American Journal of Water Science and Engineering
2025, Vol. 11, No. 2, pp. 24-29
https://doi.org/10.11648/j.ajwse.20251102.12

Research Article

Performance Evaluation and Adaptation of Mini-sprinkler Irrigation through Cabbage Production

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Abstract

The activity was conducted with the objectives of adapting and evaluating the performance of mini sprinkler irrigation technology through cabbage production. The result indicates that the distribution uniformity obtained was 78.60%, uniformity coefficient determined was 81.5% and application efficiency was 80.70%. From the result, all performance indicators for min-sprinkler irrigation; distribution uniformity, coefficient of uniformity and application efficiency were in good and recommended range of indicators classes. The study indicates that, the mini-sprinkler irrigation evaluated was performed with wind speed property of the study area. The result also shown that, maximum water productivity (9.34 kg/m^3) was obtained by mini-sprinkler irrigation and the lowest water productivity (7.10 kg/m^3) was obtained from conventional furrow irrigation method. The result shown that, the cabbage yield produced by mini-sprinkler irrigation method was 395 qt/ha. Based on the result obtained, the mini-sprinkler irrigation is recommended for further use for production of cabbage with application efficiency (80.70%), distribution uniformity (78.60%), uniformity coefficient (81.85%) and water productivity (9.34 kg/m3) for the study area and same agro-ecology. Concerning stakeholder should demonstrate this technology to improve irrigation water productivity.

Keywords

Cabbage, Irrigation, Mini Sprinkler, Performance

1. Introduction

Agriculture is central of food security and economic growth in developing countries. However, food production requires substantial amounts of water. The current world population of 7.7 billion is expected to increase to 9.7 billion by 2050 with an estimate of 11 billion by 2100 [13]. This accelerated growth implies an increase in the food production. Agriculture is a significant consumer of global water resources, accounting for approximately 70-80% of usage [13]. Therefore, irrigation water should be adequately applied to crops to avoid water waste. Hence, the efficiency of water use in agriculture needs to increase in a sustainable manner [12]. The art of irrigation can be achieved using watering cans, sprinklers, emitters, surface systems and many others. Irrigation is widely carried out through surface and pressurized systems characterized by the mode of transport of the water onto the point of application [7].

The goal of any sprinkler irrigation system is to apply the desired amount of irrigation water to the crop's root zone as efficiently and uniformly as possible. The factors that determine sprinkler performance characteristics include wetted

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Received: 17 April 2025; **Accepted:** 3 May 2025; **Published:** 19 June 2025

diameter (swath radius), droplet size, which is a function of the operating pressure, the flow rate or discharge, the application rate, and uniformity of water application among others.

Mini sprinkler irrigation is a versatile method for spreading water on soil above the surface, resembling natural rainfall through the dispersion of water via small nozzles [7].

This ensures that water is distributed evenly across the field, mimicking natural rainfall and promoting optimal crop growth [10].

The introduction of mini sprinkler irrigation represents a recent advancement in pressurized irrigation methods [15]. A sprinkler water distribution pattern depends on the system design parameters such as: the sprinkler spacing, operating pressure, nozzle diameter, and environmental variables such as: wind speed and direction [7]. The most commonly used efficiency terms, are application efficiency, water requirement efficiency and Christiansen's coefficient of uniformity. The irrigation uniformity plays an important role in the performance of the sprinkler irrigation system and for good plant quality; however, sprinkler systems are typically gauged by the uniformity of water application above the crop canopy.

Effective, sustainable, and efficient sprinkler irrigation is a combined effect of proper system design and management [2].

Overall, the adoption of mini sprinkler irrigation holds promise for improving water efficiency, increasing crop yields, and mitigating the impact of intensive irrigation practices on groundwater resources [5]. Proper management and utilization of mini sprinkler systems can play a significant role in sustainable agricultural development [14]. Therefore, the success of this combined effect improves appropriate field irrigation practices. The scarcity of irrigation water in arid and semi-arid areas of Ethiopia is increasingly threatening crop production in many areas of the country. Even though there is scarcity of irrigation water, farmers of the study area are using the traditional irrigation system by losing much water. This over exploiting of water is significantly depleting and reducing the underground water. Under this circumstance, the use of pressurized irrigation systems can be an option of enhancing the efficiency of water consumption. Sprinkler irrigation has proved to be an efficient irrigation system compared to conventional methods of irrigation although the initial cost of installation is high. Hence, the objective this study was to evaluate the performance of mini sprinkler technology through cabbage production.

2. Materials and Methods

Pump station: The pumping unit used was submersible water pump which has 1.5 HP, 3000r.p.m, maximum suction head 57 m and which was done by 220 V /9.5A. The power used was from electric for submersible water pump. The water was diverted from the manually drilling tube well through 32 mm diameter with 30 m length of HDPE pipe to the experimental setup.

Mini sprinkler assembly: Main line: A 32 mm diameter high density polyethylene pipe (HDPE) with 40 m length used. Laterals line: 25 mm diameter high density polyethylene pipe (HDPE) with 40 m length used. Full circle rotated mini sprinkler was used. It was mounted on an installation stake riser of 1m long, 8 mm diameter. The mini sprinkler was connected to the lateral using a vinyl tube of 1.2 m and 12 mm diameter. The mini sprinkler consisted of black Spray nozzle of 1.8 diameters.

Experimental setup

The experiment was performed using a full circle mini-sprinkler set. A setup with 12 mini-sprinklers were used in the experiment for cabbage production. Two laterals with row spacing of 6 m was used. The sprinklers were arranged in two rows spacing of 6 m interval depend on wetting area capacity of selected mini-sprinkler. The middle sprinklers were considered as representative of actual field data collection. A matrix of catch can was installed at ground level using 2 m × 2 m grid that cover the experimental area of the four central sprinklers for determination of distribution uniformity, application efficiency and uniformity coefficient of mini-sprinkler. In this study, furrow irrigation method was used as check treatment to evaluate performance of mini-sprinkler in terms of yield.

Soil Sampling

Before the start of treatments, soil samples were taken from three spots at random from the diagonal of the experimental field. The samples were taken from four depths (0-15cm, 15-30cm, 30-45 and 45-60 cm). The soil samples collected was analyzed for different physical properties used for determination of crop water requirement of cabbage. The soil properties analyzed was include bulk density, water retention at field capacity (FC), permanent wilting point (PWP) and soil texture.

Determination of total available water (TAW)

The total available water (TAW) for the use by the plant in the root zone was estimated as the difference in moisture content between field capacity and permanent wilting point using the following equation.

$$TAW = 1000(\theta FC - \theta PWP) * \rho b * Dz$$

Where:

TAW - the total available water in the root zone (mm/m)

θFC -moisture content at field capacity

θPWP- moisture content at permanent wilting point

ρb is the bulk density of the soil in gm cm^{-3}, and

Dz is the maximum effective root zone depth (m)

Determination of crop water requirement of cabbage

Climatic data (rainfall, temperature, and wind speed, relative humidity and sun shine hours) were used for determination of Water Requirement of Cabbage. The CROPWAT model version 8.0 calculates ETo based on the formula of FAO Penman-Monteith using equation.

$$ETo = \frac{0.408\Delta[Rn-G]+\gamma\left(\frac{900}{T+273}\right)U2[e_s-e_a]}{\Delta+\gamma[1+0.34U2]}$$

Where; ETo- The reference crop evapo-transptranspiration,
Δ- The slope of vapor pressure curve (kPa °C^{-1})
Rn - Net radiation at the crop surface (MJ m^{-2} day^{-1})
G - Soil heat flux density (MJ m^{-2} day^{-1})
T - Mean daily air temperature at 2 m height (°C)
U_2 - Wind speed at 2 m height (m/s)
e_s-e_a - Saturation vapor pressure deficit (kPa)
e_s - Saturation vapor pressure at a given period (kPa)
e^a - Actual vapor pressure (kPa) and
γ - Psychometric constant (kPa °C)
Determination of net irrigation water requirement

$$In = ETc - PE$$

Where; In =Net Irrigation Depth (mm), ETc= Crop Water Requirement (mm) and Pe =- Effective rainfall (mm). Then effective rainfall computed using the following equation.

$$P_{eff} = 0.6 * P - 10$$

for precipitation less or equal to 70 mm

$$P_{eff} = 0.8 * P - 24$$

for precipitation greater than 70 mm

Water Productivity: Water productivity is defined as crop yield per unit volume of water supply to the crops. In this study crop, water productivity estimated as the ratio of Cabbage yield to the total irrigation depth applied during the season. It is expressed as:

$$WP = \frac{Y}{W} * 100$$

Where; Y is Cabbage yield (kg/ha) and W is irrigation depth applied during the season (m^3/ha).

Determination of sprinkler discharge (q): Sprinkler discharge was assessed by collecting the water emitted by the sprinkler into a bucket in a time interval of 2 minute. The discharge was calculated by dividing the collected volume by the time of filling. The observations of discharge were recorded three times for accuracy of measurement.

Distribution uniformity: The distribution uniformity of mini-sprinkler was calculated by using Christiansen's uniformity coefficient uniformity calculation equation:

$$DU = \frac{AvgLQ}{Avg\ T} * 100$$

Where; AvgLQ= is the average of the lowest quarter of water application taken by using catch canAvgT=-is the overall average of total water application taken by catch can and DU-is distribution uniformity.

Uniformity coefficient (UC): Christiansen's uniformity coefficient (UC) is the most commonly used statistical method for evaluating sprinkler system uniformity. Christiansen's uniformity is defined as:

$$Cu = (1 - \frac{\Sigma|y-\bar{y}|}{n*\bar{y}}) * 100$$

Where; Cu- is Christiansen's uniformity coefficient (%)., $\bar{y}$- is the mean water depth collected in the catch can, $\Sigma|y-\bar{y}|$ = cumulative of numerical deviation of individual observation from the mean water depth, and n = total number of catch cans.

The coefficient of uniformity is a measure of the hydrodynamic behavior of the system. Whatever its mathematical expression may be, it is an indicator of how equal (or unequal) the application rates resulting from the delivery devices are. In sprinkler systems the application rate is the "rainfall" produced by the system measured at ground level. In trickle systems the application rate is the discharge of the emitter. A low coefficient of uniformity indicates that the application rates from the delivery devices are very different, while a high coefficient of uniformity indicates that the application rates from the delivery devices are very similar in value. The coefficient of uniformity by itself is not a measure of how well the system is distributing water within the root zone. Accordingly, application efficiency of mini-sprinkler determined as follow.

$$Ea = \frac{Ws}{Wf} * 100$$

Where Ea= application efficiency, Ws= water stored in the root zone and Wf = water diverted the field.

Wind speed Determination: wind speed is a factor, which highly determine distribution uniformity of sprinkler irrigation. The wind speed of study area was determined by anemometer instrument. The measured wind speed was range between 4.5 - 9 km/hr.

Statistical analysis of data

Descriptive statistics was used for analysis of collected data.

3. Result and Discussion

1. Soil physical property

The soil physical properties of experimental site were presented in Table 1. The analysis of particle size distribution indicated that the soil texture at depths of 0 - 15 cm was sandy clay loam, but at lower depth (15-60 cm) it was found clay loam. The average soil bulk density (0-60 cm soil depth) was 1.21 g cm^{-3}. The top soil had relatively lower available water content when compared to the subsoil (Table 1). The total available water in an effective root zone of cabbage was 120.39 mm/m.

Table 1. Analysis of soil physical property of experimental site for crop water requirement input.

Depth (cm)	Sand (%)	Clay (%)	Silt (%)	Textural class	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm/m)
0-15	47	27	25	Sandy clay loam	1.22	31.20	20.00	20.50
15-30	43	30	24	Clay loam	1.23	32.00	17.00	27.67
30-45	43	33	23	Clay loam	1.13	34.21	15.13	32.34
45-60	41	35	23	Clay loam	1.26	37.60	16.50	39.88
Total available water in an effective root zone								120.39

2. Mini-sprinkler performance indicator

The performance indicators for mini-sprinkler includes; distribution uniformity, Christian coefficient of uniformity and application efficiency were determined and evaluated with the recommended standard.

Distribution uniformity (DU): The result shown that the distribution uniformity obtained was 78.60% and in good recommended range for mini-sprinkler irrigation. The result is in agreement with the report of [1]. Who state that, any sprinkler system with distribution uniformity a minimum of 75% good and accepted? Classes of Distribution Uniformity according to [7] were as follows DU ≥ 85 – excellent, 75 ≤ DU < 85 – very good, 70 ≤ DU < 75 – good, 65 < DU < 70 – fair, DU ≤ 65 – poor and <65% is unacceptable.

Table 2. Performance indicator mini-sprinkler.

Performance parameters	Percentage indicators description
Du (distribution uniformity)	78.60%
Cu (uniformity coefficient)	81.85%
Ea (application efficiency)	80.70%
Wetted diameter (m)	14 m
Nozzle discharge (lit/hr)	156 lit/hr

Application efficiency (Ea): The application efficiency of mini-sprinkler irrigation determined was within acceptable range recommended for mini-sprinkler irrigation. According to [9], sprinkler irrigation application of 60-85% range recommended as acceptable. So, the performance of mini-sprinkler irrigation evaluated (80.70%) had good performance for cabbage production in terms of its application efficiency indicator.

Coefficient of uniformity (Cu). The coefficient of uniformity was calculated based on Christian equation. Therefore, the mini-sprinkler irrigation uniformity coefficient determined was 81.5% as in (Table 2). According to [3] the obtained mini-sprinkler coefficient uniformity was good and in acceptable. According to [3] CU was ranked as "excellent" (CU > 90%), "good" (80 < CU < 90), "reasonable" (70 < CU < 80), "poor" (60 < CU < 70) and "unacceptable" (CU < 60). The sprinkler uniformity coefficient is a very important indicator, which decide its performance. So based on this result performance of mini-sprinkler irrigation for cabbage production was in good range in terms of uniformity coefficient.

The mini-sprinkler evaluated effective wetted diameter was 14 m which in agreement with the result of [11] Who report that the mini sprinklers' effective radius of discharge was measured at 7.22 m.

3. Yield and water productivity performance of cabbage under mini-sprinkler and furrow irrigation method

From the result (Table 3), maximum yield of cabbage (426 qt/ha) was obtained by application of furrow irrigation method. Mini-sprinkler irrigation produce 395 qt/ha of cabbage yield. The comparative evaluation on water productivity shown that, maximum water productivity (9.34 kg/m^3) was obtained from mini-sprinkler irrigation method.

Table 3. Yield and water productivity of cabbage under mini-sprinkler and furrow irrigation method.

Irrigation method	Yield (qt/ha)	Water use (mm)	Water used (m^3/ha)	Water productivity (kg/m^3)
Mini-sprinkler irrigation	395	422.82	4228.20	9.34
Furrow irrigation method	426	599.00	5990.00	7.10

The lowest water productivity (7.10 kg/m^3) was obtained from conventional furrow irrigation method. Even though, maximum yield was obtained by conventional furrow irrigation method, minimum water productivity was produced by this irrigation method due to maximum consumption of irrigation water.

Figure 1. Mini-sprinkler performance.

4. Conclusions and Recommendations

From the result, all performance indicators for min-sprinkler irrigation; distribution uniformity, coefficient of uniformity and application efficiency were in good and recommended range of indicators classes. The study indicates that, the mini-sprinkler irrigation evaluated was performed with wind speed property of the study area. The result also shown that, maximum water productivity was obtained by mini-sprinkler irrigation than furrow irrigation. Based on the result obtained, the mini-sprinkler irrigation is recommended for further use for production cabbage with application efficiency (80.70%), distribution uniformity (78.60%), uniformity coefficient (81.85%) and water productivity (9.34 kg/m^3) in the study area and same agro ecology. It also recommended to demonstrate this technology for farmers to improve irrigation water productivity.

Abbreviations

BD	Bulk Density
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
ha	Hectare
Kg	Kilogram
PWP	Permanent Wilting Point
qt	Quintal
TAW	Total Available Water
WP	Water Productivity

Author Contributions

Lalisa Ofga: Data curation, Formal Analysis, Methodology, Project administration, Software, Writing – original draft, Writing – review & editing

Jemal Nur: Project administration, Validation

Ayala Tade: Data curation, Methodology, Visualization, Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

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