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FEASIBILITY STUDY - RUBEN CENTRE DEMO UNIT

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Feasibility study of the best CEA system for school feeding in Mukuru informal settlement, Nairobi

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LIST OF ACRONYMS

AMT	Akiba Mashinani Trust
Capex	Capital expenditure
CEA	Controlled Environment Agriculture
DWC	Deep Water Culture
KES	Kenyan Shilling
kg	Kilograms
m	Metres
m^2	Square metres
mcg	Micrograms
mg	Milligrams
MIF	Miramar International Foundation
Na	Sodium
NFT	Nutrient Film Technique
Opex	Operational expenditure
RE	Retinal equivalent
TDS	Trough Drip System
ToTs	Trainer of Trainers
UPA	Urban and Peri-Urban Agriculture
YFC	Young Framers Club

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1. INTRODUCTION

Where Urban and Peri-urban Agriculture (UPA) has faced several challenges posed by climate change and scarcity of resources such as diminishing agricultural land, labour shortage, lack of access to water and environmental contamination (Padgham et al., 2015), we explore Controlled Environment Agriculture (CEA) in offering a potential solution for supplementing vegetable production in informal settlements. In Nairobi, about 60 % of the population lives in informal settlements (Pinchoff, et al., 2021; Mukuru Promotion Centre, 2022). Mukuru, one of the informal settlements in Nairobi, was identified for this action research. Mukuru informal settlement consists of approximately 30 villages (Mukuru Promotion Centre, 2022) and is home to an estimated 300,000 people (UC Berkeley et al., 2017).

Informal settlements within Nairobi County face frequent displacements, the threat being development induced (Weru et al., 2015). Mukuru faces frequent evictions that results in the displacement of numerous families. Amidst recovering from the Covid-19 pandemic and having nowhere to call home, displaced communities coped through communal support initiatives such as community kitchens that provided food to the displaced and homeless people (Okem et al., 2022). This is where community-based cooking is designed, resources and labour are pooled to accumulate food which is centrally cooked and served to the community (Griebel et al., 2022). In settings such as these, where many vulnerable groups leverage on communal spaces such as schools, resource centres, community kitchens and multipurpose centres, CEA systems provide an opportunity to build food and nutritional security and enhance resilience.

The research team identified a central site in Mukuru where a demonstration unit was set up. Ruben Centre is in the heart of Mukuru informal settlement. The centre is run by the Christian Brothers-African Province and is a source of 27 community development programmes to the residents of Mukuru informal settlements (Ruben Centre, 2023). It hosts a public primary school, a health centre, a maternity ward, and a vocational training hub. The centre also has designated sections used for local functions such as community engagement meetings. Ruben Primary is a public school sponsored by the Christian Brothers of Australia. The school has a population of approximately 3,200 learners (Ruben Centre, 2023).

In Kenya, only 20 % of students receive a school meal, compared to an average of 50 % worldwide. Furthermore, 60 % of the learners do not receive adequate nutrition which has a significant negative impact on their development giving rise to an undernourished population with a suppressed academic potential (Nairobi School Feeding Programme, 2022). A report by the Strathmore University 'Centre for Research in Education' in collaboration with Muungano Akiba Mashinani Trust (AMT) on school feeding programmes in Mukuru, showed that out of 112 schools analysed, only 68 had school feeding programmes for pupils (AMT, 2022). The meals offered by the school feeding programs comprised of different combinations of food for breakfast and/or lunch. According to the report, most of the schools with school feeding programmes do not provide a balanced diet meal and only 30.4 % provided a meal rich in carbohydrates, proteins, and vitamins (AMT, 2022). These findings demonstrate the need to offer alternative sources of nutrients to narrow nutritional gaps in schools.

At Ruben primary, nursery to grade four children receive two meals daily, consisting of porridge in the morning and lunch, while the other pupils receive the lunch meal only (Ruben Centre, 2023). The lunch meal is mainly composed of boiled maize and beans; rice, beans, and vegetables; or cornmeal (locally known as *ugali*) and vegetables. This provided a unique opportunity for setting up a CEA demo unit for vegetable production in and within communal spaces hence acting as an urban nutrition hub for the school feeding programme.

Independently, CEA does not provide a cure-all solution to food, nutritional security and climate resilience for UPA. Different CEA systems in hydroponics were tested to identify the best system that ensures longevity of production, offers food and nutritional security and accessibility to vulnerable groups like school going children and internally displaced persons.

Results from a preliminary study in Mukuru, conducted by Miramar International Foundation (MIF) in 2021-2022, revealed the most preferred and consumed vegetables among Mukuru residents and Ruben Centre primary school (Miramar International Foundation 2022). These include - African nightshade (locally known as *Managu*), cowpea greens (locally known as *Kunde*), curly kales (locally known as *Sukuma Matumbo*), collard greens (locally known as *Sukuma Wiki*), Swiss chard (locally known as spinach), amaranth (locally known as *Terere*), tomatoes and cabbages. The determination of the most preferred vegetables helped in unravelling the composition of the most preferred food combinations in the area, this was termed "the Mukuru Plate" and aided in selecting crops to grow and the CEA systems employed in the demo unit.

Hydroponic CEA systems were then designed to fit the production of the preferred vegetables for Ruben Centre primary school feeding programme. Three CEA systems were selected: The Nutrient Film Technique (NFT), Deep Water Culture (DWC) and Trough Drip System (TDS).

A 7 Meter (m) by 15 m greenhouse demo unit was set up at Ruben Centre. The demo unit housed all three CEA systems to produce the identified vegetables. The research sought to answer the following questions:

1. What are the best crops for production on the CEA systems for School feeding in Mukuru?
2. What is the best CEA system for school feeding?

The research also sought to find out the necessary training, social infrastructure, and environmental considerations for operation of a successful CEA system for production of vegetables for school feeding in informal settlements.

2. METHODOLOGY

During the preliminary study conducted by MIF in 2021-2022, the potential of smart farming systems for food production and the most preferred vegetables in Mukuru informal settlement were assessed (Miramar International Foundation (2022). A descriptive research design for data collection was adopted. The respondents included community leaders such as chiefs, *nyumba kumi* heads, women, and youth leaders. The researchers also interviewed community members such as, local residents, vegetable producers, vendors, and school heads. From the responses, combinations of vegetables for school feeding were determined and CEA systems adopted for production.

As part of the social infrastructure for CEA in informal settlements, onboarding of trainers of trainers (ToTs) was explored. MIF in collaboration with Muungano wa Wanavijiji, a social movement for slum dwellers, put out word concerning training opportunity for CEA. Interested candidates made applications and interviews were conducted where a group of ToTs were selected and trained to be 'Smart Farming Champions'.

2.1 Demo unit set-up, CEA systems layout and vegetable production

A 7 m by 15 m greenhouse demo unit was set up in April 2022 at Ruben Centre. The demo unit housed three CEA systems.

The Deep Water Culture (DWC): This is a horizontal hydroponics system where plant roots are permanently submerged in water. A styrofoam sheet is used to hold crops and acts as a floating raft on a nutrient solution holding unit. An air pump is used to deliver oxygen to the nutrient solution. At the demo-unit, this system occupies 20 m^2. The system was divided into two units of sizes 12 m^2 and 8 m^2 each. Swiss chard and African nightshade were grown on this system.

The Nutrient Film Technique (NFT): This is a vertical hydroponics system of production where the plant roots are exposed to a shallow stream of nutrient-rich water flowing through layered horizontal pipes. Three NFT structures with a total production area of 75.6 m^2 were constructed. Under this system the following crops were produced: collard greens, curly kale and amaranth.

Trough Drip System (TDS): This is a horizontal hydroponics system that uses Mapal troughs as growth chambers. It can be customized into many designs to make use of vertical space, walls and fences. The roots are held in growth media loaded in Mapal troughs. Nutrient water is delivered to the crops via drip lines. Excess or unabsorbed nutrient solution flows to the bleeding tanks for recycling back into the system. The production area for the TDS system was 9.6 m^2. Four troughs, each measuring 2.4 m^2 were set-up. Tomatoes, cabbages and cowpea greens were grown on this system.

Fig. 1-3: DWC, NFT and TDS systems in Ruben Centre Demo Unit (from left to right). Photo: MIF, May 2022

2.2 Production phases and data collection

In this report we focus on the first phase of vegetable production between April 2022 to September 2022, and a short third phase between March and April 2023. The second phase between October 2022 to March 2023 provided many important insights in terms of management but is given less attention regarding data analysis due to problems in production.

During production, data was recorded on the input and output levels at the demo unit. The data points included consumption of farm utilities such as electricity and water, consumption of farm inputs e.g., nutrients and pesticides as well as the yield obtained. These data sets aided in the analysis of the viability of CEA in informal settlements and identification of the best CEA system for school feeding programmes. Data on yield obtained was compared against seed producers' projections and MIF's practice of hydroponics over the years. The expected yield data reflects the projected quantity per crop (in kilograms) depending on the established crop type and population when all factors are held constant.

3. RESULTS

3.1 Training and education, social infrastructure and environmental consideration

Training: A group of 20 trainees (15 Smart Farming Champions and 5 artisans) were trained for three months at Ruben Centre. The trainees were taken through both hydroponics crop production that involved 70 % practical and 30 % theory and soft skills such as entrepreneurship, marketing and bookkeeping. During the training, good class attendance was observed. The five artisans successfully completed the on-job training of greenhouse fabrication, construction and internal CEA furniture installation, while 12 of the 15 smart farming champions completed the course and were awarded certificates.

Additionally, as production was ongoing, Grade 6 and Class 8 pupils from the "Young Farmers Club" (YFC) at Ruben Primary were taken through onsite demonstration sessions on crop care practices and management under CEA vegetable production.

Fig 4-6: On the job training of artisans, in class and practical training of ToTs (from left to right) Photo by: MIF, April 2022

Fig 7-9: YFC pupils harvesting on DWC, NFT and delivering vegetables to school kitchen (from left to right) Photo by: MIF, June 2023

Security: At Ruben Centre, issues like pump theft, crop theft and net damage were witnessed which resulted in premature crop cycle termination. The exterior plastic cover was also damaged accidentally in a few cases by pupils which resulted in small openings on the glazing material. Therefore, operators must prioritize the physical security of the production unit to safeguard equipment, resources and crops.

Land: During construction, a land fill area had to be reclaimed for the setup of the demo unit. Here, efficient planning and systems design were carried out to enable maximum use of the available area. Systems such as NFT that utilize vertical space were incorporated. For instance, vertical utilization of space was demonstrated, with the total area under production being 20 m^2 for DWC, 75.6 m^2 for NFT and 9.6 m^2 for TDS summing up to 105.2 m^2 while the total area occupied by the greenhouse structure was 105 m^2 (7 m by 15 m)[1].

Water: At Ruben Centre, the borehole water was tested and found to have high sodium (Na) levels. Sodium toxicities can result in nutrient deficiencies of macronutrients such as calcium and magnesium resulting in stunted growth and tissue necrosis. To mitigate this, the water was treated with a buffer before irrigation.

[1] The total greenhouse area is 105 m^2, given by multiplying 7m-width by 15m length of the greenhouse. The total production area increased to 105.2 m^2 (which otherwise would have been less due to only utilizing the horizontal space and incorporating working spaces) as a result of the NFT unit which utilized the vertical space.

3.2 Best crop for production on CEA systems for school feeding in Mukuru

In this section, we determine the best crops for production with respect to yield per system, nutrition, and consumption preference at Ruben Primary. Reasons for the provisional exclusion of products in the next research phase are also described.

3.2.1 Yield

The yield expected refers to the projected yield of a particular crop based on crop variety, genetics and management practices. On the other hand, yield attained, refers to the actual yield from the demo unit. The comparisons were used to help evaluate crop productivity (Table 1).

Crop	CEA System	Cycle attained (months)	Expected Yield (kgs)	Yield attained (kgs)	Prod. area (m^2)	Yield per month total (kgs)	Yield per month (kgs/m^2)	Yield realised in %
Tomato	TDS	3	500 [2,3,4]	301	4.8	100	20.8	60 %
Cowpea greens	TDS	6	220 [2,3,4]	196	2.4	32.7	13.6	89 %
Cabbage	TDS	3	75 [2,3,4]	49	2.4	16.3	6.8	65 %
Swiss chard	DWC	6	356 [2,3,5]	110	11.2[6]	18.3	1.6	31 %
African nightshade	DWC	6	282 [2,3,4]	80	8.8[6]	13.3	1.5	28 %
Collard greens	NFT	6	229 [2,3,5]	146	26.7	24.3	1.0	64 %
Curly kale	NFT	6	57 [2,3,5]	79	11.7	13.2	1.1	139 %
Amaranth	NFT	6	297 [2,3,4]	131	37.2	21.8	0.6	44 %

Table 1: Percentage of the yield attained against the expected yield. Source: own data Phase 1.

Based on the yields realized against the yields expected, under TDS, cowpea greens were the best performing at 89 %. In NFT, curly kale was best performing surpassing its expected yield by 39 %. Collard greens also performed relatively well at 64 % under the same system. On DWC, spinach underperformed at 31 %. To further interrogate its performance across the three systems, spinach was planted in the third phase on all three (as shown in Table 6 below). Yield per m^2 was 3.8 kgs on TDS, 0.53 kgs and 0.7 kgs on NFT and DWC, respectively. This formed the basis for recommending production of spinach but only under the TDS system.

3.2.2 Nutrition

The choice of vegetables was also based on the nutritive values among the eight crops under production. Table 2 below shows the nutrients present in 100 grams of raw vegetables. This data was sourced from Kenya Food Composition Tables (2018), where 522 raw and cooked foods from ten regions in Kenya in recognition of the diverse geographical and agricultural locations were analysed.

	African nightshade	Amaranth	Cowpea greens	Collard greens	Curly kale	Spinach	Tomato	Cabbage
Vitamins A (RE) (mcg)	4	652	72	355	236	380	53	<0.01
Vitamin C (mg)	36	77	50	134	134	24	25	50
Thiamine (mg)	0.06	0.03	0.49	0.11	0.06	0.03	0.04	0.04
Riboflavin (mg)	0.32	0.22	0.37	0.13	0.23	0.1	0.04	0.04
Niacin (mg)	1.1	0.69	1.6	1.0	0.9	0.6	0.5	0.4
Dietary Folate (mcg)	4.04	64	95	62	73	121	25	15

Table 2: Nutrition values per 100 g of raw vegetables. Source: FAO/Government of Kenya. 2018. Kenya Food Composition Tables.

Amaranth and spinach have the highest level of vitamin A, followed by collards, curly kales, and cowpea greens. Collards and curly kales have the highest levels of vitamin C. Therefore, collards and curly kales are the primary sources of vitamin C among the crops at the demo unit. Cowpea greens have the highest level

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The calculations on expected yield were derived from the seed producing companies, on-farm trials, and data from Miramar's hydroponics farms:

[2] Japan International Cooperation Agency (2019). Tomato, cowpea pea, cabbage, African nightshade, amaranth, Swiss chard, collard greens and curly kales -On farm trials Repository.

[3] Miramar Archives (2023). Hydroponics Harvest Data 2019-2022. For tomato, cowpea greens, cabbage, African nightshade, amaranth, Swiss chard, collard greens and curly kales.

[4] Kenya Seed Products Guides (2021). Crop performance on cabbage, amaranth, cowpea greens, tomato, African nightshade.

[5] Royal Seed Catalogue Fact Seed (2020). Crop performance on curly kale, collard greens, Swiss chard.

[6] 11.2 m^2 was the production area (out of the total production area of 20 m^2) occupied by Spinach on the first DWC unit measuring 12 m^2 while African nightshade occupied the second DWC unit measuring 8 m^2 and the remaining 0.8 m^2 from the first unit summing up to 8.8 m^2.

of thiamine, followed by collards, therefore, provides the richest source of thiamine. Cowpea greens and African nightshade have the highest level of riboflavin, hence the most abundant source of riboflavin. Cowpea greens have the highest level of niacin, followed by African nightshade and collard greens. Spinach and cowpea greens have the highest level of dietary folate, followed by cowpea greens and curly kales. Therefore, spinach is the richest source of dietary folate among the selected crops

By analysing the data, we conclude that each crop has varying levels of nutrients, making them suitable for different dietary needs. Spinach appears to be particularly rich in vitamin A and dietary folate. Collards and curly kales are good sources of vitamin C while cowpea greens and African nightshade are rich in riboflavin. Cowpea greens also provide higher levels of thiamine and niacin. These insights were essential in narrowing down to the four vegetable crops (cowpea greens, spinach, curly kales and collard greens) for production for school feeding.

3.2.3 Why not tomato?

During production, tomatoes, cowpea greens, and cabbages were grown in the TDS system. At the demo unit, the farm manager reported requiring approximately 30 minutes of the daily average time required of 44 minutes for routine management of tomato. This therefore makes tomato production much more labour-intensive hence why it was not recommended for production for school feeding.

At Ruben Primary School, tomatoes are used as a food additive to improve the taste of food. From the data in Table 2 above, tomato does not provide significant high nutritional benefits compared to the four leafy greens selected, therefore could not be recommended for production.

Compared to cowpea greens and cabbages in the TDS system, tomatoes are relatively high consumers of nutrients and water. MIF's data from Ngong' Kibiko, Beacon of Hope and Miramar International College hydroponics greenhouse farms (2019-2022), shows the ratio of nutrient and water consumption for tomatoes, cabbages, and cowpea greens as 3:2:1. This clearly shows that tomato is a resource intensive crop, therefore less suitable for school feeding in informal settlements.

Due to the high demand for tomatoes in the market and the opportunity to fetch good prices, Ruben Centre management opted to sell the produce rather than use it in the school kitchen. Upon investigation, the researchers found out that the existing market price for a tomato fruit was between 10 KES to 15 KES per fruit or 100 KES per kg, which made the crop's economic value obvious. As a result of the high commercial value of the tomato fruit, security was a challenge. This was evident where the demo greenhouse was broken into, and clusters of tomatoes were stolen. In informal settlements, when security is not guaranteed, production of tomato cannot be recommended without thought.

Therefore, production of this fruiting vegetable is recommended for commercial purposes rather than directly bridging the food security and nutritional gaps for school going children or the community.

3.2.4 Why not cabbage?

The growth cycle for cabbage is three months in a greenhouse. Upon maturity, the cabbages are a one-of harvest. Due to daily demand of vegetables in the school, cabbages could not satisfactorily meet the quantities needed.

Among the six nutrition elements analysed, cabbage, of the eight crops under production had the lowest values for three of the six elements, which strengthened the decision to expel cabbage from production for school feeding in Mukuru demo unit.

3.2.5 Why not amaranth and African nightshade?

The yields of amaranth and African nightshade as shown in Table 1 above was low at 28 % and 44 % respectively, therefore could not be recommended for production for school feeding.

African nightshade is also known for its bitter taste, which may not be well-received by the students. Bitterness can be a deterrent for children to eat and enjoy the food leading to potential wastage, especially among the younger learners.

3.3 Best CEA system for school feeding

To identify the best production system for school feeding, information on different data points were collected and analysed.

3.3.1 Capital expenditure (Capex)

Greenhouse construction work were completed in April 2022. Table 3 below gives a breakdown of the costs incurred in setting up the greenhouse and the internal CEA structures for the demo unit.

Description	Trough Drip System costs	Deep Water Culture Costs	Nutrient Film Technique costs
Exterior greenhouse structure (KES)		171,450	
Internal CEA furniture (KES)	40,486	92,012	310,538
Production area per system (m^2)	9.6	20	75.6
Internal CEA KES/ m^2	4,217	4,601	4,108
Other works (land filling) (KES)		189,500	

Table 3: Capital expenditure per square meter for TDS, NFT and DWC. Source: own data.

The exterior of the greenhouse includes the perimeter structures that houses the interior infrastructure for the three systems. Table 3 above also highlights the cost of set up of the internal furniture such as the pumps, drip pipes and troughs, which were used to calculate the Capex per m^2 for comparison purposes. The capex per m^2 for TDS and NFT was relatively the same compared to higher costs per m^2 for DWC.

3.3.2 Operational expenditure (Opex) and labour

During the production phase, data was recorded on consumption of farm utilities such as electricity and water, consumption of farm inputs e.g., seedling costs, nutrients, organic pesticides, and labour. These data sets aided in the analysis of the viability of CEA in informal settlements. To compare Opex and labour for the first phase of production, three leafy greens were selected for each system, based on their comparative similarities in routine management, electricity, water and nutrient consumption.

Table 4 below provides information on the three CEA systems and corresponding (Opex) for cowpea greens, collard greens and spinach in Phase 1. The yield reflects the quantity of greens harvested in the first phase of production in kgs and the Opex/Yield represents the operational expenses incurred per kg of greens produced.

SYSTEM	TDS	NFT	DWC
CROP	Cowpea greens	Collard greens	Spinach
Opex (KES)	3592	3156	2727
Yield (kg)	196.1	145.6	110.4
Opex/yield (KES/kg)	18.3	21.7	24.7

Table 4: Operational cost per kg in each system in Phase 1. Source: own data.

When considering operational expenses, cowpea greens on TDS had the lowest cost at 18.3 KES/kg followed by collard greens on NFT at 21.7 KES/kg and finally spinach which had the highest cost at 24.7 KES/kg on DWC. From the above analysis concerning operational costs, it is cheaper to produce under TDS compared to NFT and DWC.

In terms of labour, Table 5 below presents information on the three CEA system for three crops in Phase 1 and spinach in Phase 3, their corresponding yields, labour hours per system per month, labour hours per crop in a month and the time required to produce one kg of greens.

SYSTEM	TDS		NFT		DWC	
	PHASE 1	PHASE 3	PHASE 1	PHASE 3	PHASE 1	PHASE 3
CROP	Cowpea greens	Spinach	Collard greens	Spinach	Spinach	Spinach
Labour hours/system/month	22	22	8	8	5	5
Labour hours/crop/month	3.5	3.5	2.9	2.6	2.8	3
Total yield (kg)	196.1	17.9	145.6	27	110.4	17.7
Yield (kg/month)	32.7	9	24.3	13.5	18.91	8.9
Production area in m^2	2.4	2.4	26.4	25.2	11.2	12
Yield per month & m^2	13.6	3.8	0.9	0.5	1.7	0.7
Time required to produce 1 kg (hrs)	0.11	0.41	0.12	0.92	0.15	0.33

Table 5: Labour requirements to produce a kg of greens in each system in Phase 1 and 3 of production. Source: own data.

Considering the labour hours per crop per month in Phase1, the TDS system requires the least amount of time at 0.11 hours to produce 1 kg followed by NFT at 0.12 hours and DWC at 0.15 hours for cowpea greens, collard greens and spinach respectively.

Based on the findings in Phase1, one reason for the recommendation of TDS as the best system for school feeding is, that it was less labour resource intensive.

To further explore the findings on labour across the three systems, spinach was grown on all systems in Phase 3. DWC had the least labour requirements at 0.33 hours to produce a kilogram of spinach followed by TDS at 0.41 hours and finally NFT which was the highest at 0.92 hours. Despite the low labour requirements for DWC in this phase, it could not be recommended due to its low yield per m^2 compared to TDS.

3.3.3 Yield

Table 6 below gives data on the yield harvested in kgs, the production area in m^2 and the yield per month per m^2 for Phase 1 and Phase 3 of vegetable production.

SYSTEM	TDS		NFT		DWC	
PRODUCTION PHASE	PHASE 1	PHASE 3	PHASE 1	PHASE 3	PHASE 1	PHASE 3
Crop	Cowpea greens	Spinach	Collard greens	Spinach	Spinach	Spinach
Total (kgs)	196.1	17.9	145.6	27	110.4	17.7
Production area in m²	2.4	2.4	26.7	25.2	11.2	12
Yield per month (kg)	32.7	9	24.3	13.5	18.4	8.9
Yield (kg) per month & m²	13.6	3.8	0.9	0.5	1.6	0.7

Table 6: Yield per month per m² in each system in Phase 1 and 3 of production. Source: own data.

In terms of yield per month per m^2 in each system, TDS recorded the highest yield for both cowpea greens and spinach at 13.6 kgs and 3.8 kgs respectively compared to NFT with yields of 0.9 kgs and 0.5 kgs for collard greens and spinach respectively and DWC at 1.6 kgs and 0.7 kgs for spinach in Phase 1 and 3 correspondingly. Given the high quantities required for school feeding (as demonstrated in Chapter 4 below), TDS emerges as the best CEA production system.

3.3.4 Overview of the results from Phase 1 of production

Below (Table 7) is an overview of the results from Phase 1 for cowpeas greens, collard greens and spinach grown using TDS, NFT, and DWC. We further analyse cost incurred such as Capex (internal CEA furniture,) and Opex (electricity, water, seedlings, nutrients, labour and pesticides) as well as yields per month and yields per m^2. The value depicts the price of a kg of vegetables at retail level while the purchase value shows the price at point of purchase for Ruben Primary on wholesale/supplier.

DESCRIPTION	TDS (Cowpea greens)	NFT (Collard green)	DWC (Spinach)
Capex (KES)	10,122	108,103	51,526
Production area (m^2)	2.4	26.7	11.2
Capex (KES/m^2)	4,280	4,071	4,601
Opex total (KES)	3,592	3,156	2,727
Opex per month (KES/ month)	592	526	454
Opex per yield (KES/Kg)	18.3	21.7	24.7
Yield (kg)	196.1	145.6	110.4
Yield (kg) per month & m^2	13.6	0.9	1.6
Market price (KES)	40	50	50
Market value (KES)	7,844	7,280	5,520
Purchase price by school (KES)	20	25	25
Purchase value (KES)	3,922	3,640	2,760

Table 7: Analysis of capital & operational expenditure and yields per system.

In terms of Capex TDS and NFT have similar costs while the DWC was higher. The Opex costs per kg yield showed that production under TDS resulted in lower Opex compared to NFT and DWC. The yield data also confirms that cowpea greens (and spinach in Phase 3) grown using the TDS system have the highest yields in terms of production per m^2.

Therefore, taking all these data points into consideration, including calculations on the amounts the school saves considering the different production areas, TDS emerges as the best CEA system for vegetable production for school feeding in Ruben Centre.

4. DISCUSSION AND CONCLUSIONS

4.1 Training and education, social infrastructure and environmental considerations

School meals interventions have been proven to provide direct quantifiable returns, such as improved school attendance and child nutrition. In Kenya, school meals play a crucial role in supporting children's development and breaking the cycle of hunger and poverty, particularly in vulnerable areas.

Adoption of CEA production of vegetables is a good intervention to support school feeding. However, from the results in this action research, successful CEA systems in schools do not only depend on the production potential but also on the social infrastructure and environment in which the CEA production unit is set up.

For instance, during training, majority of the Smart Farming Champions completed the course successfully, highlighting the interest and effectiveness of the training programme in developing their skills in CEA. Additionally, one staff member from Ruben Centre was trained as a farm manager for the demo unit. However, after his term came to an end, an untrained staff member stepped in which resulted to a dip in production and pre-mature crop termination. A trained farm manager from MIF was brought in order to continue with the production. This therefore emphasises the significance of training a dedicated team, considering employment terms, and selecting individuals with a genuine interest in agriculture to ensure the smooth and successful operation of CEA production units.

Moreover, the training also incorporated an educational component involving Grade 6 and Class 8 pupils from the "Young Farmers Club" at Ruben Primary. This initiative indicates a broader approach to disseminating knowledge and engaging with the local community and fostering an interest in agriculture and sustainable farming practices among young learners.

On matters of security, the findings underscore the importance of prioritizing the physical security of production units, emphasizing the need to safeguard equipment, resources, and crops. Implementing measures such as improved fencing, surveillance systems, and restricted access can help mitigate the risk of theft and damage, ensuring the continuity and sustainability of crop production.

Land is a very scarce resource in the informal settlements, with most of the spaces occupied by residential structures. Regarding land utilization, one of the key systems implemented was the NFT, which utilizes vertical space effectively. In the following research period, the vertical use/optimization of the space of TDS will also be examined. This will happen most likely in one of the Caritas funded units managed by Miramar and TMG. This highlights the importance of efficient planning and system design in optimizing land use.

A successful production under a CEA system in informal settlements is pegged on not only the water availability, but also the quality of water for irrigation. For instance, the detection of high sodium levels in the Ruben Centre borehole water highlights the potential risks posed to plant health and growth. Buffering aided in minimizing the effects of sodium levels on the vegetables. This confirms the importance of water testing and appropriate treatment methods to ensure optimal vegetable growth and productivity.

CEA production units in schools do not only require human capital but also finances to run the day today activities in the production units. Adequate budgeting for utilities such as water and electricity, purchase of the necessary inputs such as quality seeds and seedlings, nutrients, and organic pesticides is crucial for smooth running of the units.

4.2 Which are the preferred vegetables for CEA production for school feeding in Mukuru?

Based on the findings in Chapter 3, the following four greens are recommended for CEA production for school feeding:

i. Cowpea greens
ii. Collard greens
iii. Curly kale
iv. Swiss chard

Analysis of yields in the first phase showed that cowpea greens, collard greens and curly kales performed best. In Phase 3, spinach also performed well under TDS. The choice of vegetables was also influenced by their nutritional values. These vegetables had the highest nutrient combinations necessary for child development. The choice of crops to be cultivated under CEA should take into account both high yielding types and the nutritional advantages offered in order to meet the daily need for vegetables in schools. This formed the basis for their recommendation.

4.3 Which is the best CEA production system for school feeding?

To determine the best CEA system for production for school feeding these four factors were considered: Capex, Opex, Yield and Labour.

When considering the capital and operational expenditures, TDS and NFT costs less per m² production area compared to DWC during initial set-up, while TDS had the lowest running costs per kg harvest. In settings such as informal settlements, the choice of a CEA production system should efficiently utilize the limited resources while offering high productivity and benefits. With reference to the Capex and Opex, TDS proves to have the lowest production costs compared to NFT and DWC.

In view of labour hours required, in Phase 1 and Phase 3, NFT is labour resource intensive compared to the other two systems and therefore could not be recommended. In the first phase TDS had the lowest labour requirements per 1 kg harvest. On the other hand, DWC had the least labour requirements in the third phase of production, however DWC could not be recommended for production due to the low yield per m^2. This therefore leaves TDS, which had considerably low labour requirements in the first and third phase and furthermore high yields per m^2.

When examining the yield parameter, TDS outperformed both NFT and DWC in Phase 1 and Phase 3 of production. Taking into consideration the limited land availability in the informal settlements, it is important to consider systems efficiency per m^2.

Taking all these factors into account, that is capital expenditure, the operational costs, the labour requirements and yields, TDS emerges as the best CEA production system and therefore recommended for school feeding.

Next to the predominantly quantitative research findings from the demo unit that recommend preferred vegetables and best CEA system for school feeding in informal settlements, we, in addition, summarize the results qualitatively. Table 8 below shows a qualitative assessment of the physical, social, and environmental characteristics for determining the suitability of the different CEA systems for school feeding in Mukuru informal settlement.

CHARACTERISTICS OF BEST SYSTEM	NUTRIENT FILM TECHNIQUE	TROUGH DRIP SYSTEM	DEEP WATER CULTURE
Be relatively cost saving per m² during setup.	Medium	Medium	High
Be easily adaptable in informal settlements.	Low	High	Medium
Be able to accommodate a wide range of crops.	Medium	High	Low
Be easy to maintain and repair the system.	Low	High	High
Maximize on both horizontal and vertical spaces available.	High	High	Low
Be relatively cost saving during routine crop management and operations.	Medium	Medium	High
Be simple to detect, manage and control crop pests and diseases.	Medium	High	Low
Guarantee high quality yields of vegetables under production.	High	High	High
Guarantee high quantity yields of vegetables under production.	Low	High	Low

Table 8: Qualitative summary characterizing the best CEA system.

The Trough Drip System (TDS) emerges as the best system for school feeding based on several key characteristics. TDS is highly adaptable to informal settlements, which is important for implementing school feeding programmes in diverse communities, particularly in Mukuru. It can accommodate a wide range of crops, providing flexibility in food production.

Maintenance and repair of the TDS are relatively easy, ensuring smooth operation of the system. It maximizes the available spaces, making efficient use of limited land resources in informal settings. Additionally, TDS offers moderate cost savings during routine crop management and operations.

In terms of pest and disease control, TDS is simpler to detect, manage, and control crop-related issues compared to other systems. The system also guarantees high-quality yields of vegetables, meeting the standards for nutritious school meals.

TDS stands out as an effective and efficient CEA production system, meeting the requirements of cost-effectiveness, adaptability, wide crop range, ease of maintenance, space utilization, pest control simplicity, and high-quality yields, making it ideal for school feeding initiatives.

4.4 How to meet the vegetable demands for school feeding at Ruben Primary

Using the recommended system TDS and data on the vegetable grown on this system (spinach and cowpea greens), the below calculations highlight the production area/units required to meet the vegetable demand for Ruben Primary.

The weekly demand for leafy greens at Ruben Primary is 750 kilograms (Ruben Centre, 2023). The total requirement of the school meal of vegetables per week is 2250 kg, but this includes cabbage (750 kg) and 750 kg of potatoes, tomatoes, cassava etc. Considering the school calendar of 40 weeks in a year, the following calculations show how much production area is required to meet the need for leafy greens and what are the prices/costs for these products.

Purchase price for the leafy greens, obtained from school records, showed that one kg of leafy greens was 25 KES on average.

Monthly leafy greens demand: 750 kgs (demand per week) *4 (weeks in a month) =3,000 kgs

In a year, the school needs: 750 kgs (demand per week) * 40 (school weeks per year) = 30,000 kgs

Cost of Leafy Greens: 3,000 kgs (demand per month) * 25 KES (price per kg) =75,000 KES

From the demo unit, monthly production for cowpea greens and spinach on TDS was 13.6 kgs and 3.8 kgs per m^2 respectively.

To meet the school demand with cowpea greens: $\frac{3000\ (Monthly\ demand\ in\ kgs)}{13.6\ (kgs\ per\ m^2)} = 220.6\ m^2$

To meet the school demand for spinach: $\frac{3000\ (Monthly\ demand\ in\ kgs)}{3.8\ (kgs\ per\ m^2)} = 789.5\ m^2$

Based on the above calculations, the school would need one standard greenhouse unit of 8 m by 30 m (240 m^2) to meet the school demand using the cowpea greens output, more than three greenhouse units using the spinach performance for calculations.

4.5 Considerations for the next research phase

In the next phase of this action research, the following should be considered:

Remodelling of the Demo unit at Ruben Centre: The current demo unit houses the three CEA systems. In the next phase, the unit should be remodelled to house only the recommended TDS system. Since cowpea greens and spinach were recommended for production for school feeding, the greenhouse layout should accommodate both crops in equal spaces with separate utility consumption trackers, to aid in proper data collection. Curly kale and collard greens, as the two other recommended vegetables, are also to be grown later or in one of the four Caritas funded production units in Mukuru.

Scope of research: With these current findings, it will be vital to explore the potential of CEA system for school feeding in more schools in informal settlements. For instance, through MIFs' partnerships in the informal space, at least four more schools where CEA systems have been set up for school feeding could be onboarded to broaden the scope of the research.

Data / indicators / information: A data collection tool should be developed to capture all parameters of research necessary for comprehensive findings for the recommended vegetables and CEA system.

Training: As observed during training, knowledge transfer and skilling in CEA is important for empowerment especially considering the vulnerability of women and young mothers in informal settlements. Therefore, training in the next phase should target women and consider them prospectively for employment in the schools as farm managers.

Labour: To effectively manage CEA production units (8 m x 30 m), it is recommended to train three personnel who will be responsible for the day-to-day operations. The selection criteria for recruiting these personnel should consider factors such as the terms of employment, as casual or short-term contracts lead to high turnover and can disrupt production. It is crucial to have personnel with a genuine interest in agriculture, preferably those from schools with existing agricultural curricula or individuals involved in agricultural clubs and farm management.

Security: It is recommended that adequate security measures such as perimeter fencing, installing strong locks, for schools to safeguard their greenhouses and create a safe and conducive environment for sustainable food production. This ensures that the students can continue to benefit from the educational and nutritional opportunities provided by the greenhouse while discouraging theft and vandalism activities within the school premises.

Sustainability: To be able to run a successful CEA production unit, schools need to explore existing sources of funds, such as the daily or monthly contributions from parents for school feeding. Schools can engage parents in this manner, through reallocation of contributions made into the operational expenditure of running the production units.

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