

4 WORKERS
to operate the module

a technician, keeper, coordinator and field agent

820 M^2
per module • scalable

modular in design enables replication, not redesign

HOW TO USE THE TOOLKIT

This toolkit guides Vitara through the setup of a gravity-fed nursery pilot in Northern Ghana. It covers the context, system design, team structure, maintenance routines, and costs. Each section builds on the last. Read it through once, then use it as a reference during implementation.

THE WHY

THE TOOLKIT

5.1

WATER IS THE SYSTEM'S WEAKEST POINT

Northern Ghana is typified by long, dry seasons that start in November, peak in March, then slowly cool and become more humid in June. The climate is characterised by high temperatures and seasonal dry winds, the Harmattan, which lowers humidity and makes water scarce. The common way to irrigate in this dry climate, manual watering, which is often done in nurseries, is uneven and labour-intensive. Other options, like boreholes, break down or run dry, precisely when demand is the highest. When the water supply becomes unreliable, it triggers a chain reaction among both the seedlings and the nursery workers, ultimately degrading the entire nursery. This is why water is chosen as the ultimate controlling and compelling factor of the nursery.

Water controls both the biological system (the seedlings) and the human system (the workers). When one fails, the other follows.

Nursery Failure Cascade Module

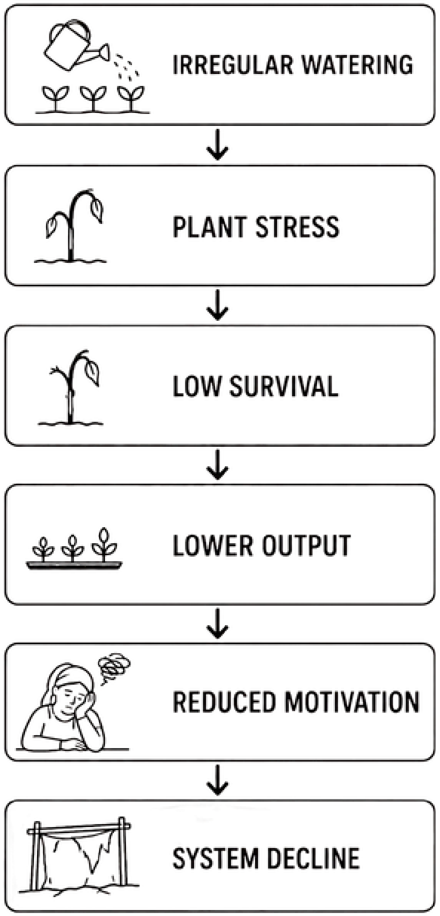


Figure 25
Nursery Failure Cascade Model , visual by author

Figure 26
Wa landscape, picture by author

5.1 WHY: WATER AS THE GUIDING PRINCIPLE

This chapter explains how the proposed system reduces its dependency on maintenance-intensive water sources and infrastructure, while also outlining when the pressures on water management are the highest in the nursery.

The nursery as a water-dependent system
As established in Chapter 01, the core design problem is not a lack of water but the inability to manage it reliably in the dry season. The irrigation pressure map makes this visible. Irrigation demand peaks between November and May, when all seedlings are in the nursery, and most vulnerable to heat and drought (Omay et al., 2023). Shea spends up to eleven months in the nursery, meaning it must survive a full dry season before transplantation (E9). The other species have shorter cycles, but overlap before transplanting (Wilkinson et al., 2014).

What the map does not show is that the human system follows the same method. One nursery visited during fieldwork dealt with a broken borehole, which meant water had to be carried on the head for over fifteen minutes from the next borehole. The seedlings struggled without reliable irrigation, which was seen as their leaves shed to preserve water (E10). When irrigation becomes unreliable, workers carry water manually, physical exhaustion increases, and maintenance becomes reactive rather than preventive (Bardasi & Wodon, 2010). The biological and human cycles are linked: when water fails the seedling, it fails the worker too (E3, E8, E10).

This is why the toolkit addresses water management as both an irrigation problem and as a human-biological exchange for a system that works for both the plants and the workers. The entire water usage calculation can be found in Appendix D.

Conclusion with design requirements
DR1 – water management requires the system to store, distribute, and deliver water reliably across the full dry season. DR2 – seedling-centred design adds the seedlings' needs in this, as their water needs change across the establishment, rapid growth, and hardening stages. It's thus essential to understand that the irrigation needs of a seedling change to create a resilient seedling that survives well beyond the nursery after transplantation. (E5, E9, E13). A fixed daily watering schedule is not enough; delivery must adapt over time.

Without solving water management, improving any other component of the nursery has a limited effect. This is why water became the guiding principle, not because it was the most visible problem, but because it was the one that, when solved, makes every other intervention possible. This answers SQ 3 – the influence of water management in Ghana and in nurseries.

IRRIGATION PRESSURE MAP

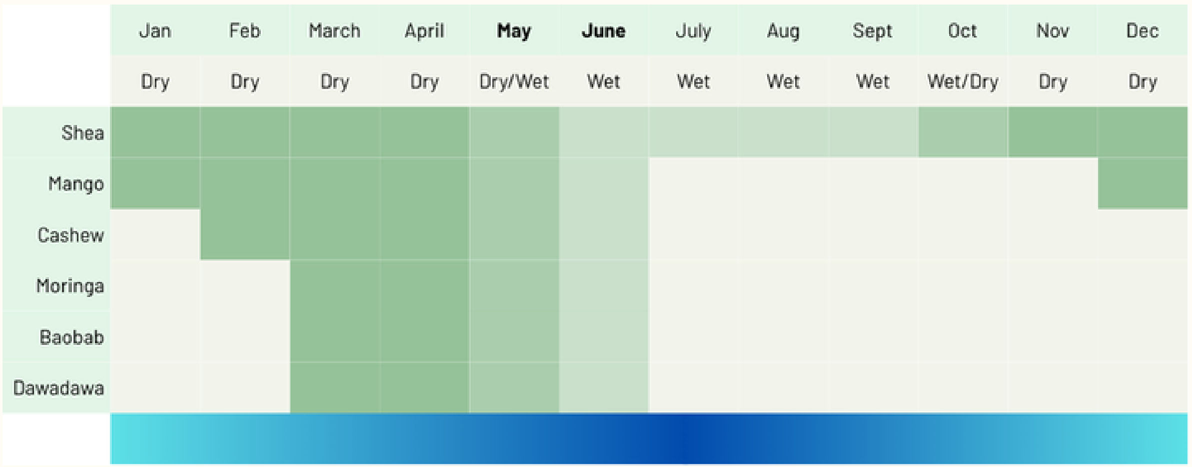


Figure 27
Irrigation pressure map

NURSERY (E9)

Figure 28
Borehole reliant nursery, picture by author

NURSERY (E10)

Figure 29
Sankana nursery, picture by author

Field visits take-aways (E9/10)

The left figure shows that even a well-shaded nursery could fail as it relied on a broken borehole, leaving seedlings dormant and dying. In contrast, the nursery on the right operated without shade nets, but with a stable water supply, and showed seedlings thriving under full sun exposure.

This highlights the importance of reliable water management over other nursery components, and the need to design around the actual needs of the seedlings.

Field visits take-aways (E8)

The left figure shows a community in Tamale relying on a mechanical borehole for water access. During maintenance, the borehole, and therefore access to water, becomes unavailable. Luckily, this is one of the boreholes were mainteance is well maintained.

Unwritten rules, such as queuing with water baskets, create structure during these moments, but they also highlight the importance of reliable water access as a key point in the nursery toolkit and the consequences when it is not consistently available.

Figure 30
Water access, picture by author

A resilient system does not depend on perfect conditions, but performs under imperfect ones.

– The core design pincriple of this nursery system

This means: design for failure, not for ideal weather. The system works at its worst conditions, during the dry Harmattan, not just when conditions are good.

THE WHAT

THE TOOLKIT

5.2

why

THE MISSION

A gravity-fed irrigation strategy was selected because it offered the strongest balance between water reliability, labour reduction, operational simplicity, local repairability, and scalability under the dry-season conditions observed in Northern Ghana.

This overview visualises the design based on two core principles.

First, producing a resilient and qualitative seedling requires irrigation that responds to the changing water needs throughout the three main growth stages: establishment, rapid growth, and hardening. These stages strengthen the seedling both in the nursery and after transplanting.

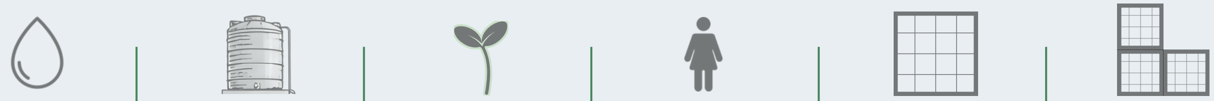
Second, creating a resilient nursery requires a stable and sustainable water supply that is nearby, reliable year-round, and capable of supporting the nursery during long dry periods. Water management, therefore, became the foundation of the overall nursery design.

The next chapters explain the decisions that shaped the final design.

the mission

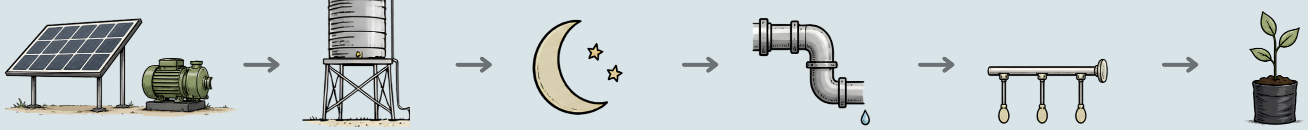
Pilot a nursery in Wa, Northern Ghana, to test site suitability and launch a modular, gravity-fed irrigation system that conserves water, adapts locally, supports women workers, and is scalable.

goals



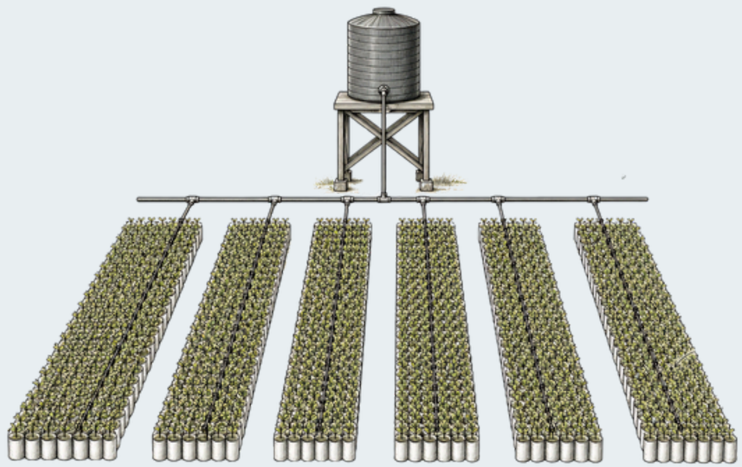
0.1 L	3000 L	>85%	4	25,000	820 m²
per seedling per 3 days	water storage per module (buffer)	seedling survival after 1 plant year	farmers/technicians can operate the module	seedlings per module	per module, and scalable

how it works



Solar pump extracts water from the dam → Water stored in polytank at 2.0 m height (head) → Night irrigation reduces evapor-ation + heat stress → Gravity-driven water distribution → Water flows: mainlines, laterals and micro-tubes → Each seedling receives a small, controlled amount

module overview



One module contains:

- One tank to feed the seedlings.
- Six seedling beds with each +- 4,200 seedlings.

Modules operate independently, but multiple modules can be deployed in parallel in the same nursery

Figure 31
Mission overview, visual by author

THE SOLUTION

Three pathways were evaluated: full manual watering, a high-tech commercial system and a mid-tech gravity-fed approach. This toolkit takes the middle road, using methods proven in other African countries with similar climates and built around precision irrigation with locally available materials.

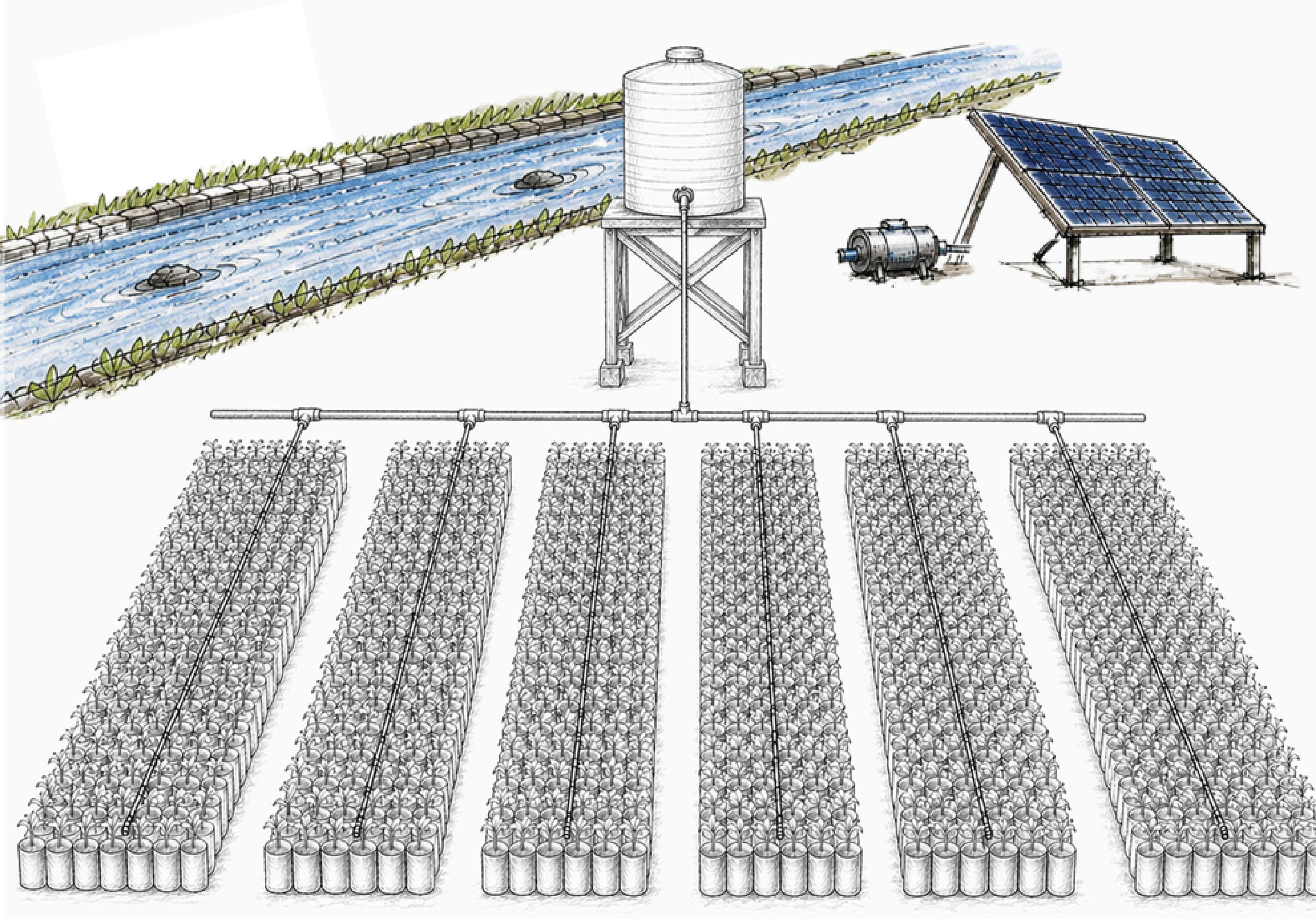
A solar pump extracts water from the dam and stores it in the polytanks. At night, the worker opens a valve, and gravity distributes the water. The nightly irrigation needs minimal labour and lowers evapotranspiration. Through target emitters, each seedling receives 0.1 L per irrigation event.

Here, a pilot is proposed, with a starting module which is defined as:

One module = one tank + six seedlings beds = 25,000 seedlings

Modules operate independently, but can run at the same time.

The distribution hierarchy: water flow from the mainline (50mm) → , submains (20mm) → , laterals (20mm) → , microtubes in polybag (0.1 L pressure emitter).

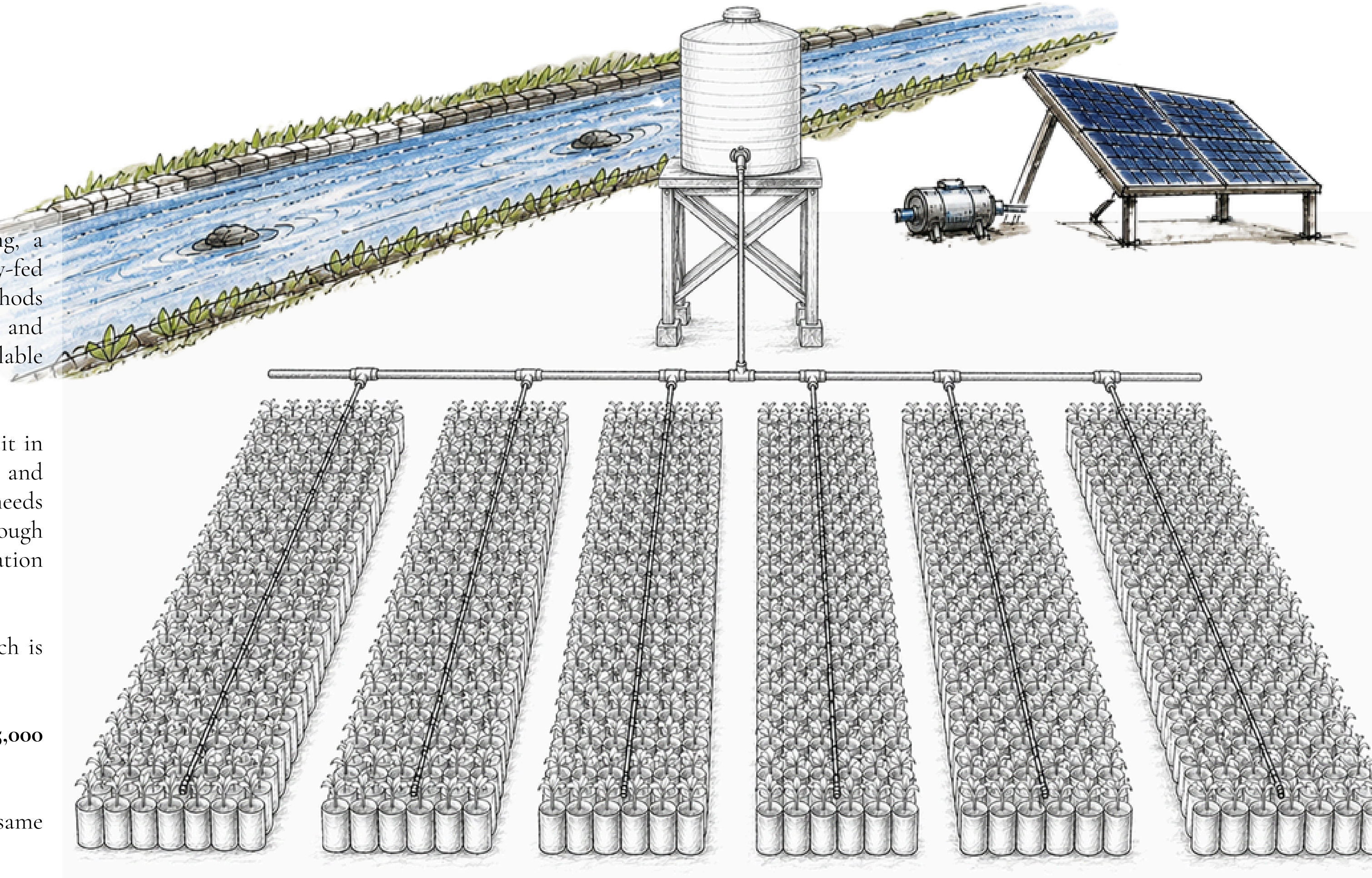


*drawing to simulate the layout. Each row would have +-4200 seedlings.

Gall's law:
"A complex system that works is invariably found to have evolved from a simple system that worked." Build one module. Prove the concept. Then scale.

Figure 32
Module overview, visual by author enhanced with AI

THE SOLUTION



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Modules operate independently, but can run at the same time.

The distribution hierarchy: water flow from the mainline (50mm) → , submains (20mm) → , laterals (20mm) → , microtubes in polybag (0.1 L pressure emitter).

*drawing to simulate the layout. Each row would have +-4200 seedlings.

Gall's law:
"A complex system that works is invariably found to have evolved from a simple system that worked." Build one module. Prove the concept. Then scale.

Figure 32
Module overview, visual by author enhanced with AI

5.2.1 WHAT: THREE PATHWAYS, ONE SOLUTION

This chapter details why gravity-fed targeted irrigation was chosen, highlighting how this mid-tech solution bridges the gap between manual watering and full automation.

Gravity-fed as the mid-tech route
It works through pumping water into elevated polytanks and distributing it through a fixed low-pressure pipe network at night, delivering targeted water directly to each seedling through microtubes without any external power source. Other comparable agricultural systems in Nigeria and Ghana show that passive gravity systems with a 2 m tank head and lateral lengths of 20 to 40 m achieve emission uniformity of 85 to 98% and have high success rates, with 85% seedling survival (Martinez et al., 2024). It means every seedling, front row or back row, receives on average 90% the same amount of water.

Additionally, quotes were requested from two irrigation companies active in West Africa to understand the full range of solutions. Both quoted between of $120-300,000 for 0.7 ha, thus requiring a large investment, and dependency on their support for maintenance. This was left out of scope, as it does not correspond with DR5 – start small and scale.

Criteria	Flood/Basin	Hose add-on	Gravity-fed
Water reliability	2/10	5/10	9/10
Labour reduction	5/10	4/10	9/10
Ease of maintenance	4/10	8/10	8/10
Local repairability	6/10	9/10	8/10
Water efficiency	4/10	4/10	9/10
Scalability	4/10	6/10	9/10
Dry-season resilience	4/10	4/10	8/10
Technical simplicity	6/10	9/10	7/10
Fit with local operations	5/10	9/10	8/10

Figure 33
Comparison of irrigation, visual by author

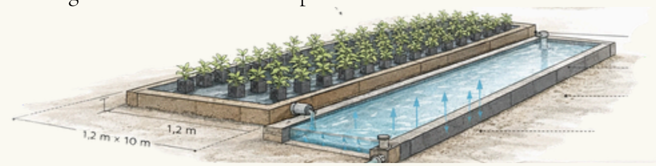
In scope, three methods were identified through the Tropical Nursery Manual (2014) and an irrigation specialist (E10) as very suitable in contexts with high environmental irrigation pressure: flood irrigation, manual hose watering, and gravity-fed drip. These were evaluated against the design requirements, seen in Figure 33. Figure 34 explains these methods.

Flood irrigation scored low on reliability, scalability, and maintenance. Water flows among the nursery floor instead of directly into the polybag, making consistent distribution across 25,000 seedlings impossible without extreme terrain levelling. It has high evaporation as the water surface is exposed for a long time in low-humidity air (Bakker et al., 2015). The hose add-on is common in Northern Ghana, but workers constantly need to perform manual labour, and it creates uneven water distribution. It fits the local routines, but it does not solve the problem of water management.

The gravity-fed trade-off
The gravity-fed has one important trade-off: lateral lines and microtubes can clog, requiring regular maintenance. However, since the use of grafity fed reduces manual labour time, it was chosen to spend more time spent on maintenance is an exchange for consistent irrigation that meets seedling needs across all growth phases, reduces evapotranspiration, and lowers overall water waste. The full three-pathway comparison is in Appendix C.

01 – Flood / Basin Irrigation

Shallow, levelled basins filled to a fixed water level inspired by rice field irrigation systems. Water moves through the subcapillary working to the root zone of the plant.



02 – Hose Add-On

Builds on worker behaviour, where hose endings are compressed to widen spray patterns. Water is applied manually through handheld hoses with an attachment.

03 – Gravity-Fed Drip

Water is pumped into elevated polytanks and distributed nightly through a fixed low-pressure pipe network. Water flows through laterals and microtubes directly into each polybag.

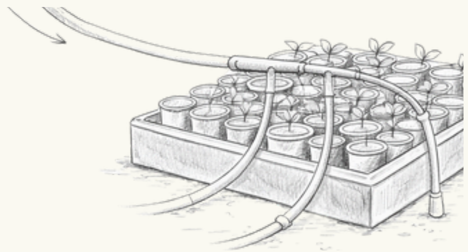


Figure 34
Three design directions, visual by author

5.2.2 WHAT: SOLAR POWER AND MODULARITY

This chapter explains how the dry season is turned into an advantage through solar energy, why a solar pump is more financially viable and sustainable over a fuel pump, and how modular polytank systems keep any failure local.

Using a solar pump

The same conditions that create pressure on seedlings provide an opportunity. Solar irradiance peaks during the dry months when water demand is highest, making solar pumping a logical fit that eliminates fuel dependency (Solargis, 2021). One pump requiring 120–370W with solar panels can fill up to six 3,000 L polytanks during the day, and thus, for the pilot, easily one. Nightly irrigation reduces evaporative losses, so the same 0.1 L delivers more effective water at night than during the day (Bakker et al., 2015). Using elevated polytanks is already the most common water storage method across Ghana, making the system locally familiar without requiring unfamiliar technology (Osabutey, 2026). DR3 – maintenance simplicity makes this a design condition: a system that workers do not understand or trust will not be maintained.

Modularity in design

Modularity follows the same logic of reducing vulnerability rather than maximising scale. Field observations repeatedly showed that if large dependent systems become exposed during the dry season, and this one central system, on which a whole nursery depends, fails, the whole nursery can suffer with it. This solution mitigates that. If one module fails, the problem stays local, visible, and fixable before it moves to other modules (E8, E15). The module with one polytank, six beds, and 25,000 seedlings, is sized to what one solar pump can easily fill in a day, and what the hydraulic system can distribute uniformly at 2.0 m head in a field of around 30 by 20 meters. The entire layout map is in Appendix D.

Conclusion with design requirements

This combination of solar pumping and modular storage directly answers DR3 – maintenance simplicity and DR6 – modular scaling. The system requires no fuel, no continuous electrical load, and no external technician to move the water. Each module operates independently, meaning failures stay contained and the nursery can grow through repetition rather than complete redesign. Together, these decisions reduce operational vulnerability precisely where it matters most: during the dry season, when the nursery is under the most pressure and the consequences of failure are greatest.

> **Solar vs. Fuel pump**
>
> Solar requires a higher initial investment of approximately **$1,500** compared to **$500** for a fuel pump.
>
> A gallon of fuel in Wa costs around 300 GH₵ ($27) and lasts two weeks for two acres of nursery irrigation (E6, field observation), amounting to **$700** per year in fuel costs alone. Solar eliminates this after the initial investment, with a breakeven point of 8-14 months depending on dry season pressure and a near-zero running costs of around **$80** per year for cleaning and maintenance, which is what a fuel pump requires anyway.

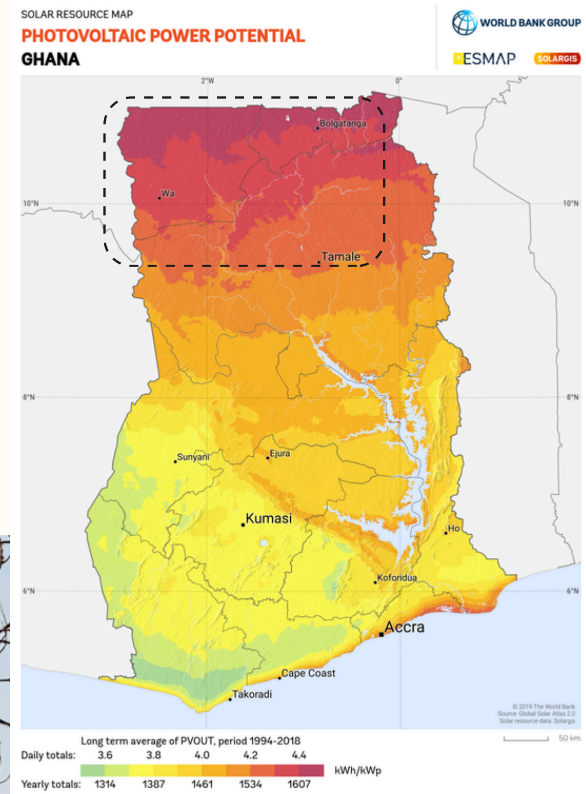


Figure 34, potential solar energy (Solargis, 2021)

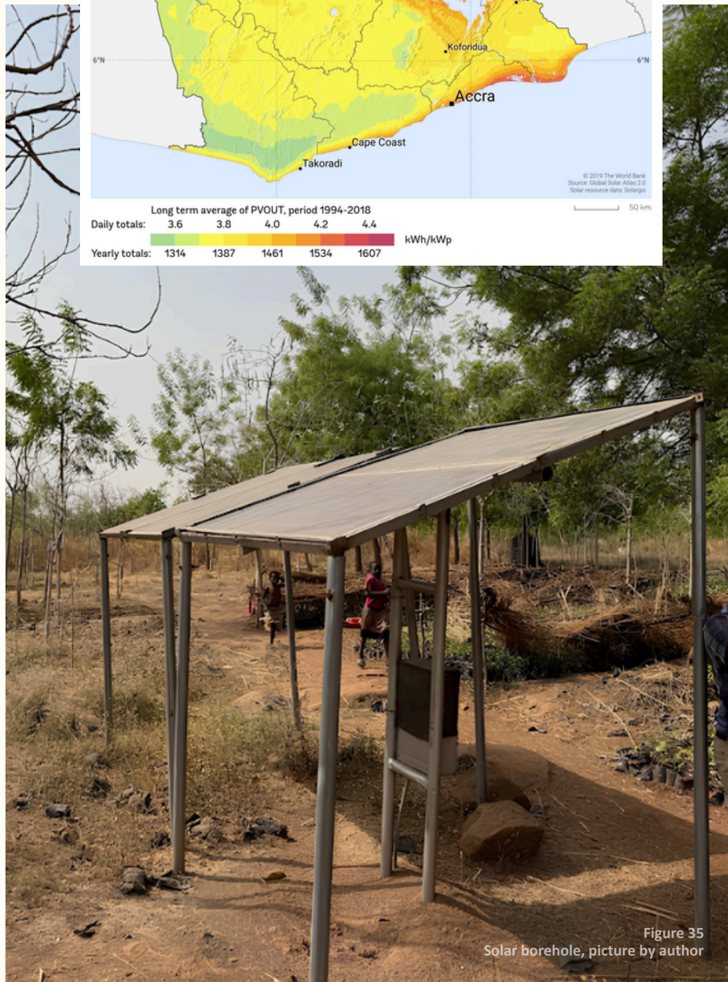


Figure 35
Solar borehole, picture by author

THE HOW

THE TOOLKIT

5.3

THE NUMBERS

The pipe diameters, tank height and lateral length were calculated to ensure a reliable flow that reaches every seedling, even when the tank is almost empty and the seedlings are at is farthest from the tank.

1 **0.872 M**

Minimum head required
The lowest water pressure that still drives flow to every seedlings. With a full tank, the head rises to 1.8m.

2 **2.0 M**

Design target height
The polytank stand height, including a 10% safety margin above the minimum calculated head.

3 **2,500 L**

Demand per day
Total irrigation demand for 25,000 seedlings at 0.1 L per plant per every day.

4 **3,000 L**

Tank capacity
Sized above demand to account for evaporation, cleaning downtime and flow variation.

Why low-pressure systems work

Since each seedling receives 0.1 L per irrigation event, pipe velocities remain very low throughout the network. The main resistance is the outlet emitter itself, not in the pipes. This means the flow is naturally self-regulating at the plant level, without the need for external pressure. Gravity creates pressure differences, with pushes water to a lower point.

Key system parameters	
mainline diameter	50 mm
lateral length	30.0 m
hydraulic head	2.0 m
emitter flow rate	0.1 L
irrigation time	nightly (+- 6 - 10 hrs)
seedlings per row	+- 4200
rows per module	6

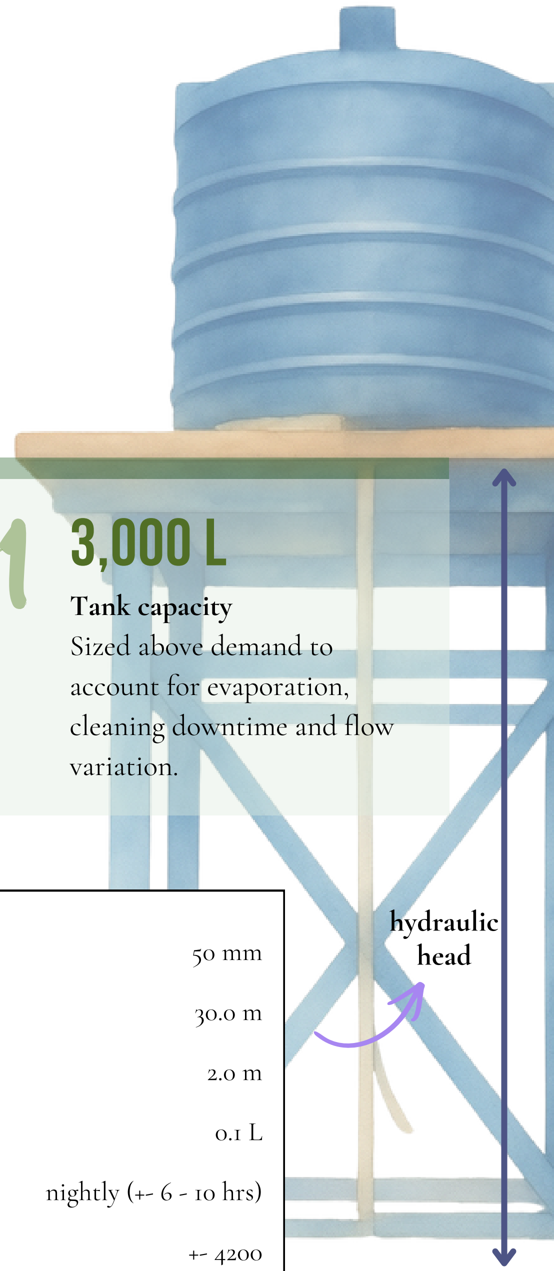
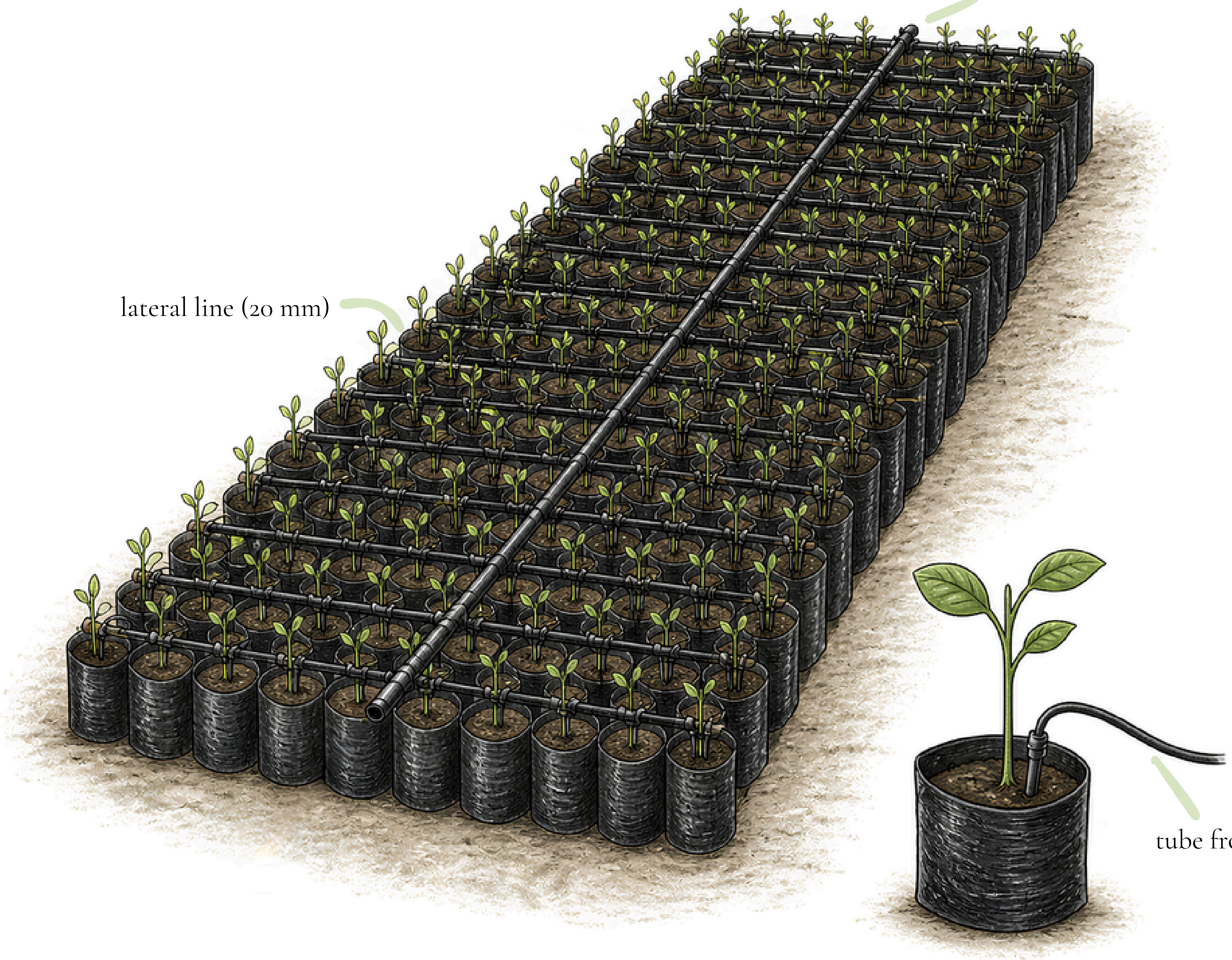


Figure 36
Elevated Polytank

Seedling bed
The living heart of the nursery. Even native plants' outplanting resilience depends on how well their waterings needs are understood and met.



1 THE POLYBAG

Every seedlings grows in a black PE polybag filled with sand and compost.

2 MICROTUBE

A thin 1/4" microtube runs from the lateral line into the polybag. It is inserted slightly; so water is delivered directly inside the bag, thereby reducing evapotranspiration.

3 EMITTER

In most irrigation systems, pressure decreases with distance and plants at the far end of a row receive less water than those closest to the source. This system eliminates that problem by design. Each micro-tube delivers only 0.1 L per irrigation event, keeping water velocity inside the 20 mm lateral pipe negligible. Calculated friction losses along a 30 m lateral fall well within the 10% uniformity threshold accepted in similar precision drip irrigation design. Field measurement during the pilot year will confirm this under real operating conditions.

Figure 37
Seedling bed, visual by author enhanced with AI

5.3 HOW: UTILISING LOW PRESSURE

This chapter explains how hydraulic calculations validated the feasibility of a low-pressure gravity-fed irrigation strategy within the environmental and operational conditions of Northern Ghana.

The hydraulic logic and seedling bed
The pipe diameters, tank height, and lateral length were calculated to ensure a reliable flow reaches every seedling, even when the tank is almost empty, and the seedling is at the far end of a 30 m lateral. Using the Darcy-Weisbach equation, friction losses across the pipe network determined the minimum tank height required to activate all emitters and overcome pipe resistance. The result was a minimum head of **0.872 m,** which is when the polytank is almost empty. As a polytank is around 1 m high, that heightens the minimum to **1.872 m**. The final design height was set at 2.0 m, with a 10% safety margin, to account for low tank levels during extended dry periods and evaporation losses during refilling cycles (White & Xue, 2021; Martinez et al., 2024). Full hydraulic calculations are in Appendix D.

Because each seedling receives only 0.1 L per irrigation event, pipe velocities remain very low throughout the network. The main resistance is in the outlet emitter itself, not the pipes, meaning the flow is naturally self-regulating at the plant level without any external pressure source. Gravity alone is sufficient to drive the system. Seedlings at the far end of a row receive, on average, 90% the same amount as those closest to the tank, a level of consistency that manual watering cannot achieve with hose or hand watering (Martinez et al., 2024).

Emitter layout
The emitter-based layout was selected because it delivers water directly into the polybag through a thin 1/4" microtube, reducing evapotranspiration compared to surface application.

Each microtube costs €0.05 per unit based on supplier quotes from Wa and Tamale (February 2026), and is replaceable on-site with limited tools. The full bill of materials and every component budget are in Appendix F.

Conclusion with Design Requirements
DR2 – seedling-centred design, makes targeted delivery a design condition: the system should respond to the needs of the seedling across establishment, rapid growth, and hardening rather than apply a standard irrigation schedule. DR3 – maintenance simplicity means that every component must be locally repairable and financially realistic at scale. These DR are met here: water reaches seedlings uniformly, delivery adapts to each growth stage, and components are locally sourceable and replaceable on-site.

Adjusting to the growth phases
0.1 L stems from expert interviews in North Ghana and is confirmed by literature showing that effective seedling water delivery is 0.08-0.12 ml per event in semi-arid conditions (Darimani et al., 2021). At 25,000 seedlings per module, this equals exactly 2,500 L per irrigation cycle, well within the 3,000 L tank capacity. The 500 L added volume accounts for losses and is hydraulically validated in Appendix D.

As seedling needs change across growth stages, workers can adjust irrigation frequency, irrigating more or less often than every three days. This is why drip irrigation was not suitable; a constant wet soil reduces the drought resistance of these species, lowering survival rates after transplanting.

Figure 38
Grafted Shea, picture by author

THE WHERE

THE TOOLKIT

5.4

Selection criteria	Proximity	Governance	Land available	Acceptance
Water reliability *Dry-season performance*	<30 min to VItara HQ *Practical oversight*	Existing WUA *Integration feasbile*	2 acres confirmed *Google Earth + stakeholders*	Local chiefs *indicated in fieldwork*

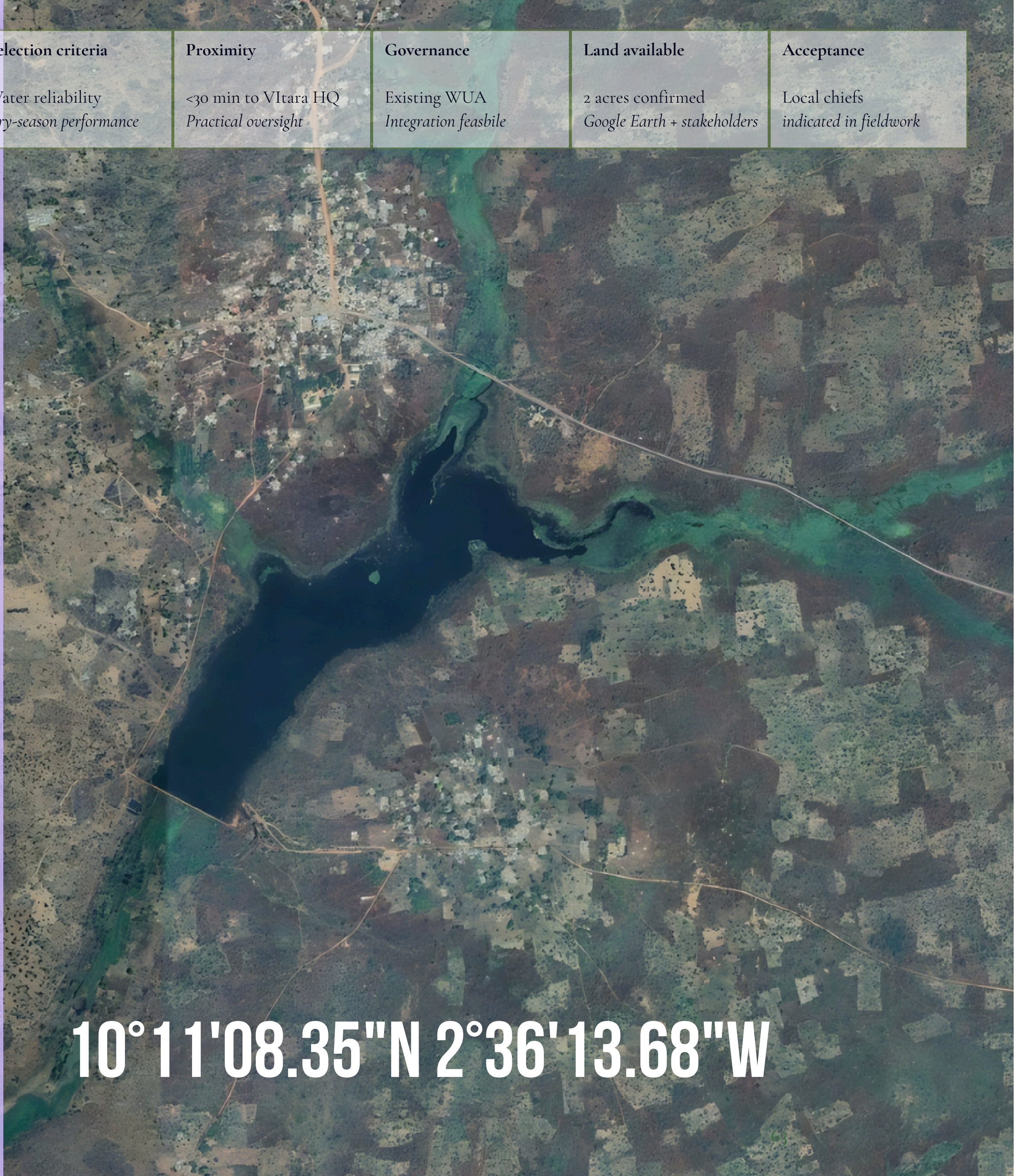


Figure 39 and 40
Map and Sankana Dam from Google Earth (2026)

SANKANA DAM

1 WHY A DAM

and not a borehole

Most nurseries in the North depend on boreholes drilled up to depths of 70+ meters. These need continuous maintenance and electricity. If manual, water extraction is very strenuous. They frequently run dry during the very months when the nursery needs water most. Sankana Dam was built in 1961 as an irrigation reservoir. It holds over 30 million litres of water, more than enough to meet the demand for tens of cubic metres per day, and is reliable throughout the six months of the dry season.

2 WHY THIS DAM

to start with the pilot

The reservoir currently uses only ± 20% of its intended irrigation capacity. Smallholder farmers already access it through sluices, and it has the acceptance of local leadership.

Research confirms that approximately 2 acres of farmland are readily available near the dam, with the possibility of extension. Its proximity to Wa supports ongoing engagement for Vitara field agents and local labour, as well as practical oversight. All essential in a pilot phase.

3 WHY NORTH GHANA

and why nurseries work different here

Unlike the south, the Upper West region has a single rainy season, followed by 6-7 months of a dry season, high temperatures, and Harmattan winds, conditions that stress both plants and workers.

This makes water access the single most critical factor in nursery performance. The system is designed for these conditions, not despite them.

5.4 WHERE: SANKANA DAM

This chapter explains the critical importance of selecting a suitable pilot location and demonstrates why a 'one-size-fits-all' approach is ineffective for nurseries.

Using a dam over a borehole

Sankana Dam was selected as the recommended primary water source for the pilot nursery based on environmental reliability, low infrastructure vulnerability, and local governance possibilities.

Site selection was a design decision. A visit to Tamale (e4) showed a thriving nursery near the Tamale dam, compared to borehole-reliant nurseries. This opened options to explore dams and replicate this in WA. As stated in Chapter 02, boreholes fail at rates reaching 67% within 2 years in the Voltaian aquifer system, during the dry season when extraction is highest and natural recharge is slow (Chegbeleh et al., 2020). Rainwater harvesting was explored, but requires infrastructure that falls outside the scope and budget of a pilot nursery. Surface water availability from an irrigation dam was confirmed by landscape and water specialists as the most reliable long-term source in the Upper West Region (E14, E15).

Sankana Dam was selected against four criteria through Google Earth satellite images and site visits. First, *seasonal water availability*: field visits confirmed the dam maintains high water levels throughout the dry season, with total nursery irrigation demand of approximately 5.4 to 7.2 million litres representing less than 0.5% of the dam's annual irrigation scheme usage, which shows that the pilot nursery irrigation demand remains feasible, even when scaled later, see water calculations in Appendix G. Second, *existing infrastructure*: on-site water infrastructure reduces setup cost during the pilot year.

Third, *operational closeness:* located thirty minutes by motorbike from Vitara's base in Wa, enabling close monitoring and rapid response. Fourth, *governance*: the dam operates through an existing Water User Association, with local chiefs indicating acceptance of new irrigation initiatives during fieldwork (E10). Initial contacts with a nursery owner have been established for Vitara to continue when implementation starts. Field evidence at the site showed E10 operated a nursery at Sankana, facing the same challenges identified in this project. Despite broken shade nets, seedlings continued to thrive due to the stable water supply, directly confirming the project's core insight that reliable water access is the foundation of nursery resilience.

Conclusion and design requirements

Sankana Dam is not just a convenient and close location. It is the site that makes the pilot possible in the short term within Vitara's vision, the only factor in the system that is hard to work around if wrong. This directly answers DR5 – site and landscape select and design sites based on the hydrological context, and make the nursery work with the local landscape.

Facts about Sankana (E8)

1961 – year built as an irrigation reservoir
20% – percentage of current irrigation capacity used by other farmers
0.8 ha – already confirmed farmland available near land for pilot

Figure 42: Tamale Dam (Google Earth, 2026)

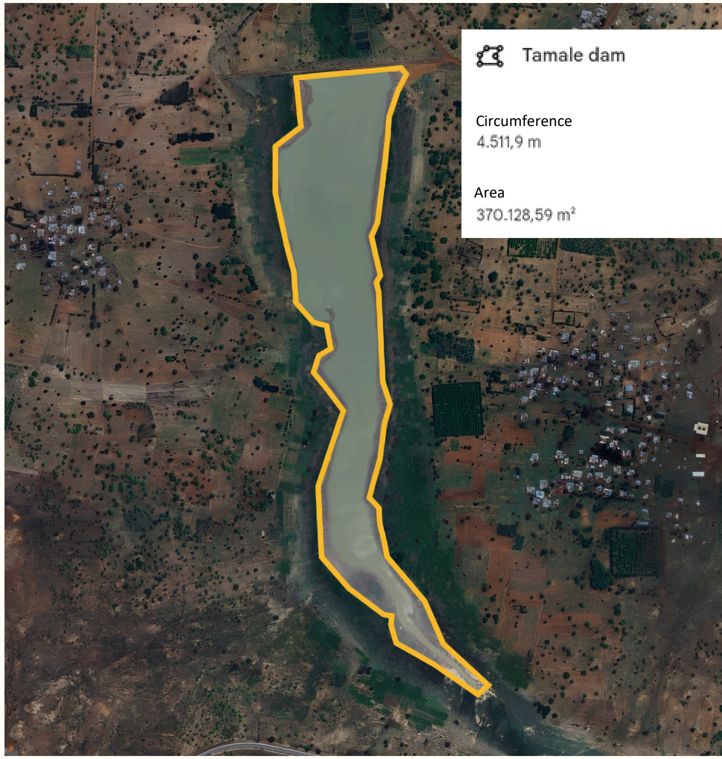


Figure 43: Sankana Dam (Google Earth, 2026)

Figure 44
Opening to the dam, picture by author

Figure 45
Sankana nursery, picture by author

Field visits take-aways (E12)

The left shows the water supply from the Sankana Dam, which is opened manually with a metal pole, without fixed schedules. The right shows the nursery during the dry season (March), with healthy seedlings continuing to grow despite the breakage of former shade structures. This shows the strong potential of the location through its stable water availability.

The current systems at Sankana still depend heavily on manual water distribution, resulting in high water losses. The toolkit builds further on the strengths of the site through solar-powered, gravity-fed irrigation and a more inclusive and efficient operational setup.

THE WHO

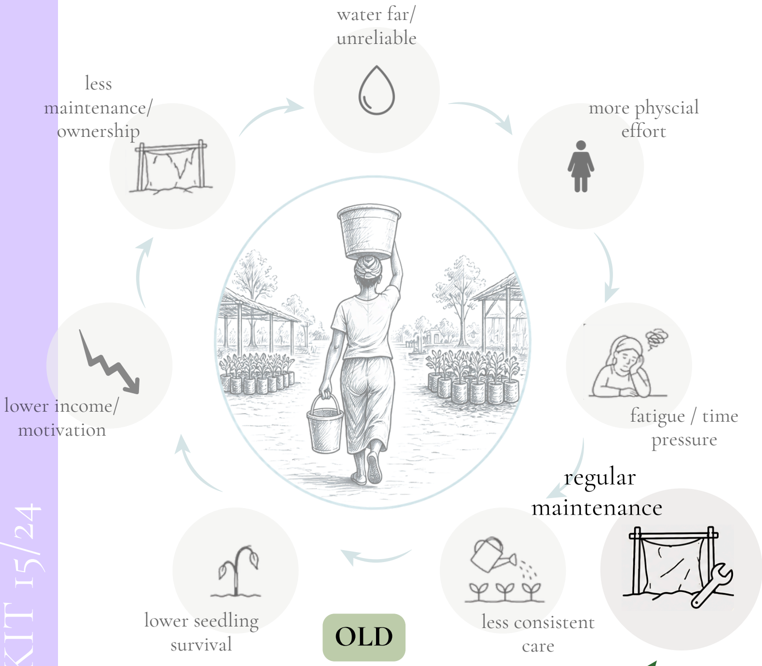
THE TOOLKIT

5.5

A SYSTEM BUILT FOR THE PEOPLE WHO SHOW UP EVERY DAY

Figure 46
Farmer near Wa (Vitara, 2026)

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.



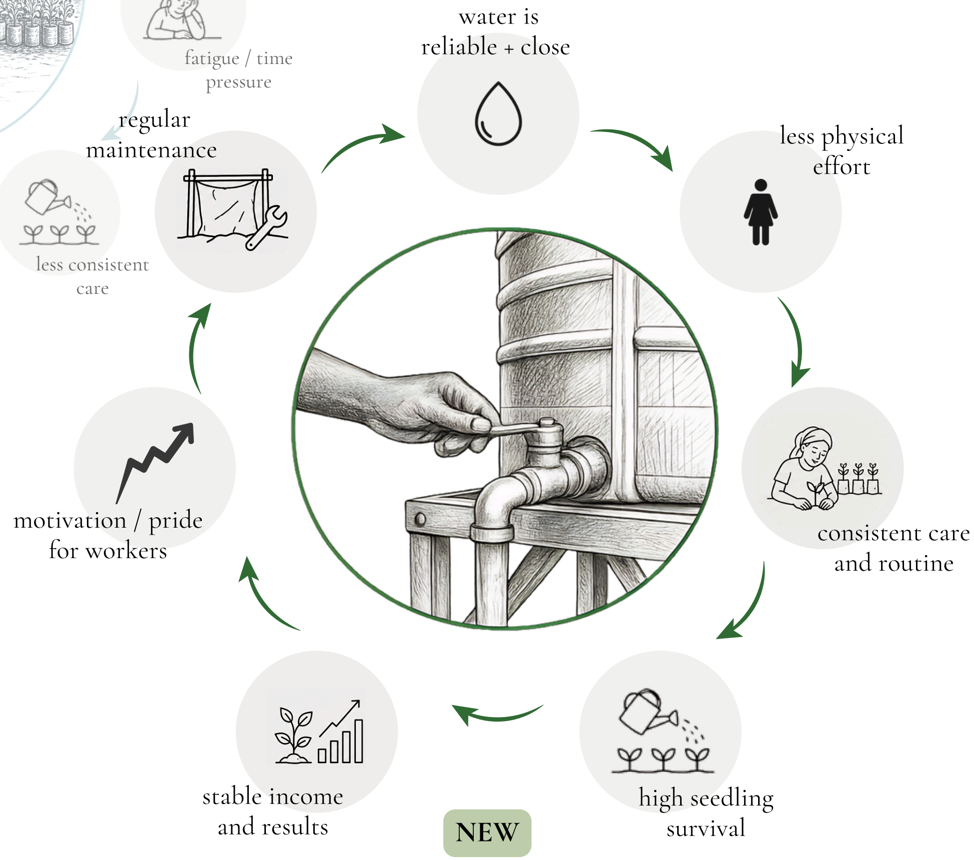


Figure 47
Nursery Cascade Model, visual by author

WOMEN'S WORK

Designing with responsiblility in mind

Historically, women in Northern Ghana have been the backbone of daily nursery operations. They manage irrigation routines, cleanup and seedling monitoring. At the same time, they carry responsibility beyond the nursery: childcare, household and community roles.

The nursery design acknowledges this. A shaded space nearby allows children to remain close during working days. Scheduling is built to share responsibilities so the nursery and children are cared for throughout the day.

To design for these women is to design for their whole lives, not only during working hours.

NURSERY MODEL

Vitara-owned nursery

This nursery is Vitara-owned, staffed by trained, paid workers, and under direct management, with shared responsibility for quality and maintenance. This is a deliberate step away from community nursery models, which often lack the oversight, quality control, and accountability needed to ensure consistent seedling output.

When workers are fairly paid, the workload is manageable, and the system they use actually works. Motivation becomes the norm, and not the exception.

MAINTENANCE AND ROLES

It takes just four people to operate a module nursery.

The structure lets the nursery run predictably. Water, plants, and management are handled in parallel, reducing delays and preventing small problems from becoming failures.

When the nursery scales, the model repeats. For a 312,000-scale nursery, which is twelve modules, two or three technicians, two keepers, and four coordinators can sustain it. Numbers can be adjusted after the pilot, based on actual workload and worker feedback.

By keeping the roles consistent and modular, the system grows without increasing its complexity, only its capacity.

Figure 48
Farmer holding Shea (Vitara, 2026)

Figure 49
The team, visual by author

THE TEAM

TECHNICIAN

Keeps water flowing

Main Role
High knowledge of technical power. Operates the solar pump, cleans filters, and maintains irrigation systems. Knows quick fixes and repairs, and which parts to operate.

Main Tasks

- Operate the solar pump and polytank
- Clean filters and check pressure
- Inspect and repair pipes, valves, and fittings
- Fix leaks and do quick repairs (tape and tools)
- Replace worn parts when needed

Acts when
Flow drops, leaks occur, system fails, or parts need repair

KEEPER

Protects plant health

Main Role
High knowledge of plant health. Knows when plants are healthy or diseased. Monitors the moisture level of the plants.

Main Tasks

- Daily monitor seedling health
- Check the moisture of the growing media
- Spot, disease, pests and nutrient issues
- Ensure even growth and healthy leaves
- Report problems early

Acts when
Plants show signs of stress, disease, pests, or uneven growth.

COORDINATOR

Gets everyone organized

Main Role
A pair of hands in the nursery. Helps with daily tasks, oversees operations and communicates between the team.

Main Tasks

- Help with daily nursery work.
- Open/close valves and check distribution.
- Communicate between team members.
- Keep the work area safe and organised.
- Can keep children safe/in the shadow.
- Contact point with the community.

Acts when
Tasks are delayed, support is needed, or communication is required.

VITARA CONSERVATION AGENT

Link between field and office

Main Role
Visits the nursery from office. Contact person between the nursery and management. File maintenance request + up to date on the current state.

Main Tasks

- Visit the nursery and assess the overall status.
- Record observations and performance.
- File maintenance requests and follow up.
- Categorise and prioritise issues.
- Report status to management.

Acts when
Issues exceed local capacity, major repairs are required, or system improvements are needed.

5.5 WHO: FOUR ROLES IN ONE NURSERY

This chapter explains how labour, water access, and organisational structure influence nursery performance during the dry season and why the people operating the system need to be included in the design.

Quantifying the change

Focus group discussions with 20+ workers across Tamale and Wa showed that water access ranked first as the highest daily priority; heavy lifting was the most physically exhausting nursery task. Further, workers preferred multiple distributed water points over one central collection point, and children were observed present during working hours, especially for women between 18 and 35, revealing how childcare and nursery work are fully intertwined in daily operations (Focus group, Wa, February 2026). Manually watering a 25,000-seedling nursery requires roughly 3 tonnes of water. With a 15-minute walk to the water source and a 20 L carrying capacity per trip, this process demands a team of five for 7 hours of repetitive physical work per irrigation event. (Bardasi & Wodon, 2010). The gravity-fed system eliminates this. A worker opens a valve at dawn. Labour shifts from carrying water to other activities like monitoring, grafting, and maintaining a system that works predictably.

Four roles

In most community nurseries observed during fieldwork, all tasks fall to the same workers simultaneously. As dry-season workload peaks, maintenance becomes reactive, and problems go undetected. The four-role structure distributes responsibility so failures stay visible, local, and fixable before they affect the whole module (E7, E8). Workers are paid fair wages, covered by SSNIT social insurance at 13% employer contribution, and operate within defined task loads. A nursery with exhausted, informally employed workers does not produce consistent seedlings regardless of infrastructure quality (FAO, 2008).

The entire interview with these experts, including the gender expert, can be found in Appendix E.

Designing for daily realities

The childcare space is integrated into the nursery layout, under an elevated polytank. It requires a one-time setup of around $500. It should not be complex: shade, water access, and basic safety create improvements for both worker well-being and operational stability. Bardasi and Wodon (2010) describe the broader challenge as "time poverty", the chronic shortage of available time caused by overlapping labour duties, disproportionately carried by women. Ignoring these needs is not an option: without a dedicated space, children end up in unsafe, exposed conditions, and women face a choice between showing up to work and caring for their children. The design addresses this because childcare and nursery work are intertwined in daily life, and a nursery that does not acknowledge that is not sustainable in that sense.

Conclusion with design requirements

DR4 – labour and gender requires the system to reduce physical workload and include their daily realities. DR6 – modular scaling requires that the structure repeat rather than become more complex as the nursery scales. Both are met here: the four-role model is manageable. A system that works for the people running it is the only system that scales and aligns with Vitara's core values.

VITARA (2026) CORE VALUES

consistent quality	full traceability	verified impact
Standardised collection ensures premium quality	Full traceability from farm to export	Sustainability data powered by TreeSyt

Reliable nursery work starts with supporting daily realities

Figure 50
Farmer with child, picture by author)

Figure 51, 52 and 53
The focus group discussion and co-creation, pictures by author

Focus Group Discussion and Co-Creation (E4)

The image on the left shows the interactive cards used to facilitate conversation, with the help of a Vitara conservation agent for translation. In this way, the priorities and challenges within the community nurseries were mapped.

The session ended with a co-creation exercise, where the workers brainstormed about the ideal nursery layout. As can be seen, water access (top right) was ranked number one, a consistent answer with all workers. The complete setup is in Appendix C.

The nursery follows a structured maintenance cycle. Tasks are scheduled over intervals to balance reliability and durability. Each role supports water flow, plant health, and infrastructure integrity. Every cycle end with data collection.

DAILY	EVERY 3 DAYS	WEEKLY	MONTHLY	YEARLY
Keep the system running	Keep water clean + running	Update system for good condition	Deep clean and inspect	Maintain, improve and plan ahead
Check water level in polytank Ensure enough water in tank → otherwise fill with solar pump	**Irrigate** Open valve and ensure water is flowing everywhere	**Clean tank inlet/outlet** Remove any dirt or debris	**Check inside Polytank** Clean and scrub if needed	**Inspect and repair infrastructure** Check tank stand, pipes, supports. Repair or reinforce.
Check for leakages / broken parts Ensure enough water in tank → otherwise fill with solar pump	**Check outlets** Inspect a few outlets in each row. Clean if dirty or blocked	**Inspect main lines** Check for leaks, loose joints or wear. Replace if need be.	**Clean filter pump** Deep clean filter screen and housing	**Replace worn parts** Replace old/outdated pipes, valves and fittings on smaller level
Observe plants Check seedling health and moisture content level	**Check media moisture** Ensure moisture is adequate for healthy growth	**Clean tool shed / weeding** Organise and clean tools	**Check irrigation lines** For blockages or algae. Flush if needed.	**System review** Evaluate layout, perforamnce and make improvements
Check flow Walk through rows and ensure water is flowing from outlets → otherwise repair and maintenance	**Clean area** Remove all weeds, fallen leaves and rubbish. Weeds → compots area Trash → thrown away	**Clean and check pump** Clear solar panels of dust, check if gates are still whole	**Checkup with all workers** Updates, feedback, maintenance request	**Team training** Refresher training on operation, maintenance and safety. Big feedback moment.

Figure 54
Maintenance schedule, visual by author

THE WHEN

THE TOOLKIT

5.6

TIMELINE

! start dry season, irrigation becomes more frequent

SET UP
- Gather all materials (BOM)
- Flatten and fence
- Build infrastructure
- Install water system
- Prepare beds and paths
- Train team

PREPARATION
- Source & select seeds
- Prepare soil/media
- Fill polybags (25,000)
- Organise layout
- System check

SOWING
- Sow all seeds
- Start watering
- Ensure uniform germination

ESTABLISHMENT
- Daily watering
- Shade management
- Early weeding
- Replace failures

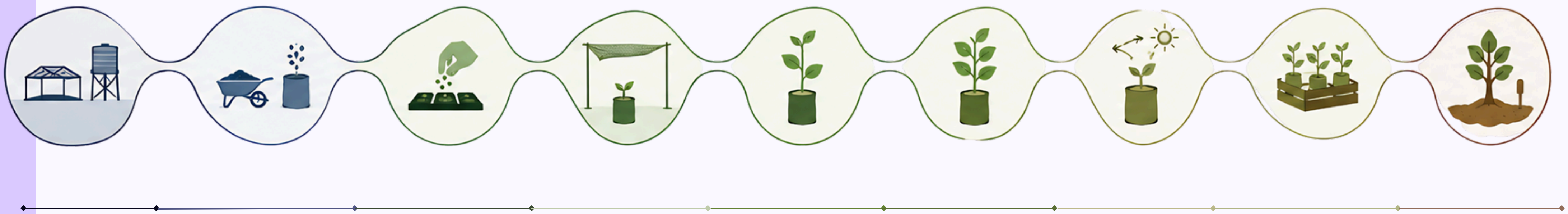
RAPID GROWTH
- Consistent irrigation
- Monitor growth
- Weeding & spacing
- Quality selection

STABLISE
- Maintain growth
- Pest & disease control
- Adjust to rains
- Strengthen seedlings

HARDENING
- Reduce watering
- Increase sun exposure
- Final grading
- Prepare transport

OUTPLANTING
- 25,000 seedlings ready
- Pack & transport plan
- Coordinate with sites & communities

PLANTED
- Plant in the field
- Monitor survival (first 6 months)
- Replace losses
- Collect data & improve



WEEK 1-3 | WEEK 4 | JULY - AUG | SEP-OCT | NOV-MARCH | APRIL | APRIL-MAY | MAY-JUNE | PLANTED

! coordinator gets extra women to help fill and allign polybags

! short term seedlings (mango, cashew) are raised now

Figure 55
Timeline, visual by author

This timeline covers one nursery year for the pilot module, from site setup to outplanting, with 25,000 shea seedlings. The irrigation system is installed and tested within three weeks. Preparation should take several months before pilot launching to have enough time for site preparation, stakeholder alignment and more (Wilkinson et al., 2014). From October, the dry season puts the system under pressure: maintenance workers monitor the gravity-fed setup daily to ensure constant water delivery.

From January to March, short-term seedlings like mango and cashew are raised alongside shea, making full use of the capacity during peak growth. The pilot year is a structured rest of water use survival rates, worker load, and maintenance demand are all tracked, so the decision to scale to module two is based on evidence, not assumption.

5.6 WHEN: ONE NURSERY YEAR AS A PILOT

The implementation timeline reduces risk before scaling. The system is first tested through one operational module under real dry-season conditions, before scaling.

Infrastructure before seedlings

Installing and testing the irrigation system before any polybags are filled means technical failures are found before seedlings depend on the system. This is the most important timeline decision in the pilot year: the best moment to find problems is before they have direct consequences (E4, E8). Field observations showed that workers in community nurseries often had no clear understanding of what growth stage their seedlings were in, or what the outplanting goal was of those seedlings, creating inconsistency and a lack of feeling of ownership about the nursery at the moments when seedlings need growth-stage-specific care. The timeline makes this explicit, and it is encouraged to create a strong overview of the outplanting goal and an average estimation of when seedlings step into the next growing stage. Well-planning can influence the resilience and appearance of the nursery. By making sure seedlings have a clear planting goal, they do not overshoot in the ground, as in Figure X.

Hardening before transplantation

The reduction in irrigation and shade during the final two weeks before transplantation is vital to the seedlings' health. This hardening phase is regularly skipped in community nurseries, but it strongly influences post-transplantation survival rates as it creates stronger roots, more used to the drought, that will establish better in the ground (E9).

Conclusion with design requirements

DR2 – seedling-centred design, DR3 – maintenance simplicity, and DR6 – modular scaling, all come together in the timeline. Irrigation adapts to growth stages, the system is testable and repairable locally, and scaling is based on evidence. The pilot will show the way for future scaling.

Figure 56
Overgrown and degraded nursery, picture by author

THE COSTS

THE TOOLKIT

5.7

COST BREAKDOWN OF ONE MODULE

This section presents a cost breakdown for the pro-posal, detailing all expenses for constructing and operating a pilot module based on Ghanaian supplier prices and local salary rates. Costs are categorised as one-time capital (CAPEX) or annual operating (OPEX) expenses to show the module's total cost.

CAPEX – one time investment

$13,117

to build the full module

irrigation system	$8,662 - 66%
Fencing	$3,212 - 25%
Seedlings + materials	$763 - 6%
Land, shed, shade	$480 - 4%

cost per seedling **$0,52**

OPEX - annual running cost

$5,400

per year to operate the module

Technician *GH¢50/day · 313 days + SSNIT*	$1,574
Keeper *GH¢50/day · 313 days + SSNIT*	$1,574
Coordinator *GH¢50/day · 313 days + SSNIT*	$1,574
materials, transport + contingency	$678

OPEX per seedling/year **$0,22**

Total costs per seedlings over time

Year 1	Year 2
CAPEX $0.52	
OPEX $0.22	OPEX $0.22
$0.74	**$0.22**

From year 2, CAPEX is recovered. The system costs $0.22 / seedling. With 3-year average: $0.39

Exchange rate: 1 GH¢ = $0.089 USD (May 2026) · SSNIT employer contribution 13% · 313 working days/year

HOW THE ECONOMICS IMPROVE WITH SYSTEM SCALE

The pilot serves as a starting point. As the system expands to twelve modules, project managers reduce costs through shared infrastructure, improved fencing geometry, and bulk purchasing. These factors lower unit costs without changing the design. This section outlines how costs change at each stage and shows the financial benefits of scaling early and strategically. The staff does not scale linearly at mid scale; two technicians, three keepers, and one coordinator work, and for full scale, this is upped to three technicians.

Pilot
1 module - 25,000 seedlings

CAPEX $0.52

OPEX $0.22

$0.74
year 1 total per seedling

total CAPEX: $13,117
Annual OPEX: $5,400

Mid Scale
6 modules - 150,000 seedlings

CAPEX $0.37

OPEX $0.07

$0.44
year 1 total per seedling

total CAPEX: $55,000
Annual OPEX: $12,994

Full scale
12 modules - 300,000 seedlings

CAPEX $0.26

OPEX $0.05

$0.31
year 1 total per seedling

total CAPEX: $79,000
Annual OPEX: $19,488

1. **Shared solar pumps**
   At 12 modules only 2 pumps are needed instead of 12, one per 6 modules. Saves ~$18,000 in infrastructure.

2. **Fencing scales with perimeter**
   12× more area = only 3.5× more fence. ~850m less than linear scaling predicts. This saves ~$3,700.

3. **Bulk purchasing discounts**
   300,000 polybags and 43,000m+ of pipe, Ghanaian suppliers offer 10–15% off at these volumes.

Cost per seedling over time

- Pilot - year 1: $0.74
- Pilot - year 2+: $0.22
- Full scale - year 1: $0.31
- Full scale - year 2+: $0.13

At full scale from year 2 onward, each seedling costs just $0.13, that is an 81% reduction from pilot year 1.

The pilot year is the most expensive. Every module added after that makes the system cheaper to run, permanently. A full-scale nursery with this system can cost after two years just $0yes c.13 per seedling.

5.7 COSTS: FINANCIAL RESILIENCE

This chapter explains why the financial model is structured as a long-term investment rather than a single-season cost, and why modularity makes the system increasingly affordable over time.

The investment in the pilot
The first-year cost of $0.70 per seedling includes the infrastructure investment. The full CAPEX of $13,117 covers the irrigation system, fencing, polytank stands, solar pump, pipe network, and seedling materials, split over the first 25,000 seedlings. From year two on, the infrastructure stays, and the cost drops to $0.22 per seedling. Averaged across three years: $0.39. As the toolkit shows, not all parts of the system scale equally, and that is precisely what drives cost reduction. At twelve modules, only two solar pumps are needed instead of twelve, saving approximately $18,000 in infrastructure. Fencing scales with perimeter rather than area: twelve times more enclosed area requires only 3.5 times more fence, saving approximately $3,700. Bulk purchasing of 300,000 polybags and 43,000 metres of pipe attracts 10 to 15% supplier discounts in Ghana. Together, these factors bring the cost per seedling at full scale from year two to $0.13, an 81% reduction from pilot year one, achieved through smart scaling, not through reducing system quality or worker pay (supplier quotes Wa and Tamale, February 2026; E4, E12).

The SSNIT inclusion has benefits for both the workers and Vitara. Formally employed workers are more likely to stay through the full plant year and show up consistently when monitoring is most important (FAO, 2008; E3, E12). Turnover mid-season is one of the most disruptive risks the nursery faces. Stable employment is cheaper in the long run, and far cheaper than a dry season with an undertrained team managing a failing irrigation system (Bardasi & Wodon, 2010).

Any financial surplus from scaling and revenue from the plant year can be reinvested directly: additional modules, fencing structure improvements, expanded water buffer, a maintenance fund, childcare facilities, or additional technician training. The nursery grows not only in production capacity but in the social, technical, and organisational resilience that makes that capacity permanent.

Conclusion with design requirements
DR6 – modular scaling governs the financial logic throughout: scale through repetition, not redesign. Each module added makes the system cheaper to run permanently. At $0.13 per seedling at full scale from year two, it is the calculated result of a system designed to grow incrementally from proven performance. It is the mechanism through which Vitara's restoration ambitions become financially self-sustaining rather than dependent on continuous external funding (Vitara, 2026; E7).

Eliminating Risks with Modularity

A key contribution of this project was identifying that scaling too quickly poses one of the largest risks to Vitara's restoration ambitions. At the scale of 300–500,000 seedlings, failures in water supply, maintenance, or operations affect the entire system.

The project, therefore, proposes a **modular pilot-first strategy**, allowing Vitara to test and strengthen the nursery system step by step before scaling further.

Figure 57
Wa, picture by author

BEYOND IRRIGATION

THE TOOLKIT

5.8

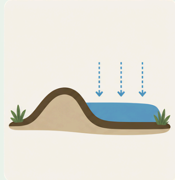
Figure 57
Water bunds (Just Diggit, 2026)

BEYOND IRRIGATION

Irrigation solves the water problem. But a resilient nursery needs more. These complementary interventions are low-cost and locally implementable. Most importantly, proven in real-world contexts and research. With limited investment, real change can be made to communities and the environments around them.

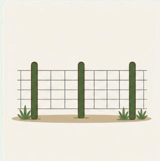
WINDBREAKS

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.



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.



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.

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.

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.

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.

5.8 INTERVENTIONS BEYOND IRRIGATION

This chapter explains why a resilient nursery requires more than irrigation alone, and how six complementary interventions strengthen the system without significantly increasing cost or complexity.

The system beyond the pipes

Together, these six interventions turn a well-designed irrigation system into a resilient nursery. Irrigation solves the water problem, but a nursery operating in the conditions of Northern Ghana faces additional pressures. The six complementary interventions are low-cost, locally implementable, and proven in similar contexts. Instead of working with shade nets, which amounts to a high amount of plastic waste over the years, investing in planting evergreen trees which do not lose leave cover with a wide top, like the fast-growing Neem trees, can act as windbreaks over the years. When planted from day one, they reduce wind velocity across the nursery, limit evaporation from both the polytanks and seedling beds, and provide partial shade, directly reducing dependency on shade nets, which field visits confirmed are the most frequently failing infrastructure component (Asare et al., 2016). Thinking about planting semi-mature plants can accelerate this process.

Waterbunds slow surface runoff and increase soil infiltration during the rainy season, extending the dam's effective storage capacity without any additional infrastructure (E14, E15). Perimeter fencing defines the nursery boundary, protects seedlings from livestock, and creates a clear maintenance zone. Standard low-cost wire fencing with wooden posts is sufficient and locally available, and prevents livestock, such as goats, like in Figure 58, from eating seedlings.

The childcare space, as established by the WHO, is a labour-enabling structure that allows women to work without choosing between their labour duties and their children (E13, February 2026). Recordkeeping through simple logbooks and QR-linked, as observed in Tamale (e6) reports, helps collect the data that helps make a decision for further scaling. It is then based not on an assumption but on evidence (E8, E15). A dedicated maintenance budget helps with quicker fixes without long delays.

Total cost estimation of all six interventions (excluding fencing, already in CAPEX): GH₵5,000–10,000 per pilot year ($450–890), which presents approximately 3.4–6.8% of total pilot CAPEX. The full estimation and breakdown are in Appendix F.

Conclusion with design requirements

DR3 – maintenance simplicity shows that local repairability and low dependency on the budget, and recordkeeping directly enable that. DR4 – labour and gender requires designing for the full reality of the people operating the nursery; the childcare space is the added section of this. DR5 – site and landscape, requires the system to work with the natural landscape rather than against it. Windbreaks and waterbunds extend beyond the irrigation scope to this nursery. Together, these six interventions turn a well-designed irrigation system into a resilient nursery.

Figure 58
Goat in a shaded nursery, picture by author

IRRIGATING TREE NURSERIES

CONCLUSION

Impact does not start with scaling to the biggest possible scale. It starts with one module, one team, and one season of learning what works in the environment in Northern Ghana..

The system in this toolkit shows that a new design of proven technology and lays the start. The site has been selected, the roles are defined, and the costs have been calculated. What remains is the decision to begin.

The pilot year will answer the questions only real operation can answer: how the system performs under Harmattan conditions, what the team needs to sustain it, and what survival rates look like when water is no longer the limiting factor. That data becomes the foundation for everything that follows.

$13,117 – one time pilot investment

25,000 – seedlings, one module, one planting year

$0.13 – per seedlings at full scale, after year 2

Recommendations

1 – **Approve the pilot**, commit to one module at Sankana Dam. The possibility is already on the table for land.

2 – **Track everything** – it is all about data; water use, seedlings survival, maintenance hours, worker feedback. The value is in the data.

3 – **Adjust as we go** – Treat the pilot as a starting point, not a fixed plan. Pipe lengths, staffing and scheduling will need adjust-ments based on real conditions on site.

4 – **Scale on evidence** – do not commit to module two before the pilot year is complete. The economics are compelling, but only if module one works fully.

Realistic note:
This proposal is based on calculations, fieldwork, expert proposals, conversations, and relevant scientific papers. It does not yet contain operational data. The actual cost, survival rates and maintenance will always differ from projections. That is exactly what the pilot is designed to find out, and why it has contingency built into it.

06 VALIDATION

6 — VALIDATION

Goal of this chapter
Throughout the toolkit, the design decisions were compared if they fulfilled the DR. The goal of this chapter is to elaborate on this by providing a summary of the DR while incorporating three expert validation meetings and hydraulic calculations to determine feasibility, viability, and desirability. The toolkit's readability is validated against five external interviewees.

Key takeaways

- Three expert validation interviews highlight that the pilot grafity fed module with the proposed interventions scores on all areas of viability, desirability and feasibility.
- The toolkit is seen as readable and clear through five readings with external interviewees.

6.1 FEASIBILITY

This chapter evaluates the nursery system to determine if it is valid to recommend implementation. This is based on the hydraulic calculations (Appendix D). Three external expert interviews (E16-E18) and five outside participants to validate the readability of the toolkit. Success is assessed across three dimensions on page 29: feasibility, desirability and viability with the six design requirements. Full approach in Appendix E.

Feasibility – can it be built and operated?
Definition: The system must be constructible using locally available materials, operable by a trained team of Vitara and maintainable without external technicians.

This draws on: DR3 – Maintenance simplicity and DR5 – Low-tech systems. DR3 requires that components are finable locally and repairable on-site. DR5 requires that the system operate without continuous pumping, at low or no pressure, with materials that withstand environmental conditions, such as wind. Both are met through the gravity-fed irrigation. The hydraulic calculations in Appendix D confirm that the system layout with a 2.0 m head, 20 mm lateral diameters, and a maximum 30 m lateral length, achieves an emission uniformity of 85 to 98% across all seedlings front and back, at a minimum hydraulic head of 0.872 m.

"With sprayers, you lose 80% to evaporation. With hoses, the force blows everything away. The choice for targeted irrigation is the only method where you actually know what each seedling receives." (E17)

The elevated polytank at 2.0 m provides a 10% safety margin above this minimum and tank height, accounting for low tank levels during extended dry periods. All pipe components, emitters, and fittings are available from suppliers in Ghana, as confirmed by field quotes in Appendix G.

Each microtube costs €0.05 per unit and is replaceable on-site with no specialised tools. The maintenance schedule in the toolkit, daily, every three days, weekly, monthly, and yearly, is designed so that all routine tasks can be completed by the four-role team without external support. E17 confirmed this:

"Drip or targeted irrigation is simply not that expensive; you mainly just need plastic pipes. It is more about the system behind it. (E17)"

E16 confirmed an additional benefit for grafted seedlings:

"For grafting, target irrigation is even better as you don't want the stem to get too wet, or it can break early and hinder the seedling growth." (E16)

Further, it draws on DR6 – modular scaling. It requires the system to be a modular pilot first. Not starting too big, too soon enables clear coordination, improving the feasibility of the project.

"The fact that you work with small modules is commendable — you can go from proven performance rather than from assumption."

Conclusion feasibility
The system is technical feasibile due to its modularity and cost analysis. The hydraulic parameters are validated, components are locally sourceable, and modularity enables a feasible pilot year.

Figure 59
Feasibility to ensure a stable nursery, picture by author

6.2 DESIRABILITY

Desirability — Does it serve the people and seedlings who use it?
Definition: The system must reduce physical labour burden on workers, particularly women who form the operational backbone of nurseries in Northern Ghana, while also carrying childcare and household responsibilities.

It draws on DR2 — Seedling-centred irrigation. DR2 requires that irrigation adapts to the seedling's changing needs across establishment, rapid growth, and hardening phases. This is met through adjustable irrigation frequency, as workers can irrigate every two, three, or seven days, depending on growth stage and weather, while the 0.1 L stays constant. E17 confirmed this approach:

"It is not only about how much water goes to the seedling each time. It is also about the quality of the product that comes out, and that depends on its growing stage. This design tackles that problem through its ability to adapt its irrigation easily."

DR4 — Labour and gender are also included here. DR4 requires that the system eliminate heavy manual lifting, be operable by four workers without specialised training, and integrate the daily realities of women operating the nursery. This is met. The gravity-fed setup eliminates the need to manually carry water, a task that, for a 25,000-seedling nursery, amounts to 25 tonnes of water per irrigation cycle, requiring a team of five for seven hours of repetitive physical labour (Bardasi and Wodon, 2010). A worker opens a valve at dawn. Labour shifts from carrying water to monitoring, grafting, and maintaining a system that works predictably. The four-role structure distributes responsibility so that no single worker carries the full operational burden, which was confirmed by E16:

"With four people, and occasionally some extra hands, it is manageable. The pilot is great for showing its true potential."

The childcare space integrated close to the polytank stand was confirmed as a non-optional labour-enabling infrastructure for the women.

"I've heard of women refusing to show up to work after a few months because of childcare responsibilities. This is a great way to mitigate this" (E18)

DR5 — Site and landscape DR5 requires that the site be selected based on water availability throughout the dry season and that the system works with natural landscape processes rather than against them. Sankana Dam meets all four selection criteria: seasonal water reliability, existing infrastructure, proximity within thirty minutes of Vitara's base in Wa, and governance through an existing Water User Association with local chief acceptance. This showed great potential for desirability for the nursery beyond Vitara for implementation (E10). E18 confirmed the natural shading approach as very desirable for the environment as well:

"Natural shade is a great option over plastic shade nets that need to be replaced constantly."

Desirability Conclusion
The system is highly desirable for Vitara, the seedlings, and the people who will use it. It eliminates the most physically demanding task in daily nursery operations, integrates the realities of women workers, adapts to seedling growth stages, and is rooted in a location confirmed by both field evidence and expert validation as the most reliable water source in the region.

Figure 60
Importance of acceptance of local interventions, picture by author

6.3 VIABILITY

Viability – can it sustain itself over time?
Definition: The system must be financially realistic for Vitara to invest in, with a clear path from pilot to full scale, and without creating dependency on continuous external funding.

This draws on: DR1 – water management as the system core. DR1 requires the system to supply a minimum of 100 ml per seedling per irrigation event, with a coefficient of uniformity of at least 80%, using surface water as the primary source. This is met. The Sankana Dam supply maintains sufficient levels throughout the dry season, with the total pilot nursery demand representing less than 0.5% of the dam's annual irrigation scheme usage. The gravity-fed set-up eliminates fuel dependency while irrigating. Solar pumping replaces a fuel cost of approximately $700 per year for two acres, with a breakeven point of 8 to 14 months and near-zero running costs thereafter.

E16 confirmed that water management as the system's foundation is the right priority:

"A nursery that focuses on water management has its priorities in order and will enhance its working resilience."

This is also shown with DR6 – modular scaling (with finance). The financial model confirms the viability logic. At pilot scale, the first-year cost is $0.74 per seedling, covering the full $13,117 CAPEX across 25,000 seedlings. From year two, CAPEX is recovered, and the cost drops to $0.22 per seedling.

At full scale of twelve modules from year two onward, each seedling costs $0.13, an 81% reduction achieved through three mechanisms: shared solar pumps across modules saving approximately $18,000 in infrastructure, fencing that scales with perimeter rather than area saving approximately $3,700, and bulk purchasing of 300,000 polybags and 43,000 metres of pipe attracting 10 to 15% supplier discounts.

E17 confirmed the investment logic:

"That is the beauty of your project — you can start small, and once that is successful, you can expand. You never over-invest and suddenly everything is lost."

The SSNIT social insurance inclusion at 13% employer contribution stabilises the workforce through the full eleven-month growing season, reducing mid-season turnover, which field observations indicated as an operational risk.

Viability Conclusion
The system is financially viable. The pilot investment of $13,117 is recoverable within the first production season. The pilot year is designed to provide the go/no-go data for module two. The access to the dam provides a stable water supply, which ensures the viability of the nursery.

Toolkit:
Five external people reviewed the toolkit and were asked to explain its contents and structure without explanation. Participants consistently interpreted the toolkit as clear, logical, and well-structured. The intended flow of information was understood without additional guidance, suggesting that the toolkit effectively communicates its purpose and implementation process, found in Appendix E.

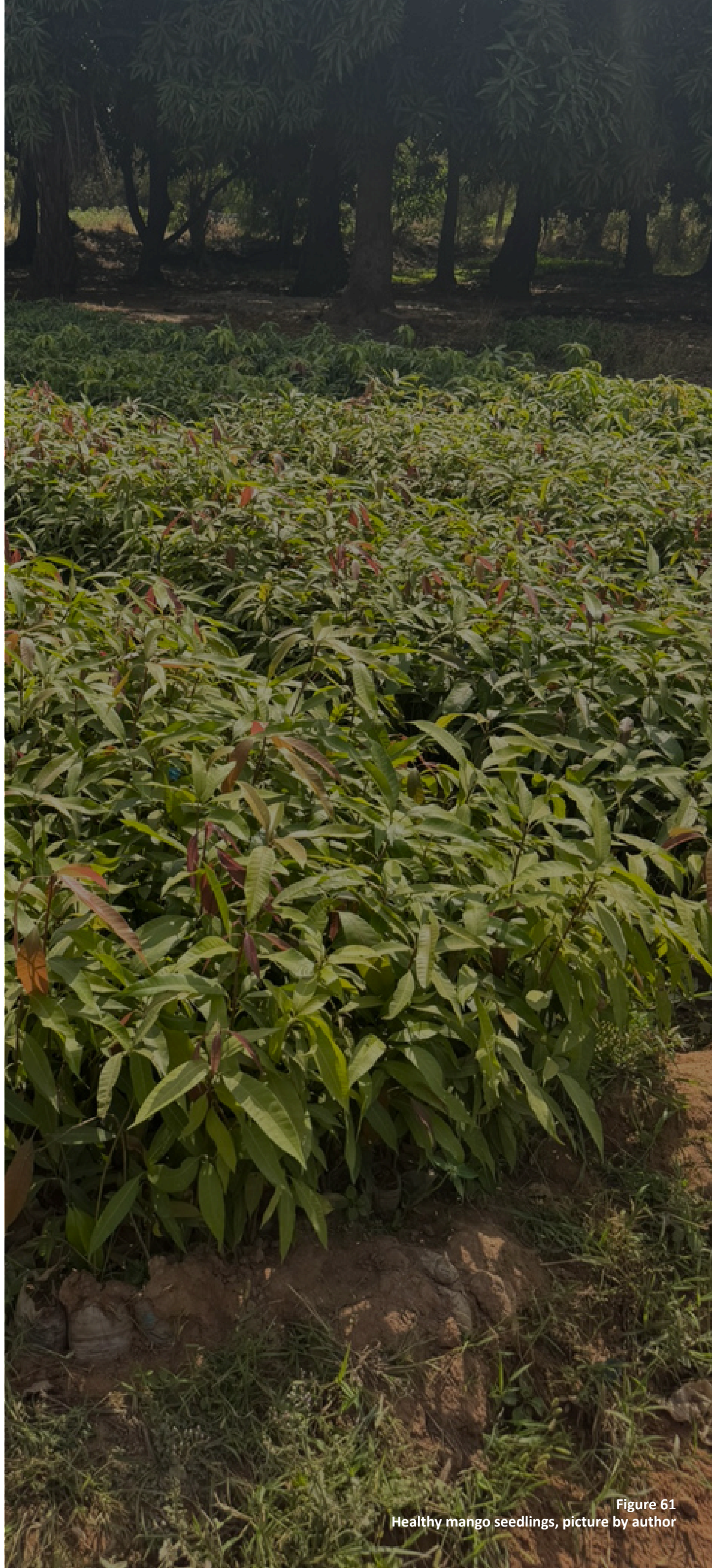


Figure 61
Healthy mango seedlings, picture by author

07 CONCLUSION

7 – CONCLUSION AND REFLECTION

Goal of this chapter
The goal of the chapter is to conclude all the findings from the thesis and recommendations for Vitara to implement the toolkit and beyond. It touches upon the limitations acknowledged in this thesis. It ends the project with a final reflection on the process and development as a designer.

Key takeaways

- The research questions are answered through the graphical fed approach in the form of a toolkit.
- The project has importance beyond the domain of nurseries for Vitara, and can be extremely relevant for similar projects in similar arid regions where water management is a core problem.
- It is recommended to start as soon as possible, and collect all the data from the pilot year to after scale, based on evidence, not assumptions.

7.1 CONCLUSION

This thesis investigated how nursery performance in Northern Ghana can be improved through a gravity-fed irrigation system and accompanying implementation toolkit. Through field research, expert interviews, observations, participatory mapping sessions, and technical validation, the research demonstrated that the primary challenge affecting nursery performance is not an absolute lack of water, but the ability to access, store, distribute, and manage water reliably throughout the dry season.

The findings showed that water availability influences far more than seedling growth alone. When irrigation becomes unreliable, labour demands increase, worker motivation decreases, nursery maintenance deteriorates, and seedling survival declines. This also means that improving water management creates benefits across technical, operational, social, and environmental dimensions simultaneously.

The answer to the research questions and the design goal, is this toolkit with a gravity-fed irrigation system. The resulting toolkit translates these findings into a practical design centred around a modular gravity-fed irrigation system, phased scaling, clear organisation, and water management that suits different seedling growth stages. All while keeping the local needs of the workers in mind.

Relevance for Vitara

The findings suggest that future nursery development should prioritise reliable water management before expanding production capacity. By reducing dependence on manual water transport and introducing a modular irrigation system, Vitara can increase production while reducing labour intensity and operational risk.

The pilot-first approach also provides a mechanism for testing assumptions before significant investments are made. Rather than committing immediately to a nursery capable of producing hundreds of thousands of seedlings, the proposed pilot creates opportunities for learning and adaptation before scaling.

Relevance Beyond Vitara

Although developed for Vitara, the toolkit addresses challenges commonly encountered by nurseries operating within dry climates. The Nursery Cascade Modules are applicable in areas where they face similar environmental and cultural challenges. The principles of modularity, gravity-fed irrigation, local maintenance capacity, and phased implementation may therefore be relevant for similar restoration programmes across Northern Ghana and other semi-arid regions.

Contributions

Practical Contribution

The primary contribution of this research is the development of a practical implementation toolkit that translates research findings into actionable design decisions. Rather than producing a design alone, the project provides the specifications, implementation guidance, organisational structures, costing models, and scaling criteria.

Scientific Contribution

The research contributes to existing knowledge by demonstrating that nursery performance is strongly influenced by water management systems rather than water availability alone. It further highlights the importance of integrating technical, organisational, and social factors when designing restoration infrastructure.

Figure 62
Baby goat, picture by author

7.2 RECOMMENDATIONS

Limitations

Several limitations should be acknowledged. First, the proposed system has been technically validated but has not yet been implemented at full pilot scale. This means long-term performance data regarding maintenance requirements, labour reductions, and seedling survival are not yet available.

Second, much of the field research was conducted within a limited number of nurseries in Northern Ghana. Although recurring patterns were identified, local conditions may vary between regions and organisations.

Third, financial calculations are based on current supplier quotations and assumptions regarding labour and operational costs. These values may change over time due to inflation, market fluctuations, and local availability.

Finally, ecological outcomes such as a complete business case, long-term survival after outplanting, fall outside the timeframe of this graduation project and therefore remain to be validated in future implementation phases.

Recommendations

Based on the findings, several recommendations are proposed:

- Implement the pilot module before pursuing large-scale expansion.
- Monitor water consumption, maintenance requirements, labour inputs, and seedling quality throughout the pilot year. Data is the key.
- Develop clear maintenance responsibilities for pumps, storage tanks, and irrigation infrastructure.
- Continue exploring opportunities for rainwater harvesting and additional water storage.
- Expand species diversity alongside shea production where possible.
- Use pilot results to refine future scaling decisions.
- Facilitate conversation with local women workers to understand the needs even better.

Future Research

Future research should focus on evaluating the performance of the pilot after implementation. Particular attention should be given to:

- Seedling survival rates after outplanting.
- Labour reductions achieved through the irrigation system.
- Long-term maintenance requirements.
- Economic performance over multiple growing seasons.
- Adaptability of the system to different species.
- Integration of rainwater harvesting systems.
- Scaling from 25,000 seedlings towards Vitara's long-term production ambitions.

Figure 63
Co-creations session, picture by author

7.3 FINAL REFLECTION

This project taught me that reality is often very different from what you expect at the start of a design process. I initially focused on improving nursery infrastructure and shade provision, but through fieldwork in Ghana, I discovered that water management was the underlying challenge influencing almost every aspect of nursery performance. Learning to let go of my initial assumptions and follow the evidence became one of the most important lessons of this project.

I also learned the value of combining technical analysis with direct stakeholder engagement. Some of the most influential decisions were not made through conversations with nursery workers, field observations, and visits to existing nurseries. These experiences reminded me that good design requires understanding the people and context behind the problem. The visit to Ghana was fundamental for the reasoning behind the design.

At times, I found it challenging to balance the scope of the project. The topic touches on water, ecology, restoration, agriculture, social organisation, and engineering. Accepting that I could not solve every challenge and instead focusing on the area where I could create the most impact was an important learning experience.

Looking back, I am proud that the outcome is not just a concept, but a practical toolkit that can be implemented and tested. More importantly, this project confirmed my interest in working on challenges where technical design, sustainability, and social impact come together.

Figure 64
Wa at sunset, picture by author

IRRIGATING TREE NURSERIES IN NORTHERN GHANA

Vera Dubbink · MSc Integrated Product Design
Delft University of Technology · 2026

In collaboration with Vitara LTD.
Supervisors: Prof. Dr. Ir. J.C. Diehl · Ir. W. Schermer

"Ziena a teɛ nang gɔŋ gaa be ka a teɛ na le gaa" —

Where the branches of a tree bend towards, it is in that direction that the tree will eventually fall. The care given in the beginning determines what something eventually becomes.

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