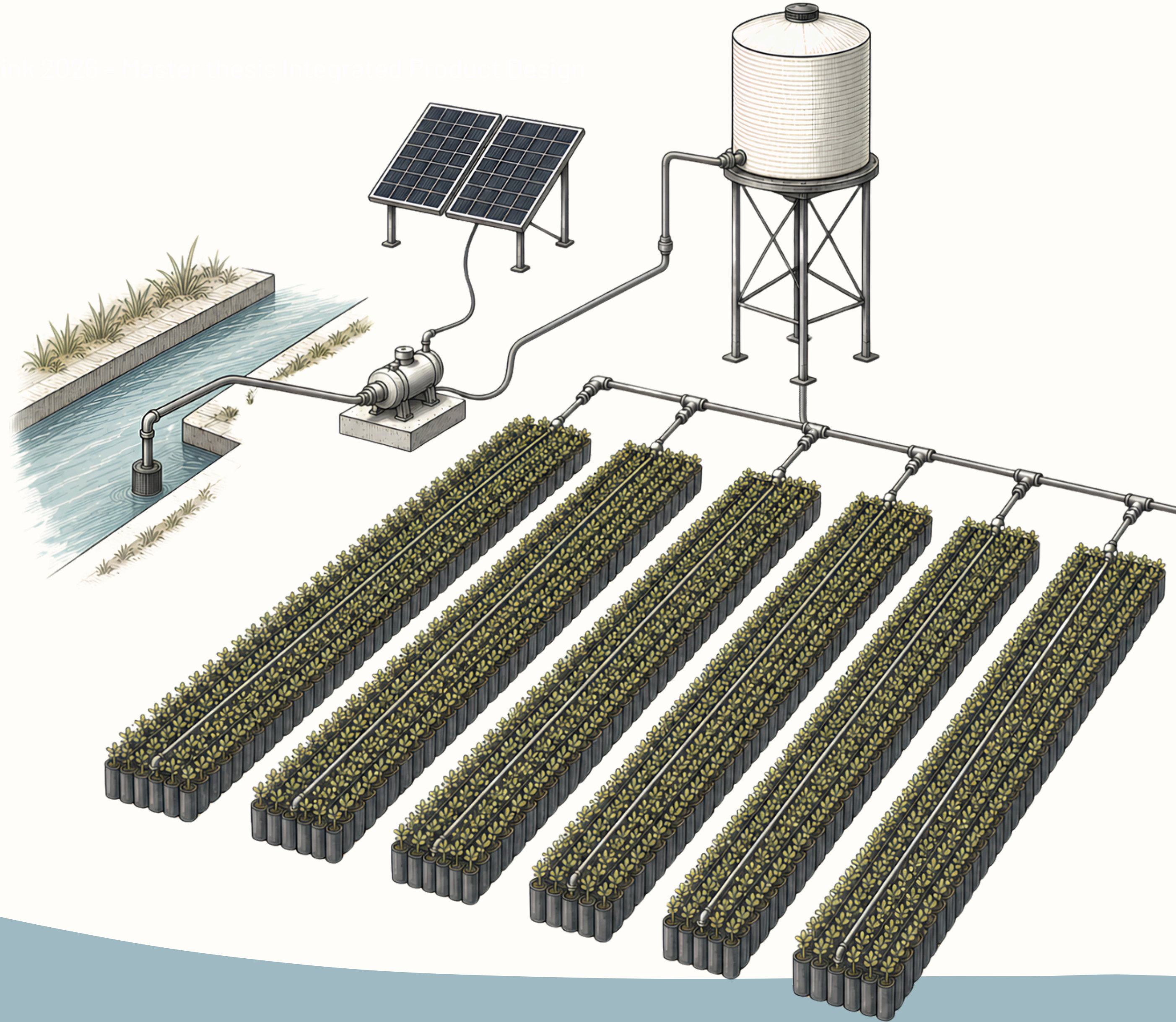
VITARA

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

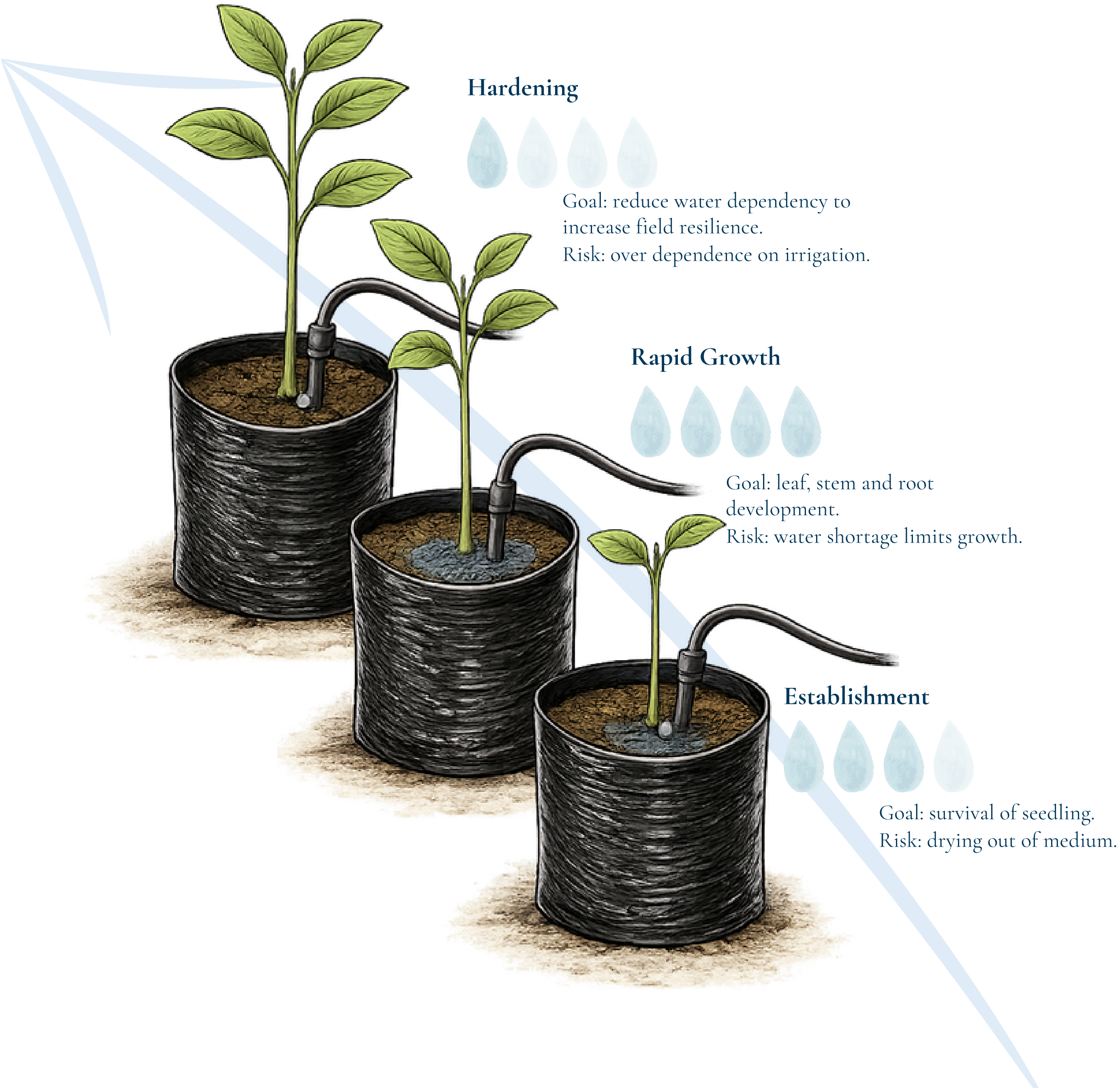
THE PLANT AT A GLANCE

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).



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

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

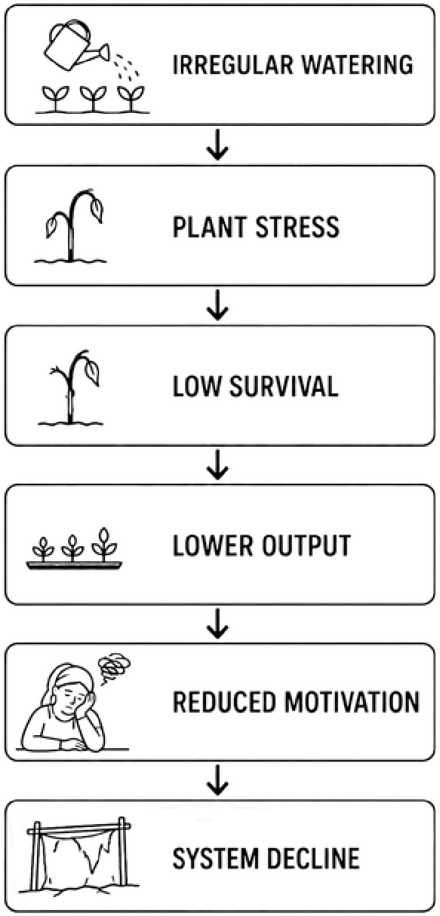
This toolkit guides Vitara through the setup of a gravity-fed nursery pilot in Northern Ghana. It covers the context, system design, team structure, main-tenance routines, and costs. Each section builds on the last. Read it through once, then use it as a reference during implementation.

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



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.

why

THE MISSION

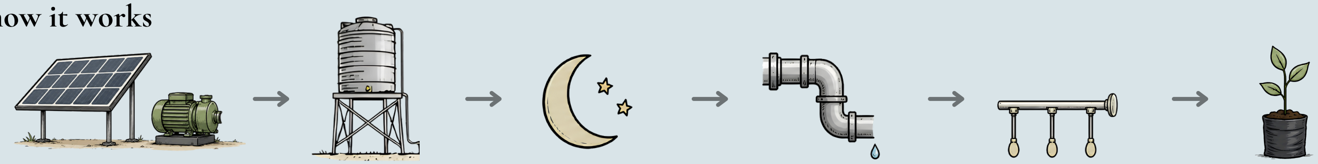
the mission

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

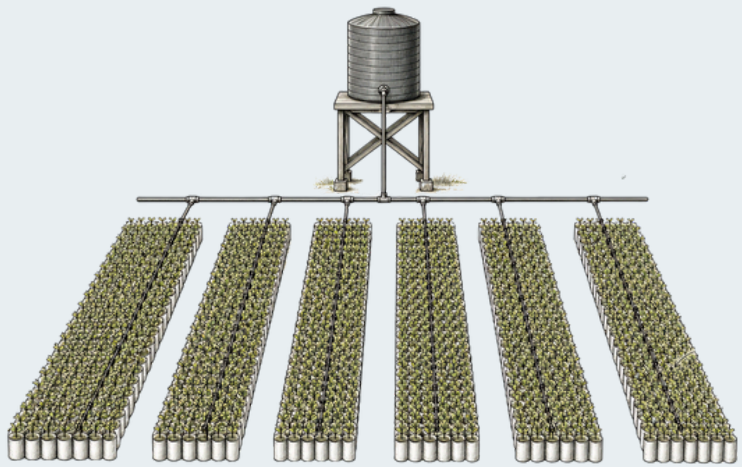
0.1 L	3000 L	>85%	4	25,000	820 m^2
per seedling per 3 days	water storage per module (buffer)	seedling survival after 1 plant year	farmers/technicians can operate the module	seedlings per module	per module, and scalable

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

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.

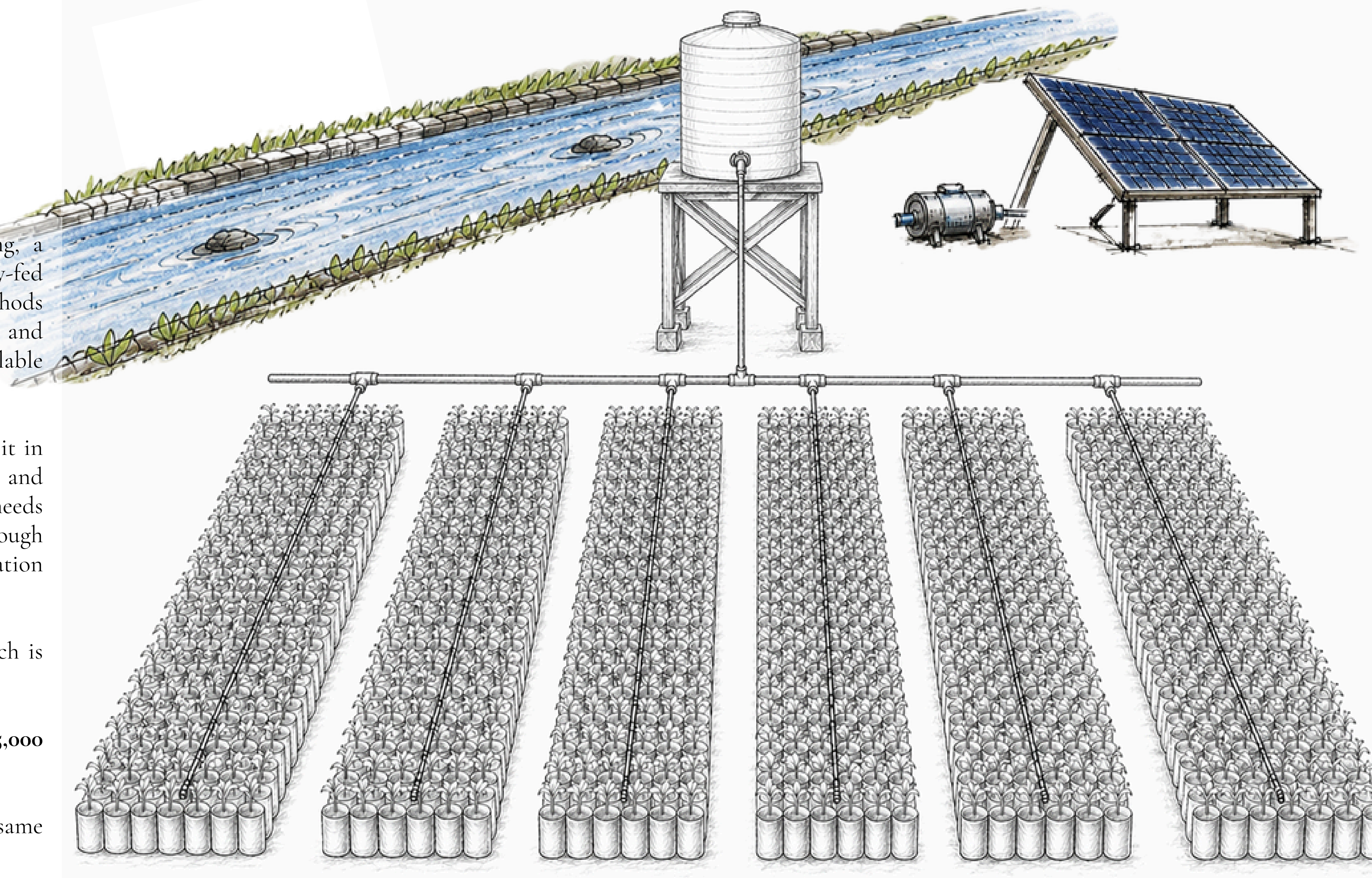
A solar pump extracts water from the dam and stores it in the polytanks. At night, the worker opens a valve, and gravity distributes the water. The nightly irrigation needs minimal labour and lowers evapotranspiration. Through target emitters, each seedling receives 0.1 L per irrigation event.

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).

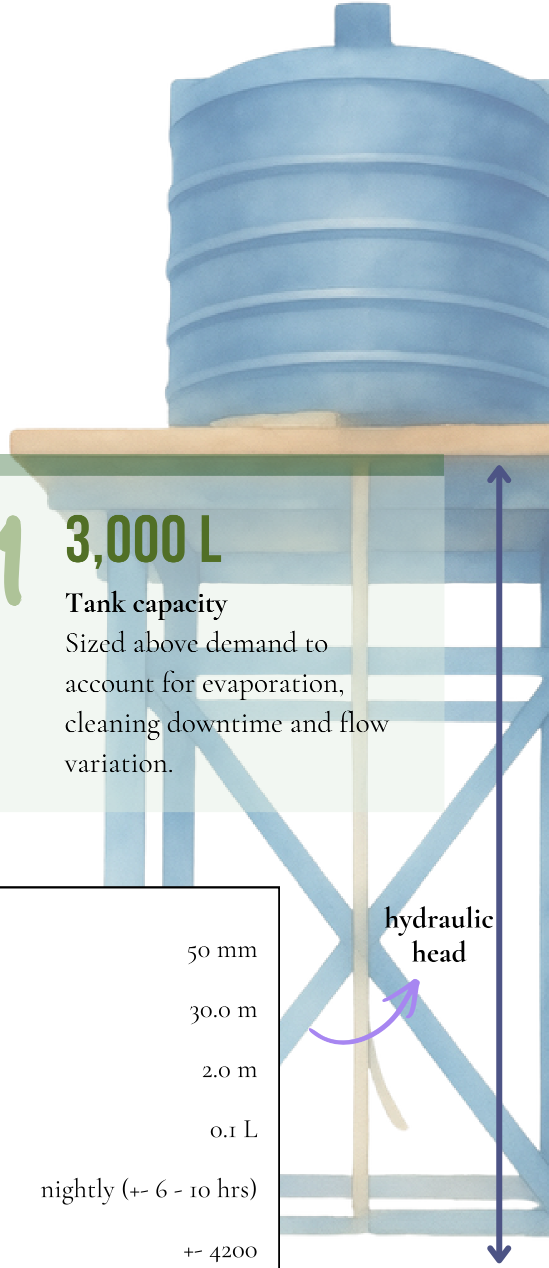


*drawing to simulate the layout. Each row would have +-4200 seedlings.

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.

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.

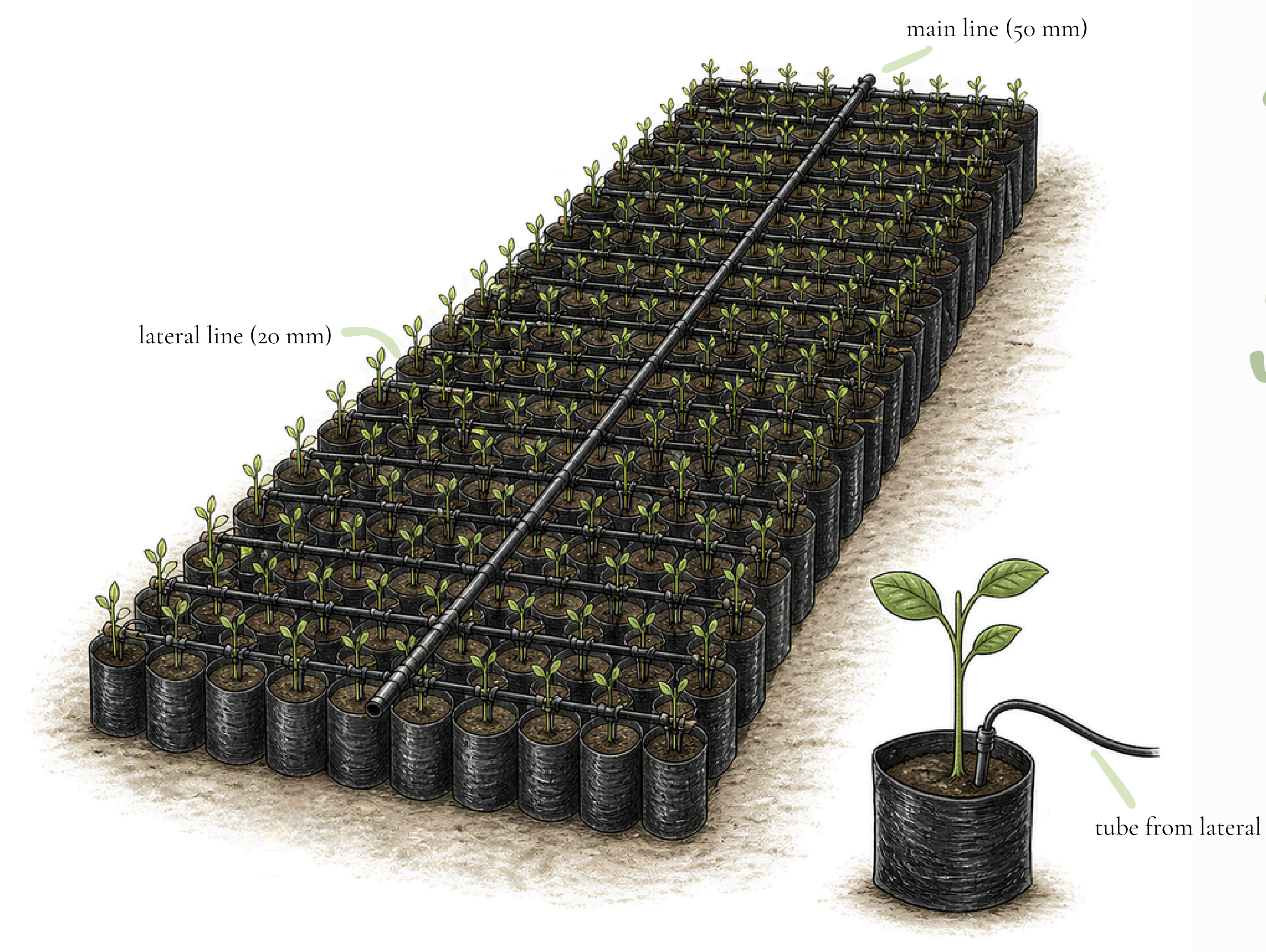
Why low-pressure systems work

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

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.

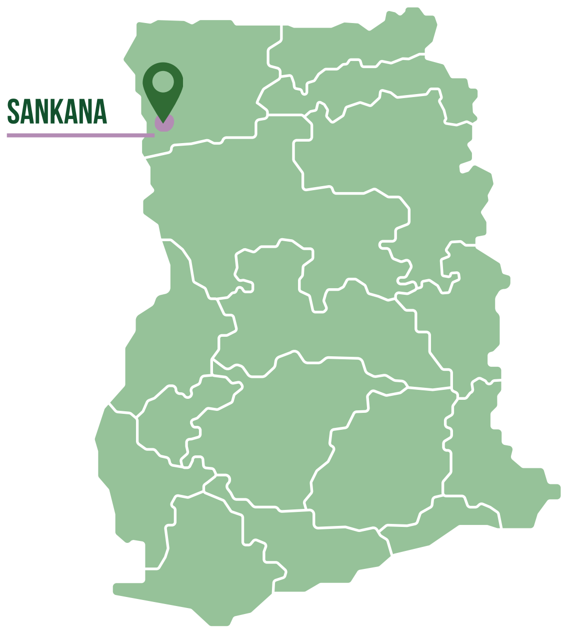
2 **MICROTUBE**

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.


10°11'08.35"N 2°36'13.68"W


SANKANA

where

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 not manual, then water extraction is very strenuous), and 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, enough to meet part of 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.

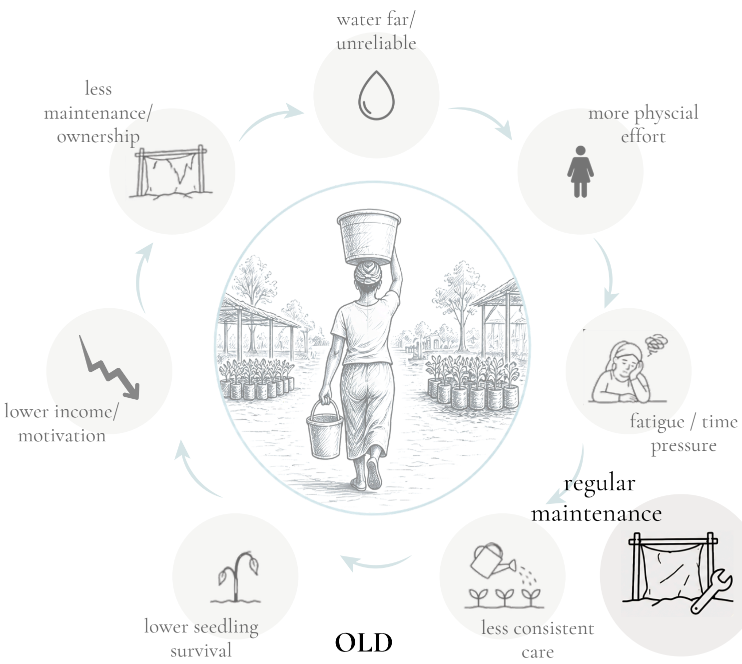
3 WHY NORTH GHANA

and why nurseries work different here

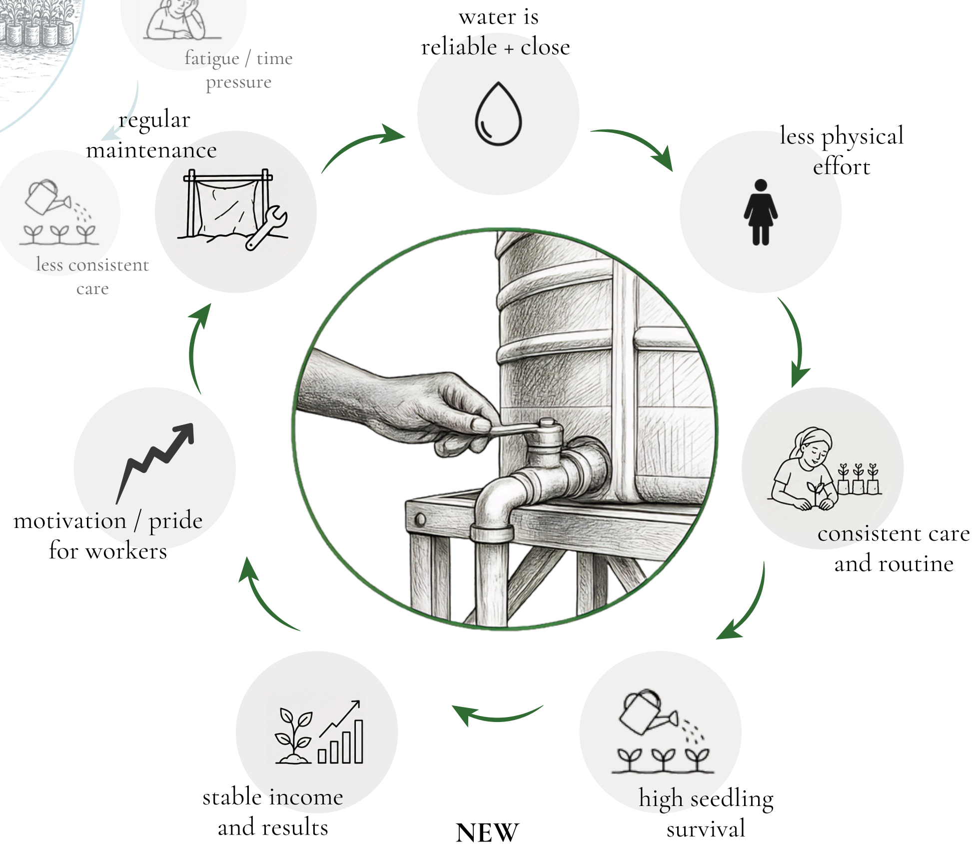
Unlike the south, the Upper West region has a single rainy season, followed by 6-7 months of a dry season, high temperatures, and Harmattan winds, conditions that stress both plants and workers.

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


A SYSTEM BUILT FOR THE
PEOPLE WHO SHOW UP
EVERY DAY



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.



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, two or three technicians, two keepers, and four coordinators can sustain it. Numbers can be adjusted after the pilot, based on actual work-load and worker feedback.

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

who

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.

how

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.

when

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

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.

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

CAPEX $0.52

OPEX $0.22

$0.74

Year 1

OPEX $0.22

$0.22

Year 2

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 costs

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

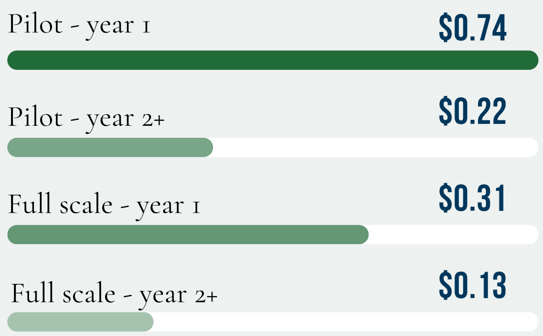
total CAPEX: $79,000
Annual OPEX: $19,488

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



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.

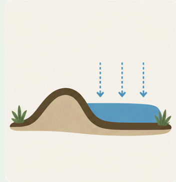
how

BEYOND THE NURSERY

Irrigation solves the water problem. But a resilient nursery needs more. These complementary interven-tions 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 environments around.

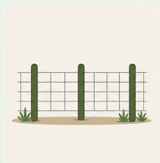
WINDBREAKS

Fast-growing, locally adapted trees, like the Neem, planted from day one. Reduces Har-mattan 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

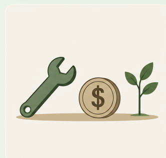
Defines and protects the nursery from animals and external disturbance. Creates a clear maintenance boundary. Low-cost wire fencing with wooden posts is standard and effective in this context.

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.

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.