EVALUATION OF TECHNICAL AND AGRONOMIC PERFORMANCE OF SOLAR-POWERED BHUNGROO WITH GRAVITY-BASED DRIP IRRIGATION SYSTEM IN NORTHERN GHANA

AfricaRISING PROJECT




Final Technical Report 2021-2022

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Summary

The **Africa R**esearch **i**n **S**ustainable **I**ntensification for the **N**ext **G**eneration (AfricaRISING) is a project supported by the United States of America Government through the Agency for International Development (USAID) to promote the exploration of diverse sustainable agricultural intensification across six countries in Africa, including Ghana. The project's Outcome 1: GH1221-20 aims to see farmers and farming communities in Ghana practice more productive, resilient, profitable, and sustainably intensified crop-livestock systems linked to markets. It seeks to integrate management practices and innovations to improve and sustain productivity and ecosystem services of the soil, land, water, and vegetation resources. The International Water Management Institute (IWMI) collaborates with other stakeholders to test, validate, and promote water management technologies and practices to increase water productivity under irrigated conditions. A sub-activity under the IWMI role is to evaluate the technical and agronomic performance of solar-powered small-scale irrigation based on the aquifer storage and recovery (ASR) system (also referred to as Bhungroo) in the Upper East Region of Ghana. The evaluation was conducted for two irrigation facilities in Gorogo and Sepaat communities in Talensi District.

This document is the final technical report on the activities carried out in the 2021/2022 irrigation season and their outcomes. These activities include: (a) the assessment of the technical parameters of the Bhungroo; (b) assessment of the water quality and isotope of the Bhungroos (c) determination of the operational performance of the drip irrigation system; (d) evaluation of the agronomic response of the demonstration trials concerning different water application regimes; (e) capacity building for farmers to know and operate the drip irrigation system; (f) Knowledge sharing of the outcomes of the study with stakeholders to advance the research development and use of the irrigation technologies in northern Ghana. The technical and agronomic evaluation activities carried out in the 2021/2022 season were a furtherance of the activities carried out for the same facilities in the 2020/2021 season.

In carrying out the technical evaluation of the Bhungroo in the 2021/2022 season, the submersible pumps in the wells were serviced at the beginning of the irrigation season, and the surfaces of solar panels were washed with water to clean the dust deposits. The static water levels and the depths of the Bhungroo were measured at the beginning and end of the season. The flow discharge from the wells was measured, and the drawdown was computed. The well recovery rates were also measured at the beginning and end of the season. Water samples were taken from the Bhungroo for laboratory determination of the physio-chemical parameters to assess the water quality. Water samples were also taken from the Bhungroos and other surface- and groundwater sources within the vicinity of the Bhungroo for isotopic analysis. The gravity-based drip irrigation systems were set up in each demonstration field, and their operational performances were investigated. The drip irrigation system setups were used to administer different levels of water application regimes to tomato and onion crops transplanted on the demonstration fields. The demonstration fields were set up to showcase and train farmers on how to manage irrigation water and operate the drip irrigation system and assess the agronomic performance of the crops (in terms of yield and

irrigation water productivity) under the water application regimes. Four water application regimes were imposed on each in each demonstration field. These include water application at 65 % of crop water requirement (65% CWR), 85% CWR, and 100 % CWR. The fourth was based on farmers' decisions (Drip+FD), where the driplines were allowed to run for a duration. The treatment plot was adjudged and irrigated by the farmer groups trained to manage the fields. The demonstration fields were irrigated throughout the growing season using the drip irrigation system, and the water applied was documented. Crop yields were harvested at maturity, and irrigation water productivities were computed as the relationship between crop yield and seasonal water applied to grow the crop. The farmers' capacity-building activities consisted of a training workshop, on-farm training and field days, which were conducted to increase farmers' knowledge and skills in operating and managing the drip irrigation system. The study outcomes were shared with regional stakeholders at a knowledge-sharing workshop.

The evaluation of the Bhungroo revealed that the structures of the wells were stable, and there were no cavities or collapses at the bottom. The submersible pumps were easily and freely lifted out of the well for servicing, implying that the pumps were not clogged in mud, inhibiting the water suction, pumping and discharges. The static water levels of the Bhungroos at the beginning of the season were as high as 2.0 to 3.0 m below the soil surface. This is very near the ground surface, indicating that the wells were fully recharged at the beginning of the season. The peak pump flow rate measured at noon in the Bhungroo in Gorogo was 32.0 l/min, recorded in March. The seasonal drawdown was 17.2 m which is 28.6% of the total depth of the Bhungroo. The well recovery rates at the beginning and end of the season were 38.9 l/min and 32.4 l/min, respectively. In Sepaat, the seasonal drawdown was 23.1 m, about 57.5% of the depth of the Bhungroo. The well recovery rates at the beginning and end of the season were 35.5 l/min and 29.4 l/min, respectively.

The wells could be pumped throughout the day from 7:00 am to 6:00 pm without stopping; however, the pumping rates were influenced by the voltage generated by the solar panels. The recovery rates of the well were higher than the peak pumping rate, which makes them viable and sustainable throughout the season. The water quality analysis revealed that the physio-chemical parameters were all within limits recommended by FAO for irrigation water, except for potassium. The high potassium content could probably be due to the parent material of the aquifer because the composition was similar in both Bhungroo. The Sodium Absorption Ratio (SAR) of the water were within FAO limits, implying that the potassium content does not threaten the water's use for irrigation of vegetable crops.

Moreover, the water could be categorized as C2-S1 (medium salinity and low sodium hazard), which implies it can be used for irrigation for moderate salt tolerant crops such as tomato, onion, cabbage, etc. The Isotopic analysis revealed that the water in the Bhungroo has a signature of 25 to 33 % of surface water. The results imply that the Bhungroo are still actively recharged from the surface/flood water.

The agronomic performance assessment showed that the seasonal water applied in the tomato demonstration fields varied from 314.7 mm to 502.0 mm in Gorogo and 288.0 to 460.3 mm in Sepaat. In the onion demonstration fields, the seasonal water applied varied from 321.7 mm to 610 mm in Gorogo and 363.5 mm to 641.0 mm in Sepaat. The lowest values in the ranges were obtained from the irrigated plots at 65% CWR, while the maximum values were obtained from the Drip+FD plots. The fruit yield of the tomato varied from 9.96 t/ha to 17.46 t/ha in Gorogo and 7.13 t/ha to 11.8 t/ha in Sepaat. The dry onion bulb yields also varied from 14.6 t/ha to 23.4 t/ha in Gorogo and 13.42 % to 22.5 t/ha in Sepaat. The least values in the ranges were obtained from the plots irrigated at 65% CWR, while the highest values were obtained from the plots irrigated at 100 % CWR. The results suggest that reducing water application by 35 % (65 % CWR) reduced irrigated tomato yield by 40 to 43.0% in the study area. Water applied at 15% less CWR (85 % CWR) reduced the area's tomato yield by 26.0 to 30.0 %. Applying water at 15 % and 35 % less CWR reduces onion yield by 18.7 to 23 % and 37 to 40 %, respectively, in the study locations. It implies that to obtain better yields of tomato and onion, the crops should be irrigated to meet full water requirements. In comparison with the 2020/2021 season, the tomato yields in the 2021/2022 season transplanted in early December were better than the yields obtained in the 2020/2021 season (4.9 to 12.6/t/ha) transplanted in January, which confirms that the tomato yields were influenced by the time the seedlings were transplanted. The onion yields for the two seasons were compared closely, which suggests that the difference did not influence the Bawku red onion variety in the transplanting period between December and early January.

The capacity development training deepened farmers' knowledge and skills in drip irrigation system practices. Farmers now know how long to allow the drip irrigation system to run to apply water to meet the crop water requirement. The regional stakeholders were receptive to the outcomes of the study. They were willing to promote groundwater exploration for irrigation and the practice of drip irrigation systems in the region.

1. Introduction

1.1 Background

The vagaries of climate and its effect on water resources have continued to contend with the quest for food security and poverty alleviation in nations whose agriculture largely depends on rainfall. Ghana, and especially the regions in the northern part, are caught in this predicament. This part of the country, whose population is largely agrarian and the major fruits and vegetable producers, has a unimodal rainfall pattern. The rains sometimes come with challenges, such as heavy splash floods that destroy farmlands, produce, and other infrastructure. So, the threat of food insecurity has remained in the area, a contention that the people and other stakeholders have employed several options to confront and overcome. One such option is irrigated agriculture.

Irrigation development offers the promise of food and nutrition security in northern Ghana. The dry season which goes for 5 to 7 months in the areas, can favour two to three cycles of intensive production of vegetable crops under irrigation. The prevailing threat is the rate at which the surface water bodies dry up, making it difficult for farmers to successfully complete one crop production cycle. Exploring sources of water that can enable sustainable intensification of crop production in the dry season has become inevitable if the regions continue to lead in dry season agriculture and enhance the country's quest for food and nutrition security.

The United States Agency for International Development (USAID), as part of the United States of America government's Feed-the-Future initiative, has supported the Africa Research in Sustainable Intensification for the Next Generation (AfricaRISING) programme to promote the exploration of diverse sustainable agricultural intensification across six countries in Africa (https://africa-rising.net/). These countries include Mali, Ghana, Ethiopia, Tanzania, Malawi, and Zambia. In Ghana, AfricaRISING Project Outcome 1: GH1221-20 aims to see farmers and farming communities in the study areas practice more productive, resilient, profitable, and sustainably intensified crop-livestock systems linked to markets. The project seeks to integrate management practices and innovations to improve and sustain productivity and ecosystem services of the soil, land, water, and vegetation resources.

In the frame of the AfricaRISING project, the International Water Management Institute (IWMI) is collaborating with other stakeholders to test, validate, and promote water management technologies and practices to increase water productivity under irrigated conditions. One of the series of field activities toward achieving this project output was to test and promote water management technologies and practices to increase water productivity in small-scale irrigation systems. A sub-activity under this was to evaluate the technical and agronomic performance of solar-powered Aquifer Storage and Recovery (ASR)-based small scale irrigation systems in some communities in the Upper East Region of Ghana,

The ASR, commonly called Bhungroo, was introduced to Ghana in 2015 by Conservation Alliance in collaboration with Naireeta Services (www.naireetaservices.com) from India under the Bhungroo Project: Water management solutions to support diversified cropping systems for men and women in the northern part of Ghana. Between 2015 and 2017, Six Bhungroo wells were drilled in Jagsi, Kpasenkpe, Weisi, Baare, Gorogo and Sepaat communities in Upper East and Northeast Regions (Mante et al., 2017; Magombeyi et al., 2018). Each site was equipped with submersible pumps powered by solar/diesel to lift water into overhead storage tanks. Farmers in the communities use these Bhungroo to irrigate vegetable crops like tomato, onion, pepper, and leafy vegetables. While some of the Bhungroo have challenges, especially with maintenance and vandalism, the ones in Gorogo and Sepaat have remained active and used by a few community farmers. They connect a 25 mm rubber hose pipe directly to the overhead tanks to convey water to irrigate check basins/sunken plots or furrows. This system of irrigation was laborious and efficient in water management. There was a need to explore a more efficient irrigation system and water management techniques for the Bhungroos. These Bhungroos, therefore, were selected for the execution of the IWMI-AfricaRISING objective. Gorogo and Sepaat are two communities in Talensi District, Upper East Region, Ghana.

1.2 Overview of field activities in study location in the 2020/2021 season

In the 2020/2021 irrigation seasons (November to May), IWMI set up demonstration trials in Gorogo and Sepaat communities. The purpose was to showcase to farmers the drip irrigation system as an efficient water management kit and to investigate the technical and agronomic performance of the Bhungroo with the drip irrigation system under different water application regimes. The Bhungroo with the irrigation facility is referred to as Bhingroo Irrigation Technology (BIT). The technical evaluation revealed that the Bhungroos yielded sufficient water for the irrigation of the test crops (tomato and onion) and other leafy vegetables planted in adjoining areas by the farmers throughout the crop growing season. The seasonal drawdown of the wells (recorded between February and May) was 12 m and 9 m in Gorogo and Sepaat, respectively. However, the discharge monitored on monthly bases varied from 1.07 to 1.42 m^3/h in Gorogo and 0.63 to 1.14 m^3/h in Sepaat. The flow pattern of the Bhungroo in Sepaat was inconsistent. A malfunction of the solar panels or low recovery rate of the well was initially suspected. In April, a technical service provider (PumpTech Ltd, Ghana) was requested to visit the site to assess the Bhungroo. No specific cause was identified, and somehow, the fluctuation in the flow pattern ceased. The service provider recommended that the pumping unit be serviced at the end of the cropping season.

The evaluation of the agronomic performance also presented varying effects of water application regimes on crop yield, irrigation water productivity and sustainable agriculture intensification (SAI) indicators. Four water application regimes (WAR) were investigated, which include water applied at 100 % of Crop water requirement (100% CWR), 85% CWR, and 65% CWR. The fourth water regime was based on the decision of the groups of farmers and trainees on the operation of the drip irrigation system (Drip+FD). They allowed the driplines to run for a duration; the concerned plots were adjudged by them as well irrigated, and the hours of irrigation were noted. The tomato yields based on the WAR varied from 6.0 to 12.6 t/ha in Gorogo and 4.9 to 9.2 t/ha in Sepaat. The highest yields were recorded when both crops were irrigated at full crop water requirement. The tomato yields were considered low compared to 15 t/ha, the average yield that enables domestic production to outstrip consumption in Ghana (Robinson and Kolavalli, 2010). The low yields were attributed to the time the tomato seedlings were transplanted. The tomato was transplanted in January due to logistic challenges caused by the COVID-19 Pandemic. January was considered late since farmers in the area transplant tomato within November and early December. The yield of the onion crop varied from 15.2 to 24.2 t/ha in Gorogo and 14.2 to 25.4 t/ha in Sepaat. The onion yields were relatively good as they compared closely with the yield range reported for the country (15 -25 t/ha, FAOSTAT, 2019). Transplanting the onion in January did not seems to have affected the yield of the onion.

The irrigation water productivity (IWP) of the tomato trials in Gorogo and Sepaat varied from 2.14 to 3.24 kg/m^{3,} with the highest value recorded in the plots irrigated to meet full crop water requirement and least value in the plots irrigated at 65% CWR. Moreover, the IWP of the tomato trial in the Gorogo field were higher than those in the Sepaat field by between 9 to 16 %, with the least coming from the Drip+FD plots. The IWP values implied that about 2 to 3.24 kg of tomato was produced from one cubic metre of water applied to the field. The IWP of the onion trials varied from 3.15 to 4.51 kg/m^{3,} with the highest value recorded in the plots irrigated to meet full crop water requirement and least value in the Drip+FD plot. IWP values implied that 3 kg to 4.5 kg of onion could be obtained from one cubic metre of water applied to the field in the study location.

1.3 Scope of 2021/2022 activities

The field activities in 2021/2022 were designed to re-examine some of the issues and knowledge gaps from the field activities of the 2020/2021 season. What will be the performance of the Bhungroo when the pumps are serviced? What will be the response of the tomato and onion to the water management regimes when transplanted in November/December? Other features incorporated into the field activities 2021/2022 season include (1) expansion of the farmers' capacity building (knowledge and skills) to operate and maintain the Bhungroo Irrigation Technology. This was necessary to guarantee the effective utilization and sustainability of the irrigation facilities. (2) Establish the differential quality of the water in the Bhungroo and its suitability for irrigation. (3) Determined the isotope of water in the Bhungroo system to establish how much water the Bhungroo contributes to recharging the aquifer. (4) Disseminate the findings from the BIT evaluations to stakeholders in a knowledge-sharing workshop. This report synthesises the 2021/2022 field activities and their outcomes. Detailed reports of key specific activities have already been submitted. Moreover, the detailed reports of the combined analyses of the 2020/2021 and 20212022 field demonstrations on the response of the trial crops (tomato and onion) to different water management regimes have also been submitted.

2. Implementation Approach

2.1 Assessment of the technical performance of the Bhungroo

The Bhungroos in the two study locations have been equipped with a Lorentz PS-1500 submersible water pump. The pumps are powered by three pieces of solar panels (260-watt capacity each) connected in parallel and mounted on a frame about 2.3 m in height, slanting North-South direction. There are two Poly tanks of 5000-litre capacity each in each field. The two tanks are placed on a separate stanchion of 2.5 m in height. They are reticulated to the Bhungroo, so the two tanks can either be filled simultaneously or one after the other when the solar pumps are switched on to lift water from the Bhungroo. These tanks deliver water to the drip irrigation system used in the experiment. Figure 1 shows the water system in Gorogo and Sepaat fields.

The solar panel, Bhungroo and overhead tanks in Gorogo field (Picture: Henry E. Igbadun)

The solar panel, Bhungroo and overhead tanks in Sepaat field (Picture: Henry E. Igbadun)

Figure 1 (a & b): The water system (solar panel, Bhungroo and overhead tanks) in the experimental fields

At the beginning of the 2021/2022 irrigation season, a technical service provider (PumpTech Limited Ghana) was invited to service the Bhungroo and the solar power unit. The servicing was carried out on the 11th of November, 2021. The submersible pumps were lifted out of the Bhungroo for examination and service. (Figure 2). The submersible pump in Gorogo was uncoupled, washed in water, assembled and placed back in the well. The surfaces of the solar panels were washed with water to remove dirt. The static water level (depth to water surface was carried out using a tape reel water level meter. Other measurements carried out after servicing the pump include depth of well, depth of pump installation, flow rates and voltage supplied from the solar panel to power the pump. The rate of recovery of the wells was computed from observations of water levels in the Bhungroos after pumping and allowing the well to recover for 24 hours. The measurements were carried out at the beginning and end of the irrigation season to characterize the Bhungroo. The flow rates and volume of water pumped were recorded by the water flow meter connected to the delivery system.

Figure 2: Servicing of the submersible pumps in Gorogo and Sepaat, 2021/2022 season

2.2 Assessment of the water quality and isotope of the Bhungroos

Water samples were collected from the Bhungroos in November 2021 and January 2022 for isotopic and physio-chemical analyses, respectively. The water samples for isotope analysis were taken from the Bhungroo and other ground-and surface-water sources within the vicinity of the Bhungroos. A total of eight (8) samples were obtained from the different water sources in the two communities. Besides the water from the Bhungroo, samples were taken from hand-operated boreholes (one each from Gorogo and Sepaat), a deep open well (one each from Gorogo and Sepaat), a dugout pond in Gorogo, and a flowing stream in Gorogo). The samples from each source were first collected into a bucket, and the 100 ml glass bottles were completely submerged into the bucket and filled to the brim of the bottle, ensuring that there were no air bubbles and that the bottles were airtight. The samples were adequately labelled and stored in a chest filled with ice and transported to the Water laboratory of the Ghana Atomic Energy Commission (GAEC) Accra, where the laboratory expert conducted the analysis. The isotopic results were expressed in per mil (‰) deviation from the Vienna Standard Mean Ocean Water (VSMOW) using the delta (δ) – scale (Pelig-Ba, 2009). The stable isotopes (deuterium (^{2}H) and Oxygen-18 (^{18}O)) of the water samples were used to determine the source of recharge of the Bhungroo.

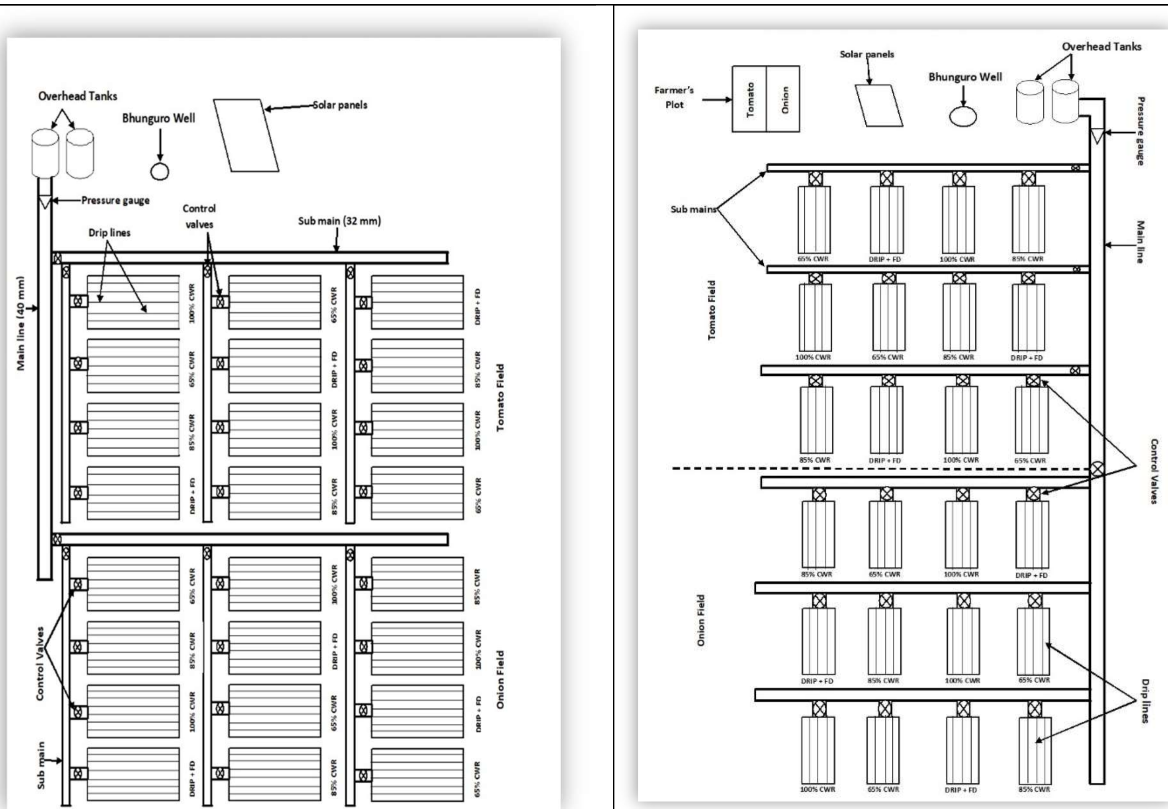
The rainfall isotope from the nearest meteorological station (Navrongo, about 40 km from the study location) from the databank of the GAEC was also provided by the Commission, along with the isotope of the groundwater. The data were used for the isotope hydrograph separation to determine the ratio of surface water in the groundwater in the Bhungroo. A two-component isotope hydrograph separation (Kanduc *et al.*, 2014) was used in the computation. The Bhungroo water is composed of local precipitation and groundwater. So, the water was separated into two components using the methods detailed in Fan *et al. (*2016).

Water samples from the Bhungroos analysed for physio-chemical properties were collected in January 2022 using a sterilized plastic container. At the sampling point, the Bhungroo were allowed to run to remove old water from the pipeline for a while. This was to ensure that the water collected was from the well and not stale in the pipeline. Two samples were taken from each well for physio-chemical and metal analyses. Drops of Nitric acid were added to water samples meant for metal analysis. The samples were labelled, stored in an ice chest filled with ice blocks and transported to Water Research Institute (WRI) in Accra for analysis. Each sample was analysed for the pH, conductivity, total dissolved solids, Sodium, Potassium, Calcium, Magnesium, Total Iron, Ammonia, Chloride, Sulphate, Phosphate, Manganese, Nitrite, Nitrate, Fluoride, Total hardness, Total alkalinity, Calcium hardness, Magnesium hardness, Bicarbonate and Carbonate. The data obtained were first compared with water quality reported for the same Bhungroo in 2017 (Mante et al., 2018) to determine whether the quality was deteriorating. The data obtained were also compared with the Food and Agriculture Organization (FAO) limits for irrigation water (Ayers and Westcot, 1985) to assess the fitness of the Bhungroo water for irrigation.

2.3 Drip irrigation setup and assessment of operational performance

The gravity-based drip irrigation systems were laid out on 18th and 19th November 2021 in Gorogo and Sepaat, respectively. Each layout comprised the main line (40 mm diameter uPVC pipe) from the water storage poly-tanks, delivering water to two demonstration fields in Gorogo and Sepaat. The sub-main lines were 32 mm-diameter High-Density Polyethylene (HDPE) pipes connected to the main line and fitted with a control valve such that the flow of water into each sub-main could be closed. The sub-main lines ran across each replicate block of the sub-divisions of the demonstration fields. Plots connected to the sub-main lines is a 25 mm diameter HDPE pipe to which the drip lines were connected. The driplines were 16 mm in diameter with in-line emitters 30 cm apart.

Each study location's demo field comprised twelve sub-divisions (plots) per crop. Each was 4 m by 6 m, and the total field size for each crop was 450 m^2. The space between each division was 1.0 m, while the space between the replicate blocks was 1.5 m wide. The space of 2.0 m separated the two crops. Each of the 12 plots of tomato crop had 7 drip lines of 6 m in length, spaced 60 cm apart. The experimental plots for the onion crop had 20 drip lines spaced 20 cm apart. Control valves were installed on each plot to regulate water flow into each plot based on the scheduled irrigation time. Figure 3 shows the schematic representations of the field layout, while Figure 4 shows sections of the physical layout.



(a) (b)

Figure 3: Schematic representations of the field layout in Gorogo (a) and Sepaat (b)

Figure 4: Images of field layout and drip system set up in Gorogo and Sepaat experimental fields, 2021/2022 Season

The operation performance of the drip setup was carried out on 8th December 2021 in both Gorogo and Sepaat fields to determine the uniformity of the emissions across the field to establish the water application efficiency. Ten (10) catch cans were randomly placed in each plot to collect the drops for 4 minutes. The volume of water collected was measured and recorded. The data obtained were computed into flow rates from which the operational performance assessment indices were computed based on equations 1 to 5 (Jamrey and Nigam, 2018). The wetted diameters of the drip spot were randomly measured from five points per plot. The flow collections were carried out for one field at a time while the control value for the other field was closed.

$$Q_{ave} = \frac{V_{ave}\ (litre)}{T(hr)}$$ (Equation 1)

$$E_d\,(\%) = \left(1 - \frac{\Delta Q_a}{Q_{ave}}\right) * 100$$ (Equation 2)

$$EU_f(\%) = \left(\frac{Q_{4th\ ave}}{Q_{ave}}\right) * 100$$ (Equation 3)

$$C_u = \frac{SD}{Q_{ave}}$$ (Equation 4)

$$SUC = 1 - C_v$$ (Equation 5)

Where:

Q_{ave} = Average Emitter flow rate; V_{ave} = Volume of water dripped into the can; T = Time of flow; E_d = Field distribution efficiency; ΔQ_a = Average absolute deviation; EU_f = Emitter flow uniformity; Q_{4thave} = Average low quarter volume of water caught; C_U = Coefficient of uniformity of emitter flow rate; SD = Standard deviation of emitter flow rate; SUC = Statistical uniformity coefficient;

2.4 Setting up and management of demonstration trials

2.4.1 Water application regimes

Each demonstration field was treated with four water application regimes (WAR) replicated three times and laid in Randomized Complete Block Design (RCBD) on the 12 plots. The water application regimes were based on the fraction of crop water requirement (CWR). Table 2 gives a further description.

Table 1: Description of water application regimes for tomato and onion crops

Treatment Label	Description*
Drip + FD	The driplines were allowed to run for a duration; the treatment plot was adjudged and irrigated by the farmer groups.
65% CWR	Drip system where water is applied to meet 65% of daily crop water requirements
85% CWR	Drip system where water is applied to meet 85% of daily crop water requirements
100% CWR	Drip system where water is applied to meet 100% of daily crop water requirements

2.4.2 Agronomic practices

Tomato seedlings (Tomato Tropimech) were transplanted in Gorogo and Sepaat fields on the 27th of November and 4th of December 2021, respectively. The seedlings were spaced at 60 cm between drip lines by 30 cm intervals between emitter spacing. In both locations, the tomato crops were weeding 3 and 6 weeks after transplanting (WAT). Inorganic (NPK-23-10-5) fertilizer was applied at 180 kg N/ha at 3WAT for the tomato trials (Robinson and Kolovilli, 2010). Sulphate of ammonia fertilizer was applied at the rate of 100 kg/ha as top dressing at 6WAT. Golan 20 SL (Aceramiprid 200 g/L) pesticide was sprayed every 2 weeks during the full vegetative and flowering growth stages, only at the rate of 12 ml/16 litres, as recommended by Boateng and Cornelius (2013) to control aphids (Aphis sp.) and grasshoppers.

The onion seedlings were transplanted in Gorogo and Sepaat on the 2nd and 5th of December. The onions were spaced at 20 cm between drip lines by 30 cm intervals between emitter spacing. There were 20 onion stands per drip line and a total of 400 stands per trial plot. The field was weeded two times also in both locations at 4 and 7 weeks after transplanting. Inorganic (NPK-23-10-5) fertilizer was applied at 200 kg N/ha after the first weeding. Sulphate of ammonia fertilizer was applied at the rate of 100 kg/ha as a top dressing after the 2nd weeding as recommended by Addai and Anning (2015). The onion in Gorogo was attacked by Beet armyworm (*Spodoptera exigua*), which ate the leaves of some of the crops (Figure 5). The fields were sprayed with Belt Expert

480SC pesticide twice a week at the rate of 20 ml/16 L knapsack sprayer for three weeks to eradicate the insects and redeem the crop. Figure 6 shows demonstration fields for both crops.

Eggs and larva of Armyworm on onion leaves in Gorogo

The onion crop in Gorogo with some tender shoots/leaves eaten by Armyworm

Figure 5: Beet armyworm on leaves of the onion plants and part of the fields attacked in Gorogo

Tomato demonstration field in Gorogo

Onion demonstration field in Gorogo

	
Tomato demonstration field in Sepaat	*Onion field in Sepaat*

Figure 6: Demonstration fields setup in Gorogo and Sepaat, 2021/2022 season

2.4.3 Irrigation practice

The fields were first irrigated two hours daily for ten days after setting up the driplines to moisten the soil sufficiently before transplanting. After transplanting, the fields were irrigated two hours daily for seven days to aid the establishment of the seedlings. After that, an irrigation interval of 2 days was observed throughout the crop growing season. The depths of water applied were based on the WAR imposed. The irrigation time for each application regime was computed based on the amount of water applied, and the driplines were allowed to run for the time computed. Each plot had a control valve to open and shut the water flow into the driplines. The crop water requirement, gross water application depth and the irrigation time for the onion crop were computed according to Equations 6 to 8. The drip irrigation efficiency was taken as 90 % (Panigrashi et al., 2010):

$$CWR = ETo \ x \ Kc \qquad \text{(Equation 6)}$$

$$GWR = \frac{\text{CWR}}{\text{Drip irrigation system efficiency}} \qquad \text{(Equation 7)}$$

$$Irrigation \ time = \frac{GWR \ x \ Plant \ spacing \ x \ Wp}{Emmitter \ flow \ rate} \qquad \text{(Equation 8)}$$

Where:

- CWR = crop water requirement (mm/day); ETo = Reference evapotranspiration (mm/day) computed from climatic data based on the Penman-Montieth models (Allen *et al*., 1998). Kc = Crop coefficient; GWR = Gross water requirement (mm/day); Wp = Wetted percentage for tomato taken as 50% (Panigrashi et al., 2010),

The administration of the Drip+FD WAR for both crops was carried out by the farmers participating in the demonstration in each study location. The group in Gorogo had 15 members (5 males and 10 females), while the group in Sepaat had 10 members (5 males and 5 females). These farmers also took part in the setting up and training on the operation and maintenance of the drip systems. In the Drip+FD WAR, the farmers allowed the driplines to run until the time they collectively agreed that the plots were well irrigated. The irrigation time per event was noted and used to compute the water application depths based on the emitter flow rates of the driplines. The seasonal water applied in each WAR was a summation of the depths of water applied over the season.

2.4.4 Harvesting

The tomato fruits were harvested when ripe from five middle driplines (18 m^2) in each plot. The fruits picked were weighed and sorted into marketable and non-marketable based on their sizes and outlook. Fruits that looked very small, bruised or rot were considered non-marketable. The weights of the marketable and non-marketable fruits were recorded per treatment. In Gorogo, harvesting was carried out four times at 4 days intervals, while in Sepaat, harvesting was done three times before the fruits were exhausted from the plants. The total weight of the fruits harvested was weighed in a balance and recorded. The harvested sampled area's weight was converted to metric tons per hectare. The onion was harvested at full maturity (105 days after transplanting). The dry onion bulbs were removed from the soil using a small hand hoe. The onion bulbs from 18 m^2 were harvested, sorted, and graded (using an onion hand-held wooden grader) according to sizes (less than 4 cm diameter, above 6 cm, and between 4 and 6 cm diameter). Analysis of variance test was carried out on the crop yield data, and the mean values were ranked using the Least Significant Difference test.

2.5 Computation of Irrigation Water Productivity

The Irrigation water productivity (IWP) was computed as the relationship between crop yield produced per unit volume of irrigation water applied in the fields (Equation 9):

:

$$IWP\ (\frac{kg}{m^3}) = \frac{Fruit\ yield\ (\frac{kg}{ha})}{Seasonal\ Water\ applied\ (\frac{m^3}{ha})} \quad \text{(Equation 9)}$$

2.6 Capacity Building for Farmers

Three activities were executed during the season to build farmers' capacity (knowledge and skills) to sustainably use the Bhungroo-based solar-powered irrigation system. These include (1) sensitization and training workshop on the potential of groundwater exploration and management of irrigation water using the drip irrigation system; (2) On-farm training on installations, operations, and maintenance of drip irrigation facilities; (3) a Field Day to showcase the demonstration trials on Bhungroo Irrigation Technology.

The sensitization and training workshop was held on the 10th of November 2021 for 25 farmers (10 males and 15 females) and five (5) extension workers. There were audio-visual presentations (including video clips) of groundwater lifting techniques for irrigation, drip irrigation system installation, and water management techniques. The Agricultural Extension Agents interpreted the presentations to the farmers in the native Talensi language. There were group discussions and reporting of the lesson learnt. The on-farm training was carried out during the field installations of the drip lines. Ten (10) farmers from Gorogo and six (6) from Sepaat participated in the training in their respective fields. The training was on the field layout, setting up, operation and maintenance of the drip system. The Field Day was carried out on 4th February 2022. It was done in collaboration with the Tongo District Department of Agriculture, which arranged and brought 35 farmers and three (3) Agricultural Extension Agents from the district to participate in the activity. The farmers were conducted round the fields while the farmer groups who managed the demos explained the operation to the farmers. The IWMI team coordinated the field day.

2.7 Knowledge sharing workshop with stakeholders

The workshop took place on the 30th of June 2022 in Bolgatanga; the administrative headquarter of Upper East Region, Ghana. The goal was to share knowledge on the project's outcome of the field activities. The workshop was also targeted toward inviting the stakeholders to discuss strategies for adopting and propagating water management technologies to improve irrigated vegetable production in the region. Thirty-six (36) participants attended the workshop. They include the Regional Director of Agriculture, the Regional Head of Extension, six districts' Directors of Agriculture, representatives of Northern Ghana Development Authority, Ghana Irrigation Development Authority (GIDA), AfricaRISING project office in UER, and six representatives of male and female farmers from Gorogo and Sepaat communities. The six districts include Bolgatanga Municipal, Bolgatanga East, Nabdam, Bawku-west, Bongo, and Talensi. The research team leader made power-point presentations; participants were divided into groups according to their professional categories (Policy managers and institutions, crop officers, agricultural extension agents and farmers) to discuss the presentations and deliberate on strategies to adopt and propagate the lessons learnt from the presentations

3. Outcomes

3.1 Technical performance of the Bhungroo

The parameters measured from the Bhungroo in Gorogo and Sepaat are presented in Table 2. There has been no remarkable change in the depths of the Bhungroo since its construction in 2017. This implied that the casings of the wells are stable; there are no cavities and collapse at the bottom. The submersible pumps were easily and freely lifted out of the well, which implies that the pumps were not clogged in mud. There was, however, evidence of rescue stains on the pump in the Gorogo well; hence, the components were disassembled and washed. The pump in Sepaat was cleaned and replaced after the well depth and measured water level. The static water levels of both wells ranged between 2 to 3.2 m below the surface. This is very near the ground surface, indicating that the wells were fully recharged at the beginning of the season. The values compared closely to when the wells were first constructed. The peak pump flow rate measured at noon in the Bhungroo in Gorogo was 32.0 l/min, recorded in March. The seasonal drawdown was 17.2 m which is 28.6% of the total depth of the Bhungroo. The well recovery rates at the beginning and end of the season were 38.9 l/min and 32.4 l/min, respectively. In Sepaat, the seasonal drawdown was 23.1 m, about

57.5% of the depth of the Bhungroo. The well recovery rates at the beginning and end of the season were 35.5 l/min and 29.4 l/min, respectively. The wells could be pumped throughout the day from 7:00 am to 6:00 pm without stopping. However, the pumping rates were influenced by the voltage generated by the solar panels. The recovery rates of the well were higher than the peak pumping rate, which makes them viable and sustainable throughout the season.

Table 2: Parameters of the Bhungroos in Gorogo and Sepaat in the 2021/2022 season

Item	Gorogo	Sepaat
Depth (m)	58 (60)*	40 (42)*
Static water level (m)	2.2 (3.42)*	3.2 (3.35)*
Depth of the submersible pump	55	37
Voltage supply from the Solar panel (Volt)	110	98
Peak Pumping rate (l/min)	32.0	28
Water level at the end of the season	19.4	26.3
Seasonal Drawdown	17.2	23.1
Well recovery rate @ the beginning of the season (l/min)	38.9	32.5
Well recovery rate @ the end of the season (l/min)	35.4	29.4

**Values at construction in 2017 (Mante et al., 2018)*

The volume of water pumped on monthly bases as recorded from the flow meter connected to the delivery pipeline to the overhead tanks is presented in Table 3. More water was pumped in Gorogo than in Sepaat because of the size of the field irrigated. Besides the demonstration fields, the farmers managing the field used the adjoining field to go leafy vegetables and used a hose to irrigate the field. Table 3 gives insight into the seasonal water extracted from the Bhungroo over the recorded drawdown, which is just a third of the depth of the well in Gorogo and half the depth in Sepaat. This implies that the Bhungroos were viable throughout the dry season and could generate enough water to irrigate two or three times the area irrigated

Table 3: Amount of water pumped from the Bhungroo wells in the 2021/2022 irrigation season

Month	Volume of water pumped (m^3) in the month	
	Gorogo	Sepaat

November (17 days)	237	217
December	364	320
January	383	330
February	417	390
March	351	300
Total volume of water pumped in the season	1752	1557
Irrigated area (ha)	0.22	0.10

3.2 Water Quality and Isotope of the Bhungroo

Table 4 shows the physio-chemical parameters that define the water quality in the Bhungroo. A comparison of the data with those obtained in 2017 when the wells were drilled shows that the turbidity of the water in Sepaat has decreased considerably. The water's pH in both locations remains relatively the same, slightly alkaline. The electrical conductivity of the water in Gorogo remains relatively the same, but that of Sepaat has decreased considerable (32 %) compared to 2017. Most cations and anions were also noticed to have decreased considerably in both wells. This suggests that the water quality has improved over the years of use.

All the parameters were within the FAO irrigation water limits except for potassium. The high potassium content could probably be due to the parent material of the aquifer. The content seems to also decrease considerably over the years of use. The Sodium Absorption Ratio (SAR) values of the water were within limits, implying that the potassium content does not limit the water's use for irrigation of vegetable crops. On the Salinity-Sodium Hazard Chart (Sivakumar et al., 2015), the Bhungroo fell in the C2-S1 indicating medium salinity and low sodium hazard. According to Zaman et al. (2018), such water can be used for irrigation for moderate salt-tolerant crops (such as tomato, onion, cabbage, etc.). They also stated that waters with low sodium (S1) could be used to irrigate most soils without fear of exchangeable sodium

Table 4: Physio-chemical properties of the Bhungroo in Gorogo and Sepaat

Parameter	**Unit**	**FAO Guideline**	**Gorogo**			**Sepaat**		
			2022	**2017***	**% diff****	**2022**	**2017***	**% diff.****
Turbidity	NTU	-	<1.00	*5.0*	-	<1.00	1	`-
Colour	Hz	-	<2.50		-	<2.50		-
Odour	-	-	-	Odourless	-	-	Odourless	-
pH	pH	6.0-8.5	7.58	7.54	0.5	7.83	7.55	3.7
Conductivity	µS/cm	0-3000	449	438	2.5	312	463	-32.6
Tot. Dis. Solids (TDS)	mg/l	0-2000	269	282	-4.6	187	299	-37.5

Parameter	Unit	FAO Guideline	Gorogo			Sepaat		
			2022	2017*	% diff**	2022	2017*	% diff.**
Sodium	mg/l	0-920	24	22.2	8.1	19.5	39.8	-51.0
Potassium	mg/l	0-2	5.1	5.9	-13.6	3.7	6.9	-46.4
Calcium	mg/l	0-400	32	38.5	-16.9	21.4	53.7	-60.1
Magnesium	mg/l	0-60.8	13.8	38.4	-64.1	10	31	-67.7
Total Iron	mg/l	5	0.024	*0.679*	-96.5	0.146	0.62	135.5
Ammonia (NH_4-N)	mg/l	0-5	0.001	0.121	-	0.001	0.054	-
Chloride	mg/l	0-1050	7.54	19.9	-62.1	1.49	23.8	-93.7
Sulphate (SO_4)	mg/l	0-960	4.88	9.34	-47.8	1	11.4	-
Phosphate (PO_4-P)	mg/l	0-2	0.001	0.001	0.0	0.001	0.001	0.0
Manganese	mg/l	-	0.118	0.289	-59.2	0.011	0.009	22.2
Nitrite (NO_2-N)	mg/l	-	0.011	0.014	-21.4	0.001	0.019	-
Nitrate (NO_3-N)	mg/l	0-10	0.227	5.645	-96.0	0.038	4.078	-99.1
Total Hardness (as $CaCO_3$)	mg/l	0-610	137	254	-46.1	94.8	262	-63.8
Fluoride	mg/l	0 – 1	0.39	0.989	-60.6	0.29	1.946	-85.1
SAR	mg/l	-	0.893		-	0.873		-

The Isotopic analysis revealed that the water in the Bhungroo has a signature of 25 to 33 % of surface water, which is a reasonable contribution to the Bhungroo storage that can be made available for irrigation. The results imply that the Bhungroo are still actively recharged from the surface. However, surface water's contribution may increase if the wells' filtration systems are regularly maintained to avoid clogging. The current outlook of the filtration unit suggests siltation and consolidation, which can reasonably influence the future replenishment and utilization of water resources technology.

Table 5: The concentration of tracer isotopes in different water types and the fraction of water sources discharged from the Bhungroo irrigation water

Bhungroo site	**18-Oxygen**			**Estimated fractions**	
	Bhungroo water (‰)	Groundwater (‰)	Rainfall (‰)	Q_{GW}/Q_{BHUN}	Q_{RAIN}/Q_{BHU}
Gorogo	-3	-2.28	-5.79	0.79	0.21

Sepaat	-3.62	-2.58	-5.79	0.68	0.32
	2-Hydrogen				
Gorogo	-16.77	-12.89	-26.43	0.71	0.29
Sepaat	-18.75	-15.02	-26.43	0.67	0.33

3.3 Operational performance of the Drip irrigation setup

Table 3 shows the performance indices of the experimental field's drip irrigation system setup. The emitter flow uniformity (EU) indicates a very good emission uniformity. This implies that the drip system setup was good, and water was distributed evenly on the fields within the demonstration fields.

Table 3: Operational performance indices of the drip irrigation setup

Performance parameter	Gorogo		Sepaat	
	Tomato	Onion	Tomato	Onion
Average Emitter flow rate Q_{avg} (l/hr)	0.42	0.40	0.81	0.70
Irrigation Distribution Efficiency E_d (%)	96.4	94.3	90.9	91.3
Field Emission Uniformity EU_f (%)	91.0	94.8	93.6	92.0
Coefficient of variation of Emitter flow rate (CV)	0.03	0.04	0.04	0.06
Statistical Uniformity Coefficient (SUC)	0.96	0.94	0.91	0.90
Average wetted diameter (cm) (1hr:30 min water application)	23.4	25.9	20.6	21.4

3.4 Agronomic Performance of the Field Trials

3.4.1 Crop Yields

Table 7 shows the fruit yield of tomatoes in Gorogo and Sepaat for the season. The yield varied from 9.96 t/ha to 17.46 t/ha in Gorogo and 7.13 t/ha to 11.8 t/ha in Sepaat. The mean yield of tomatoes in Sepaat was lower than Gorogo by about 35%. This may be due to differences in management by different farmer groups. The Gorogo field was easily accessible compared to the Sepaat field. The Sepaat field was about 3 km away from the community where the farmers live. The Gorogo field was less than 500 m away from the farmers' homes, which made it easy to give more care to their fields. However, the yield difference concerning the WAR has a similar pattern in the two locations. The least yields were obtained from the plot irrigated at 65% CWR (35% reduction of CWR), while the plot irrigated at 100% CWR recorded the highest yield. The results imply that reducing water application by 35 % (65 % CWR) reduced tomato yield in Gorogo and Sepaat by 43.0% and 40.0%, respectively. A reduction in water application by 15 % (85 % CWR) reduced tomato yield by 26.8% and 30.0 % in Gorogo and Sepaat, respectively. This suggests that the water application regimes strongly influenced the yield response.

It may also be noticed that yields of the Drip+FD plot were not significantly different from 100% CWR plots. This was because the water applied on the plots was up to CWR and slightly more (see next section) based on farmers' decisions. The average yield of tomatoes in both locations was above the average reported for Ghana, which is 7.8 t/ha (FAOSTAT, 2019). The yields of the plots irrigated to meet the full crop water requirement (100% CWR) compared with the 15 t/ha considered as the average yield to enable domestic production to outstrip consumption in Ghana (Robinson and Kolavalli, 2010). A similar trend in tomato yield was recorded in the 2020/2021 season, even though the fruit yields were lower across water application regimes. The tomato yield in Gorogo was higher than the 2020/2021 season by 36 to 66 %. In Sepaat, percentage increases in yield between the two seasons ranged from 28 and 46 %. The differences in yield between the season confirm that transplanting tomatoes in late November/early December will give better yields than those planted in January in the study area.

Table 7: Fruit yield of tomato in an experimental field in Gorogo and Sepaat in the 2021/2022 season

Demo label	Gorogo			Sepaat		
	Total Fruit (t /ha)	Marketable yield (t/ha)	Non-marketable yield (t/ha)	Total Fruit (t /ha)	Marketable yield (t/ha)	Non-marketable Yield (t/ha)
Drip + FD	15.11^{a*}	12.02^{b}	3.09^{a}	11.55^{a}	9.16^{a}	2.39^{a}
65 % CWR	9.96^{c}	8.65^{c}	1.31^{b}	7.13^{b}	5.52^{b}	1.61^{b}
85 % CWR	12.78^{b}	11.20^{b}	1.58^{b}	8.44^{b}	7.25^{b}	1.19^{b}
100 % CWR	17.46^{a}	14.07^{a}	3.39^{a}	11.83^{a}	9.27^{a}	2.56^{a}

**Mean with a different alphabet in the same column are significantly different at P<0.05 level of significance level*

Figure 7 compares the percentages of the tomato crop's marketable (PMK) and non-marketable (PNMK) yield across the WAR and demonstration field location. The results did not show a similar trend in both locations. The percentages of marketable tomato yield in Gorogo were higher in the treatments under deficit irrigation (where water was applied at less than CWR) compared to the treatments with full water application. In Sepaat, marketable yields of 85% CWR and 100% CWR were higher than the other WAR. This suggests that the water application regimes may have strongly determined the total yield but did not necessarily the percentage of marketable yield. It may therefore be concluded that water application regimes did not dictate tomato's markable and non-marketable yield but affected total fruit yield.

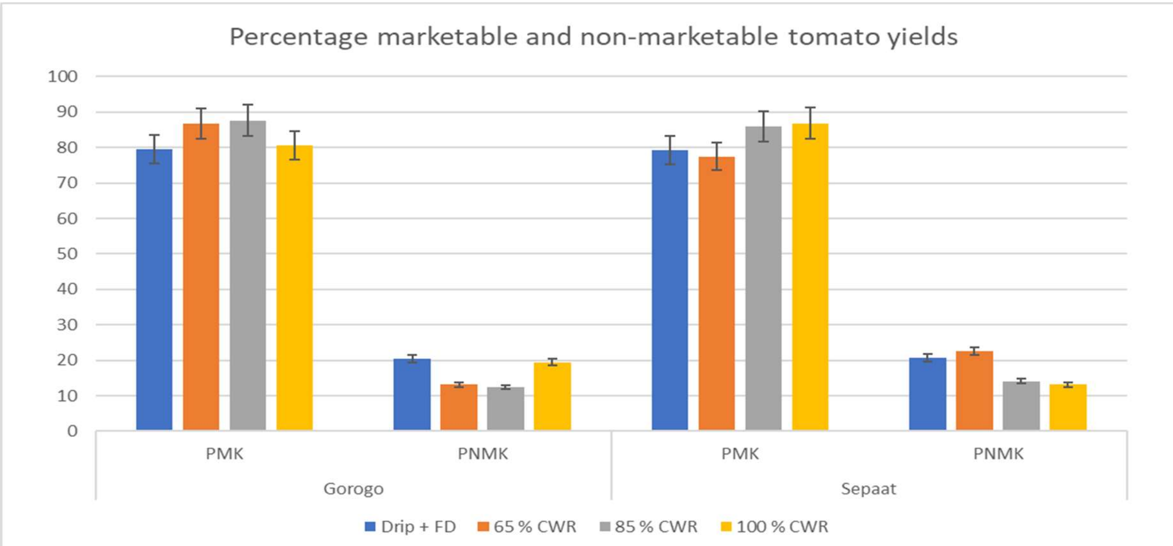


Figure 7: Percentage of marketable (PMK) and non-marketable (PNMK) yield of tomato in Gorogo and Sepaat

Tables 9 and 10 show the dry onion bulb yields from the demonstration fields in Gorogo and Sepaat, respectively. The yields also varied from 9.23 t/ha to 15.59 t/ha in Gorogo and 13.42 % to 22.5 t/ha in Sepaat. The minimum values in the ranges were obtained from the plots irrigated at 65% of the crop water requirement (CWR), while the maximum values were obtained from the plots irrigated at 100 % CWR. These results trends were expected since the application of water below crop water requirement reduces crop yield. The onion yields in Gorogo were quite lower than in Sepaat; the pest attack on the onion in Gorogo at an early stage of vegetative growth may be responsible. However, the yields compared favourably with those reported in the literature (10 t/ha, DAI, 2014, van Asselt et al., 2018), which implies that the crops recovered from the pest attack

A comparison of the grading percentages (Figure 8) did not show a consistent pattern either with WAR or location. In Gorogo, the 65% CWR water application regime recorded the highest percentage (45%) of bulbs <4 cm diameter, while the plots irrigated at 100% CWR recorded the least (28%). In Sepaat, while the 100% CWR plot recorded the least bulb diameter size (23%), the Drip+FD plot recorded the highest (36%). In Gorogo, the dominant yield size of the onion across the WAR was between 4 and 6 cm. In Sepaat, the WAR did not seem to influence bulb sizes. While the 100% CWR recorded the least in the < 4 cm grade size, the 85% CWR recorded the highest in the >6cm bulb size.

The yield obtained from these demonstration fields was higher than the range of yield (10.05 to 15.65 t/ha) reported by Enchalew et al. (2016). Using gravity drip irrigation in Ethiopia, they practised deficit irrigation scheduling at 50, 60, 70, 80, and 90 %. The yields from this study were around the average reported for Ghana, which is 19 t/ha (MoFA, 2019). Applying water at 15 % and 35 % less CWR reduced the yield of dry bulb onion by 18.7 to 23 % and 37 to 40 %, respectively, in the study locations. The onion yields in Gorogo were about 30 % lower than that of Sepaat, which may be due to the armyworm infestation. However, the yields in both locations followed a similar trend in response to the deficit irrigation application.

Table 9: Dry bulb yield of onion in an experimental field in Gorogo in the 2021/2022 season

Treatment label	**Dry bulb yield (t/ha)**			
	< 4 cm Dia	4 cm = Dia ≤ 6 cm	> 6 cm Dia	Total
Drip + FD	5.09	5.72	4.55	15.34
65 % CWR	4.37	3.76	1.60	9.73
85 % CWR	4.22	5.02	3.44	12.68
100 % CWR	4.35	6.44	4.80	15.59

Table 10: Dry bulb yield of onion in an experimental field in Sepaat in the 2021/2022 season

	Dry bulb yield kg/ha			
Treatment label	< 4 cm dia	4 cm = Dia ≤ 6 cm	> 6 cm dia	Total
Drip + FD	7.92	7.72	6.59	22.23[a]
65 % CWR	4.22	4.06	5.09	13.37[b]
85 % CWR	4.24	3.75	6.33	14.31[b]
100 % CWR	5.28	8.89	8.39	22.56[a]

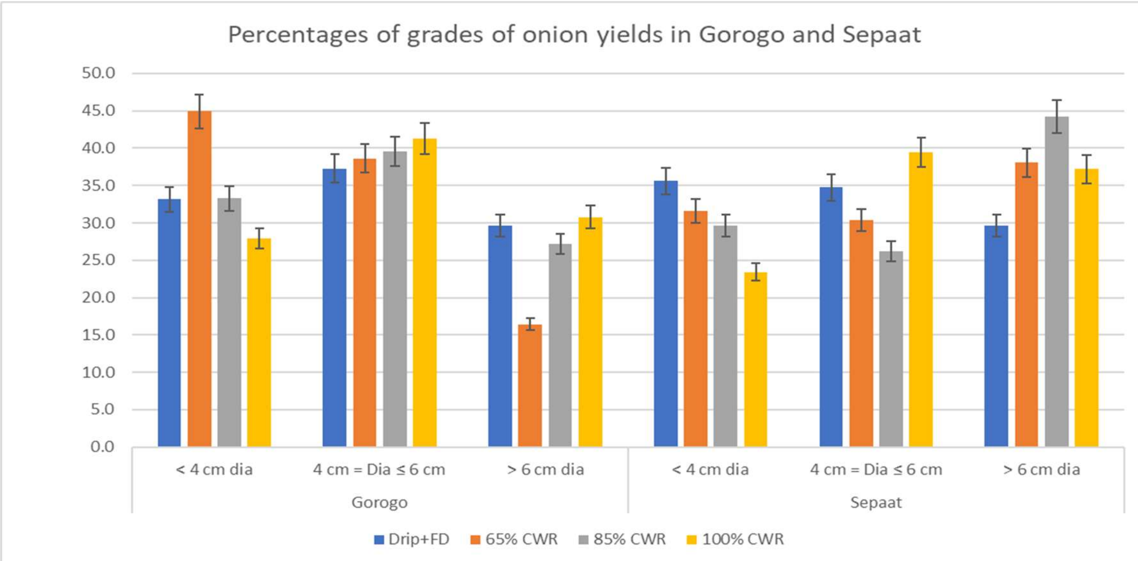


Figure 8: Comparison of percentage yield sizes of onion in Gorogo and Sepaat

3.4.2 Seasonal Water applied

The seasonal water applied in the experimental tomato fields varied from 314.7 mm to 502.0 mm in Gorogo and 288.0 to 460.3 mm in Sepaat. In the experimental onion fields, the seasonal water applied varied from 321.7 mm to 610 mm in Gorogo and 363.5 mm to 641.0 mm in Sepaat. The lowest values in the ranges were obtained from the irrigated treatments at 65% CWR, while the maximum values were obtained from the Drip+FD treatments. Means separation shows that in the tomato trials in both study locations, the water applied in Drip+FD plots was not significantly different from the 100% CWR. This suggests that the farmers operating the drip were beginning to decide to apply water new crop water requirements. In the 2020/2021 season, the water applied by the farmers in the Drip_FD plots was over 15 5% higher than the 100% CWR.

Table 9: Seasonal water applied (mm) in tomato and onion trials in the 2021/2022 season

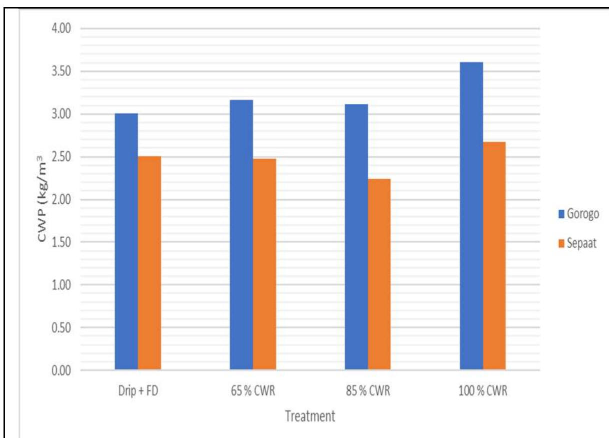
	Tomato crop		Onion crop	
Treatment	Gorogo (mm)	Sepaat (mm)	Gorogo (mm)	Sepaat (ccm)
Drip + FD	502.0^{a}	460.2^{a}	623.6^{a}	614.0^{a}
65% CWR	314.6^{c}	288.0^{c}	368.5^{d}	363.5^{d}
85% CWR	411.6^{b}	376.6^{b}	481.9^{c}	475.4^{c}
100% CWR	484.2^{a}	440.3^{a}	566.9^{b}	559.3^{b}

Mean values with the same letter along the same column are not significantly statistically different at a 0.05 % level of significance

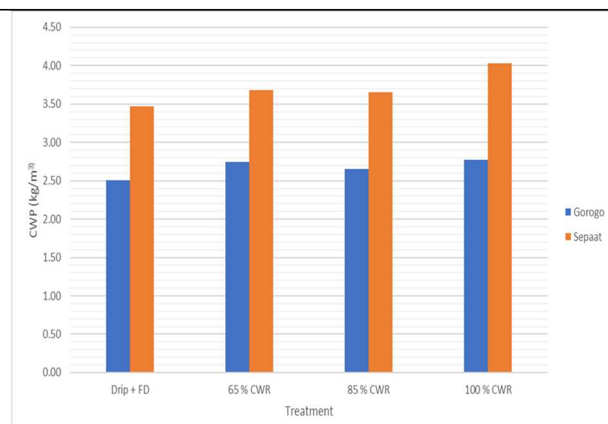
3.4.4 Irrigation Water Productivity

Figure 9 shows the tomato and onion demonstration fields' irrigation water productivity (IWP). The IWP (kg/m^3) expresses the quantity of yield produced per cubic of water applied on the field. The IWP values for tomatoes in Gorogo ranged from 3.01 kg m^3 in the Drip+FD treatment to 3.61 kg/m^3 in the 100% CWR treatment. In Sepaat, the IWP values for tomatoes varied from 2.24 kg/m^3 in the 85% CWR plot to 2.64 kg/m^3 in the 100% CWR plot. The results show that water productivity in the tomato treatment irrigated by the farmers based on their discretion was 17% less than the treatment irrigated at 100% CWR in Gorogo. Moreover, the plot irrigated at 65% CWR and 85% CWR were also found to be less than the 100% CWR by 12 and 14 %, respectively. In Sepaat, the treatments irrigated at 65% CWR and 85% CWR were also found to be less than the 100 % CWR plot by about 7 % and 16 %, respectively. The water productivity of the plot based on farmers' discretion was also less than the 100% CWR by about 6 %.

The water productivities in the onion fields in Gorogo and Sepaat vary from 2.51 kg/m^3 to 2.77 kg/m^3 and 3.05 kg/m^3 to 4.03 kg/m^3, respectively. The onion crop irrigated based on farmer discretion at Gorogo was 9% less than the plot irrigated at 100% CWR. Similarly, the plots irrigated at 65% CWR and 85% CWR were only 1 % and 4 % less than the 100% CWR. In Sepaat, the treatments irrigated at 65% CWR and 85% CWR were also found to be less than the 100% CWR by 9 % each, respectively, while the treatment irrigated based on the farmer's discretion was less by 14 %. These results imply that the deficit water application regime decreased the productivity of water in the deficit application regime. It also inferred that irrigating the tomato and onion crops to meet crop water requirements will give better water productivity in the study locations.



Comparison of IWP of tomato in Gorogo and Sepaat, 2021/2022 season



Comparison of IWP of onion in Gorogo and Sepaat, 2021/2022 season

Figure 9: Irrigation water productivity of tomato and onion in Gorogo and Sepaat, 2021/2022 season

3.5 Capacity building for farmers

Images of the capacity-building workshop, on-farm training and field Day activities are presented in Figure 10. During the training and field day, the participants were taken through the water application facilities (ASR well, solar panel setup, and drip irrigation system setup); and their operations and maintenance explanations were provided. The farmers were allowed to try their hands on how to open and close the control values of the driplines set up, observe the driplines' work, and ask questions and answers.

The training revealed the enthusiasm of the farmers for irrigation water management practices. Most participants admitted seeing different irrigation technologies like a sprinkler, drip, and surface systems using petrol-powered and solar-powered pumps but have never been involved in using any. They admitted the relatively easy and labour-saving advantage of using a solar pump to lift water for irrigation and, as against fuel-based irrigation pumps but purchasing cost of solar pump is not within their reach. They may be comfortable with a flexible financial mechanism with marketers and distribution agents that may see farmers acquiring solar pumps and drip systems and paying over a long period. External aid is needed to explore groundwater for irrigation in the area, as expressed by the farmers.

Sixty-eight percent (68 %) of the participants expressed willingness to invest in a drip irrigation system powered by a solar pump if they have access to groundwater. Only 2 % indicated a willingness to invest in groundwater exploration for irrigation purposes. Their take is that boreholes for irrigation may be very expensive, and the feasibility of getting sufficient water for irrigation in the area remains a source of anxiety.

Figure 10: Images of the training workshop

Figure 11: Participants (Farmers and Agricultural Extension Agents) at the Field Day and On-farm training in Gorogo

3.6 The Knowledge Sharing Workshop

The images of the knowledge-sharing workshop sections are presented in Figure 12. Two presentations were made, which include (1) Exploring groundwater for irrigation in Ghana: Status and opportunities, and (2) Technical and agronomic evaluation of Bhungroo Solar-powered irrigation system in Upper East Region. The participants were divided into groups to deliberate on the knowledge shared and come up with what they will do going forward with the knowledge shared. The policy managers comprising the directors and representatives of institutions in their group agreed to share the knowledge gained from the workshop with their staff and District Assemblies members; facilitate the gathering of more data on groundwater potentials for irrigation in their districts; facilitate training on the use solar powered gravity drip kits, and press harder for the inclusion of these facilities into the districts assemblies' budget. The crop officers in their group agreed to identify groups interested in solar-powered drip irrigation systems in their respective districts, service providers and markets and bring them together for demonstrations, training and establishment of linkages. The Agricultural Extension Agents (AEA), together with farmers in their groups, agreed to continue to reach out to other farmers to educate them on the advantages of the water management technologies discussed and facilitate field visits to where these facilities are used to gain more inspiration.

Banner Slide of the workshop


Plenary Session (Regional Director of Agric giving goodwill message)


Group session: The Policy managers (Directors and Authorities Representatives)


Group session: Crop Officers the Districts


Group session: AEA and farmers group 1


Group session: AEA and farmers group 2

Figure 12: Images during the knowledge sharing meeting

4. Conclusions and Recommendations

Evaluation of the technical and agronomic performance of the Bhungroo powered by solar pump to lift water to irrigate crops used using the gravity-based drip irrigation system was carried out for the facilities in Gorogo and Sepaat in the 2021/2022 season. This assessment was in furtherance of the evaluations carried out in the 2020/2021 season.

- The Bhungroo structures are stable and viable, with recovery rates higher than the peak pumping rate. The wells were pumped daily and could flow non-stop for 10 hours of sunshine.
- The water quality concerning irrigation was satisfactory as all physio-chemical parameters were within the FAO recommended limits, except for potassium content, which level does not threaten the use of the water for irrigation of vegetable crops. Moreover, the water with medium saline and low sodium hazard can be used for irrigation for moderate salt tolerant crops such as tomato, onion, cabbage, etc.
- The Bhungroos are still actively recharged from the surface/flood water, with 25 to 33 % surface water based on the isotope.
- Water application regimes less than full water requirement reduced tomato and onion yield water productivity considerably. The best irrigation regime is to apply water to meet the full crop water requirement.
- The transplanting should be done between November and the first week of December for a better yield of tomatoes. Transplanting tomatoes in January will depress yield.
- Farmers trained in drip irrigation operation and maintenance now know how long to allow the drip irrigation system to run to apply water to meet the crop water requirement.
- The regional stakeholders who gladly accepted the study's outcomes are willing to promote groundwater exploration for irrigation and the practice of drip irrigation systems in the region.
- It is recommended that Bhungroo Irrigation Technology be adopted and promoted in flood-prone areas of Ghana as water conservation technology to mitigate against flooding and save and store water for irrigation.

5. References

Addai I.K and Anning, D.K. (2015). Response of Onion (Allium cepa L.) to Bulb Size at Planting and NPK 15:15:15 Fertilizer Application Rate in the Guinea Savannah Agroecology of Ghana. Journal of Agronomy 14(4):304-309

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998). Crop Evapotranspiration: Guideline for Computing Crop Water Requirements. FAO Irrigation and Drainage. Paper 56:300.

Boateng, B. and Cornelius, E.W. 2013. Efficacy of Golan 20 SL (Acetamiprid 200 g/l) for the control of insect pests of tomato (*Lycopersicon esculentum Mill*.). Technical Report. Project: Efficacy Evaluation of Newly Introduced Insecticide.

DAI. 2014. "DFID Market Development (MADE) in Northern Ghana Programme." Bethesda, MD, USA: DAI.

Enchalew B, Gebre SL, Rabo M, Hindaye B, Kedir (2016) Effect of Deficit Irrigation on Water Productivity of Onion (Allium cepal.) under Drip Irrigation. Irrigation and Drainage Systems Engineering Vol.5: 172. doi: 10.4172/2168-9768.1000172

Fan, Y., Chen, Y., He, Q., Li, W., Wang, Y. (2016). Isotopic Characterization of River Waters and Water Source Identification in an Inland River, Central Asia. Water 8, 286. doi:10.3390/w8070286.

Jamrey, P.K. and Nigam, G.K. (2018). Performance evaluation of drip irrigation system. The Pharma Innovation Journal. Vol. 7 (1): 346-348.

Kanduc, T., Grassa, F., McIntosh, J. (2014). A geochemical and stable isotope investigation of groundwater/surface water interactions in the Velenje Basin, Slovenia. Hydrogeology. J., 22, 971–984.

Magombeyi, M., Mante, y and Mul, M. (2018). An evaluation of the performance of the Bhungroo groundwater system for dry season crop production in Ghana. Final Technical Report, SecureWater Project, IWMI.

Mante, Y., Mul, M., Kadiampakayni, D., Salifu F., Magombeyi, M., & Adimasu, Z. (2017). Characterization of sites for Aquifer Storage and Recovery system in Northern Ghana. IWMI. Accra.

MoFA (Ministry of Food and Agriculture). (2019). "National Agricultural Commodity Price Database."

Panigrahi B.B., Roy, D.P., and Panda, S. N. (2010). Water use and yield response of tomato as influenced by drip and furrow irrigation. International Agricultural Engineering Journal. Vol. 19 (1):19-30.

Pelig-Ba, K. B. (2009). Analysis of Stable Isotope Contents of Surface and Underground Water in Two Main Geological Formations in the Northern Region of gHANA. *West African Journal of Applied Ecology, 15*.

Robinson E. J. Z. and Kolavali, S.L. (2010). The case of tomato in Ghana: Productivity. Ghana Strategy Support Program (GSSP) Workig Paper 9. International Food Policy Research Institute (IFPRI).

Sivakumar, D., Pavithra, S.L., Vasuki, K., Lavanya, B. (2015). Groundwater suitability for irrigation around Perungalathur, Chennai, Tamil Nadu. International Journal of Applied Engineering Research, Vol. 10 No.53 (2015) Research India Publications; http///www.ripublication.comijaer/

Van Asselt, J., Masias, I. and Kolavalli, S. (2018). Competitiveness of the Ghanaian vegetable sector. Finding from a farmer survey. IFPRI Strategy Support Program Working Paper 47.

Zaman, M., Shahid, S. A., & Heng, L. (2018). Irrigation Water Quality. In *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques* (pp. 113-131). Springer, Cham. doi:10.1007/978-3-319-96190-3_5.