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Thomas Apusiga Adongo
[1)] West African Center for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies, P. O. Box TL 1882, Tamale, Ghana
[2)] Department of Agricultural Mechanisation and Irrigation Technology, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana

Olaniyan O Olajumoke
[1)] West African Center for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies, P. O. Box TL 1882, Tamale, Ghana
[2)] Department of Agricultural Engineering, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana

Felix K Abagale
[1)] West African Center for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies, P. O. Box TL 1882, Tamale, Ghana
[2)] Department of Agricultural Engineering, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana

Corresponding Author:
Thomas Apusiga Adongo
[1)] West African Center for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies, P. O. Box TL 1882, Tamale, Ghana
[2)] Department of Agricultural Mechanisation and Irrigation Technology, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana

Effects of organic fertilizers and irrigation regimes on soil moisture content and beetroot (*Beta vulgaris* L.) performance in Northern Ghana

Thomas Apusiga Adongo, Olajumoke O Olaniyan and Felix K Abagale

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Abstract
Beetroot (*Beta vulgaris* L.) is a highly nutritious and economically valuable crop globally; however, its optimal production in tropical and semi-arid regions is increasingly threatened by declining soil fertility, erratic rainfall, and rapid soil moisture depletion. These constraints are particularly severe in the semi-arid ecological zone of Northern Ghana, where high evapotranspiration rates and poor soil moisture retention significantly limit crop development and yield. To address these challenges, this study evaluated the effects of different organic fertilizers and irrigation regimes on soil moisture content, growth, and yield performance of beetroot. A pot experiment was conducted at the University for Development Studies in Ghana, during both wet and dry seasons using a factorial design. Treatments included three organic amendments (Cow Dung, Sheep Droppings, and Compost) and a control, combined with three irrigation regimes (100%, 75%, and 50% Crop Water Requirement [CWR]). Growth parameters (plant height, number of leaves, leaf area, Leaf area index and chlorophyll content) and crop yield parameters (root length, bulb weight, dry bulb weight, bulb diameter, and water use efficiency) were monitored.

Analysis of Variance (ANOVA) revealed that the efficacy of the treatments varied significantly by season. During the wet season, the application of organic fertilizers showed no significant difference ($p>0.05$) on most growth and yield parameters. Conversely, in the dry season, organic amendments had a significant effect on fresh bulb weight ($p<0.05$) and total yield ($p<0.05$), with compost producing the highest vegetative growth and yield. Result also indicated that soils amended with sheep droppings consistently recorded the highest soil moisture content across all irrigation levels, demonstrating superior moisture retention capacity. Furthermore, ANOVA demonstrated that irrigation regimes significantly impacted the final yield ($p<0.05$) and Water Use Efficiency ($p<0.05$). The 100% CWR regime produced the maximum fresh bulb yield of 4.45 t/ha, whereas deficit irrigation significantly constrained production, reducing yields to 2.80 t/ha at 75% CWR and 2.46 t/ha at 50% CWR. A significant interactive effect between organic amendments and irrigation regimes ($p<0.05$) was recorded for bulb weight, with the combination of compost and 100% CWR resulting in the highest overall yield (8.06 t/ha). The study concludes that while sheep droppings are most effective for soil moisture conservation, the application of compost under full irrigation (100% CWR) is the optimal strategy for maximizing beetroot productivity in Northern Ghana. This approach can help farmers increase production, use water effectively and maintain soil health in drought-prone regions, paving the way for more resilient agricultural systems.

Keywords: *Beta vulgaris* L., organic fertilizers, deficit irrigation, soil moisture retention, water use efficiency, drip irrigation, soil amendments

1. Introduction
Beetroot (*Beta vulgaris* L.) is a root vegetable valued for its high nutritional content, natural pigments, and medicinal properties (Akan *et al*., 2021; Thiruvengadam *et al*., 2022) [2, 41]. It is rich in essential nutrients such as folate, iron, potassium, and antioxidants that contribute to its importance in both local diets and agro-industrial applications (Chen *et al*., 2021) [10]. Despite its potential, beetroot production in many tropical and semi-arid regions is often limited by poor soil fertility, nutrient depletion, and inadequate water management (Tayyab *et al* 2023; Naorem *et al*., 2023) [40, 21]. These constraints collectively affect root development, yield, and quality (Tayyab *et al*., 2023) [40].

The use of organic fertilizers has gained attention as an environmentally friendly alternative to synthetic fertilizers for sustainable crop production (Khan *et al*., 2024) [17]. Organic soil amendments such as cow dung, sheep droppings, and compost enhance soil structure, increase microbial activity, and improve water retention and nutrient availability (Singh *et al*., 2022) [37]. Several studies have reported that organic fertilizers not only improve soil health but also contribute to gradual nutrient release, which promotes sustained plant growth and development (Singh *et al*., 2015; Shaji *et al*., 2021) [36, 34]. Crucially, the incorporation of organic matter plays a significant role in regulating soil moisture content. By improving soil bulk density and porosity, organic amendments increase the soil's hydraulic conductivity and water-holding capacity, ensuring that moisture remains available to the root zone for longer periods (Veettil *et al*., 2024) [42].

Water availability remains a critical factor in crop production and beetroot production is not an exception (Liliane *et al*., 2020; Mancosu *et al*., 2015) [19, 24], particularly in semi-arid environments where rainfall is inconsistent and evapotranspiration rates are high (Allakonon *et al*., 2022) [4]. Efficient irrigation management is therefore essential to achieve optimal crop performance (Bwambale *et al*., 2022) [9]. When used properly, deficit irrigation can save a significant amount of water while having little effect on the yield's quantity and quality (Tari, 2016) [39]. Various field crops, such as sugar beet (*Beta vulgaris* L.), are particularly suited to deficit irrigation techniques (Mansuri *et al*., 2018) [26]. Sugar beet has a high-water requirement (Kiymaz *et al*., 2015) [18]; it is reported that sugar beet is a crop with deep roots and is not very resistant to water stress (Bodner, 2023) [8] due to the root system's structural and physiological characteristics (Wasaya *et al*., 2018) [43]. However, excessive irrigation can lead to nutrient leaching and root rot, while water deficit conditions can restrict root expansion and yield (Bhattacharya *et al*., 2021) [7]. Therefore, monitoring soil moisture levels is vital to understanding the exact water status of the soil profile and preventing moisture stress before it visibly impacts plant turgor (Loconsole *et al*., 2025) [20]. Determining the appropriate irrigation regime for beetroot under organic soil management can help optimize soil moisture, growth, and water use efficiency (Ali, Al Hasir 2021; Addo *et al*., 2021) [3, 1].

Integrating organic fertilizers and appropriate irrigation schedules provides a practical route to sustainable beet production (Azevedo *et al*., 2025; Shanmugam *et al*., 2022) [6, 35]. This combined approach not only enhances soil fertility but also ensures efficient water utilization and maintains optimal soil moisture levels, contributing to improved yield and resilience against climatic stress (Karri *et al*., 2024; Ndegwa *et al*., 2023) [16, 29]. Previous research on similar vegetable crops such as okra and lettuce has demonstrated the effectiveness of this approach in improving growth performance and water use efficiency under controlled irrigation (Farhan *et al*., 2023; Olaniyan *et al*., 2025) [13, 30].

Thus, the purpose of this study was to assess how irrigation schedules and organic fertilizers affected soil moisture retention, the development, and yield performance of beets (*Beta vulgaris* L.) in pot experiments. Specifically, this study aimed to determine how various organic fertilizers and irrigation levels affect soil moisture content, root production components, plant development characteristics, and water use efficiency in a semi-arid environment during both wet and dry seasons.

2. Materials and Methods

2.1 Location and experimental design

The pot experiment was conducted at the WACWISA Research Field, Nyankpala Campus of the University for Development Studies, Ghana (Latitude 9°24′N, Longitude 0°59′W). The experiment was carried out during two growing seasons, the wet season (19th July - 20th October 2022) and the dry season (24th October - 26th January 2023). The 36 pots were arranged in a 3 × 4 factorial Randomized Complete Block Design (RCBD) with three replications. Treatments consisted of three irrigation regimes: 50% Crop Water Requirement (CWR), 75% CWR, and 100% CWR, combined with three organic fertilizers; Cow Dung (CWD), Sheep Droppings (SHD), and organic compost (CMT) and a control without fertilizer (CTR). Each pot contained 12 kg of soil whose physical and chemical properties are presented in Table 1. Weather parameters recorded during the experimental periods are summarized in Table 2. Standard agronomic practices including weeding, pest, and disease management were carried out throughout the growing period.

Table 1: Soil physical and chemical properties

(a)		(b)	
Soil physical property	**Values**	**Soil chemical property**	**Values**
% Sand	76.2	Organic carbon (mg/kg)	11,895
% Silt	20.28	Total Nitrogen (mg/kg)	1,096
% Clay	3.52	Available P (mg/kg)	7.44
Textural class	Sandy loam	K (mg/kg)	88
Field capacity (%)	19.6	Ca (mg/kg)	28,056
Permanent wilting point (%)	9.1	Mg (mg/kg)	7,293
Bulk density (g/cm^3)	1.30	pH (1:2.5)	6.18
Available water (%)	10.5	EC (µS/cm)	79.9

Table 2: Weather parameters

Month	Rainfall (mm)	Tmin(°C)	T_{max} (°C)	RH_{mean} (%)	Wind speed (Km/h)
Jan	0.00	19.4	35.39	37.06	2.21
Feb	0.00	23.65	37.82	41.21	1.85
Mar	5.74	27.26	37.58	58.13	2.55
Apr	21.63	25.55	34.21	72.00	2.96
May	12.55	25.32	32.89	76.40	1.65
Jun	18.94	23.97	32.00	82.70	1.24
Jul	14.4	23.78	29.51	88.24	1.64
Aug	25.31	23.13	28.69	85.34	1.60
Sep	17.53	23.53	28.79	84.02	0.96
Oct	11.08	23.64	31.37	84.74	0.87
Nov	0.00	22.19	35.08	78.33	0.99
Dec	0.00	19.97	35.31	76.53	1.30

2.2 Soil sampling and preparation

Prior to the experiment, composite soil samples were obtained from the top layer of 0-20 cm. The soil was air-dried, sieved through a 2 mm mesh, and examined for texture, pH, electrical conductivity, organic carbon, total nitrogen, available phosphorus, exchangeable cations, and bulk density according to standard procedures (Gee and Bauder, 1986 for particle size analysis; Walkley and Black, 1934 for organic carbon]. Soil was classified as sandy loam with moderate fertility and low organic matter content (Table 1).

2.3 Organic fertilizer preparation and application

Three organic fertilizers were used: Cow Dung (CWD), Sheep Droppings (SHD), and organic compost (CMT). These materials were air-dried, crushed, and applied uniformly into the soil in each pot at a rate equivalent to 60 t/ha (Mojeremane *et al*., 2015) [27], three days before sowing. The fertilizers' chemical compositions (nitrogen, phosphorus, potassium, and organic carbon contents) are presented in Table 3.

Table 3: Chemical properties of the organic fertilizers

Properties	Cow dung	Sheep droppings	Compost
pH (1:2.5)	9.82	10.06	8.11
Total organic C (%)	22.62	31.98	12.48
Total N (%)	2.1038	2.976	1.154
Total P (mg/kg)	2580	4020	2360
Total K (mg/kg)	36100	38100	7000
Ca (Cmol+/kg)	2.6	3.2	1.8
Mg (Cmol+/kg)	1.8	1.6	1.2

2.4 Crop establishment and management

Beetroot seeds were sown directly into polyethylene pots, and seedlings were later thinned to one healthy plant per pot after full emergence. Irrigation treatments commenced two weeks after emergence, allowing plants to establish. The Crop Water Requirement (CWR) for beetroot was determined using CROPWAT 8.0 software based on local climatic data, crop coefficients, and growth stages (FAO Irrigation and Drainage Paper No. 56). The corresponding irrigation water amounts for 50%, 75%, and 100% CWR were applied via drip emitters (Table 4). Routine management practices such as manual weeding, insect-pest control, and removal of senescent leaves were conducted uniformly across treatments.

Table 4: Crop water requirement of beetroot

Month	Stage	Kc	CWR/100% Irr. Req	75% Irr. Req	50% Irr. Req	CWR	75% Irr. Req	50% Irr. Req
		Coeff	**mm/dec**	**mm/dec**	**mm/dec**	**mm/day**	**mm/day**	**mm/day**
Sep	Init	0.5	14.4	10.8	7.2	2.06	1.55	1.03
Oct	Init	0.5	21.5	16.13	10.75	2.15	1.61	1.08
Oct	Deve	0.55	24.7	18.53	12.35	2.47	1.85	1.24
Oct	Deve	0.73	36.4	27.3	18.2	3.31	2.48	1.66
Nov	Deve	0.92	42	31.5	21	4.2	3.15	2.10
Nov	Mid	1.03	47.7	35.78	23.85	4.77	3.58	2.39
Nov	Mid	1.03	45.5	34.13	22.75	4.55	3.41	2.28
Dec	Mid	1.03	43.2	32.4	21.6	4.32	3.24	2.16
Dec	Late	1.01	39.9	29.93	19.95	3.99	2.99	2.00
Dec	Late	0.95	26.3	19.73	13.15	3.76	2.82	1.88
Total			**341.6**	**256.2**	**170.8**			

2.5. Data collection and analysis

Plant growth parameters and agronomic data were measured throughout the experimental period. Weekly assessments included leaf chlorophyll intensity using a SPAD chlorophyll meter (SPAD-502 plus, Konica Minolta), Plant height using a meter rule, number of leave by manual count. At harvest, data on leaf area, leaf area index, dry bulb weight, fresh bulb weight, blub diameter, and crop water use efficiency. Data were prepared using Microsoft Excel (2019) and subjected to Analysis of Variance (ANOVA) using Minitab 21 at a 5% significance level.

3. Results and Discussion

3.1 Soil moisture variation

Figure 1 shows the variation in soil moisture content during beetroot growth in the wet season experiment. The sheep droppings added soils had the highest average soil moisture content of 38.3%, while the cow dung and compost amended soils had the lowest soil moisture content of 21.5% each. In the dry season experiment, the soil moisture content for beetroot irrigated at 100% CWR was reported in soils modified with sheep droppings, which also had the highest moisture retention capacity (Figure 2). Soils modified with sheep droppings had the highest moisture content for beetroot irrigation at 75% CWR (Figure 3). As shown in Figure 3, soils modified with sheep droppings had the maximum soil moisture content for beetroot irrigation at 50% CWR. Descriptive statistics (mean values) were utilized to show soil moisture content because the goal of this section was to demonstrate temporal variance and treatment trends. Soil moisture content was frequently measured over time, and the results were largely utilized to explain moisture retention patterns under various organic additions and irrigation regimes. As a result, mean values were deemed adequate for clearly displaying these trends.

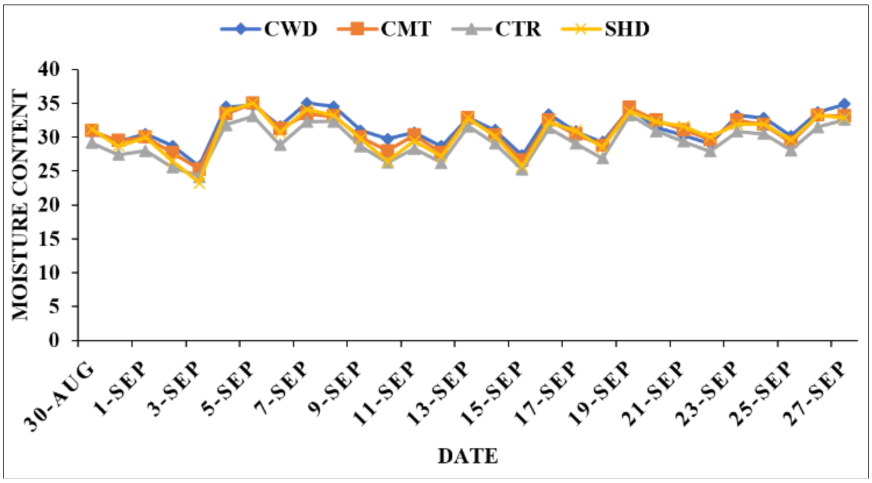


Fig 1: Soil moisture variation during beetroot production in the rainy season experiment

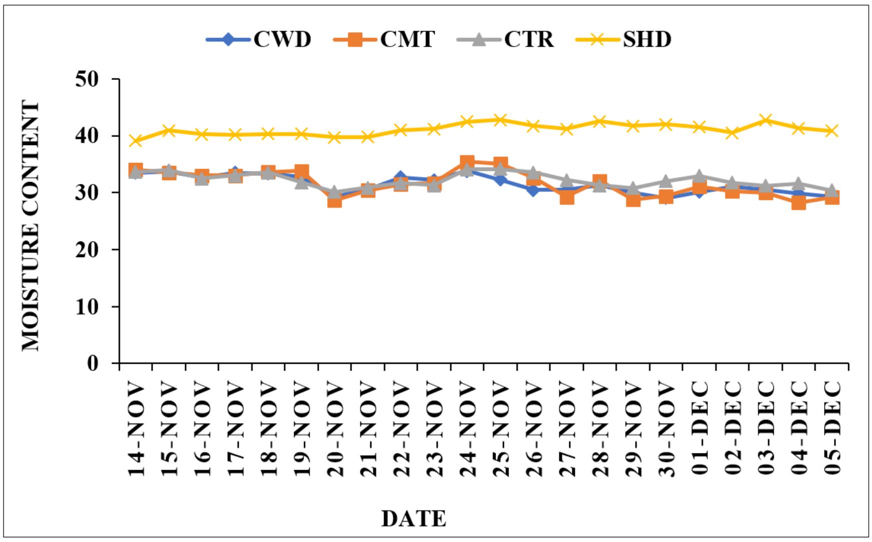


Fig 1: Soil moisture variation during beetroot production at 100% CWR irrigation regime

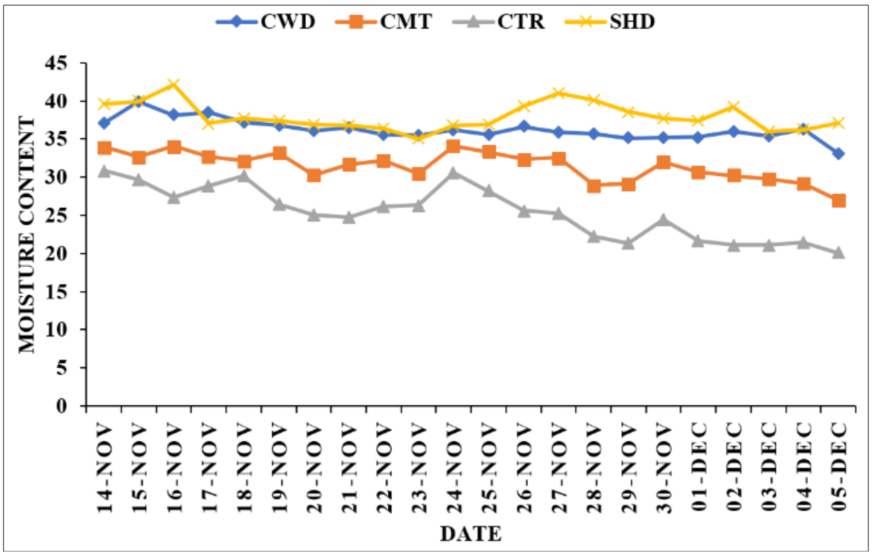


Fig 2: Soil moisture variation during beetroot production at 50% CWR irrigation regime

3.2 Growth parameters

3.2.1 Plant height

At harvest (7 WATP), the plant height of beetroot ranged from 27.58 to 30.44 cm, with the least height recorded in the plant treated with cow dung and the tallest recorded in the pot treated with compost. The ANOVA results showed that there were no significant differences (p>0.05) in the effect of organic fertilizers on beetroot plant height throughout the wet season. During the second trial, ANOVA findings indicated a significant difference at 4 and 5 WATP (p=0.006 and p=0.039, respectively). At 4 WATP, plant height ranged from 14.11 to 20.67 cm, with the lowest height reported in pots treated with cow dung and the highest recorded in pots treated with sheep droppings. At 5 WATP, plant height ranged from 17.94 to 24.28 cm, with the shortest plant in pots treated with cow dung and the largest in pots treated with sheep droppings (Table 5). Similarly, the ANOVA findings revealed a significant difference (p=0.002) between irrigation regimes and plant height of beetroot at harvest. The tallest plant measured 31.17 cm in the 100% CWR irrigation regime, followed by 31 cm in the 75% CWR irrigation regime, and the shortest, 26.67 cm, in the 50% CWR irrigation regime (Figure 4). The interaction between irrigation regimes and organic fertilizer remained statistically insignificant throughout the second experiment. At harvest, the tallest plants in the pots treated with compost were 33 cm tall; at 75% irrigation, the tallest plant was 34 cm tall; and at 50% irrigation, the tallest plant was 27.33 cm tall.

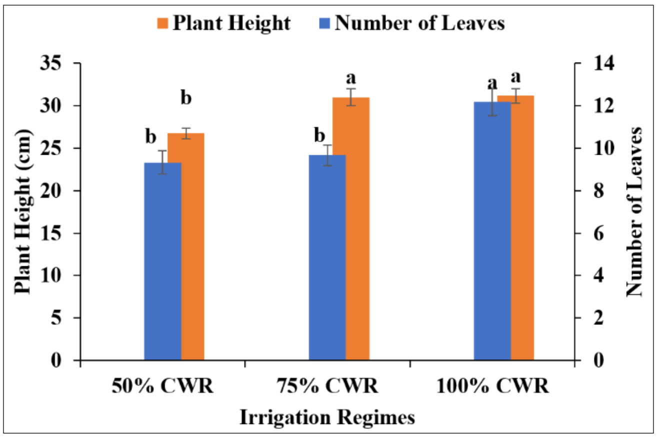
Table 5: Effect of organic fertilizer on plant height of beetroot at 4 and 5 WAP

Organic fertilizers (Treatments)	Weeks 4 WAP (cm)	5 WAP (cm)
CTR	16.22ab	20.94ab
CMT	19.43bc	22.11ab
CWD	13.75c	17.94b
SHD	20.67a	24.28a
P-value	0.006	0.039

(Means that do not share a letter are significantly different)

3.2.2 Number of leaves

The use of organic fertilizers on beets resulted in no significant difference (p>0.05) in the number of leaves throughout the wet season. However, at harvest, the average number of leaves ranged from 7.24 to 7.78, with the lowest reported in pots treated with cow dung and the greatest recorded in pots treated with compost. During the dry season experiment, ANOVA findings revealed no significant difference (p>0.05) in the influence of organic soil amendment on the number of beetroot leaves. At harvest, the average number of leaves ranged from 9.67 to 10.78, with the lowest number reported in the pot treated with cow dung and the greatest in the pot treated with compost. However, ANOVA findings demonstrated a significant difference (p<0.001) at harvest due to the effect of irrigation regimens on the quantity of beetroot leaves. The largest number of leaves (12.17) was reported at 100% CWR irrigation regime, followed by 9.67 at 75% CWR irrigation regime, and the lowest (9.33) at 50% CWR irrigation regime (Figure 4). ANOVA revealed a significant difference at 5 WATP (p=0.039) and harvest (p=0.01) due to the interaction of irrigation regimes and organic soil amendment at 5 WATP. The pots with no organic soil amendment treatment had the highest number of leaves (9.67) at 100% irrigation, while the pots treated with sheep droppings had the highest number of leaves (8.67) at 75% CWR irrigation. At harvest, 14 leaves were found in pots treated with compost at 100% CWR irrigation, 11 leaves in pots treated with cow dung at 75% CWR irrigation, and 11.79 leaves in pots treated with sheep droppings at 50% CWR irrigation (Table 6).



(Means that do not share a letter are significantly different)

Fig 3: Effect of irrigation regimes on plant height and number of leaves (Beetroot)

Table 6: interactive effect of irrigation regimes and organic soil amendment on number of leaves of beetroot at 5 WATP

Irrigation (% CWR) levels		5 WATP			AT harvest			
		Organic fertilizers						
	CTR	CMT	CWD	SHD	CTR	CMT	CWD	SHD
50%	6.33bc	6.33bc	8.00abc	8.67a	7.33f	8.67def	9.33cdef	11.79abc
75%	8.00abc	6.67bc	6.00c	8.00ab	11.00bcde	9.67cdef	8.33ef	9.67cdef
100%	9.67a	8.67a	6.67bc	8.00ab	12.67ab	14.00a	11.33abcd	10.67bcde
	P- value	0.024				0.014		

(Means that do not share a letter are significantly different)

3.2.3 Chlorophyll content

There was no significant difference (p>0.05) between the effect of organic soil amendment on beetroot chlorophyll content during the wet season. The average chlorophyll content at harvest ranged from 38.00 to 49.38 spad, with the lowest levels obtained in pots treated with cow dung and the highest in pots treated with sheep dropping. In the dry season, the ANOVA results of chlorophyll content recorded significant difference relating to the effect of organic soil amendment at 4 WATP (p=0.015), 6 WATP (p<0.001) and at harvest (p=0.033). At 4 WATP, chlorophyll content ranged from 35.31 to 44.04 spad, with the lowest levels found in pots treated with cow dung and the highest in pots treated with sheep dropping. At 6 WATP, chlorophyll content ranged from 41.55 to 54.38 spad, with cow dung adjusted pots having the lowest chlorophyll content and sheep dropping producing the greatest. The chlorophyll content at harvest ranged from 50.21 to 62.84 spad, with the lowest measured in pots treated with sheep droppings and the highest in compost-treated pots (Table 7). ANOVA revealed no significant difference (p>0.05) at harvest between irrigation regimes and beetroot chlorophyll concentration. The maximum chlorophyll content (57.53 spad) was obtained at 100% CWR irrigation, followed by 57.32 spad at 75% CWR irrigation and 54.58 spad at 50% CWR irrigation. The ANOVA findings revealed no significant difference (p>0.05) in the interaction between irrigation regimes and organic soil amendment during the dry season. At harvest the pots treated with compost recorded the highest chlorophyll content of 64.07, 64.53 and 59.93 spad in the three irrigation regimes of 100%, 75% and 50% CWR respectively. The observed variation in chlorophyll content between seasons, particularly the reversal in performance of sheep droppings, may be attributed to seasonal differences in nutrient mineralization and environmental conditions. During the rainy season, higher soil moisture likely enhanced microbial activity, leading to increased mineralization of nitrogen from sheep droppings, thereby promoting chlorophyll synthesis, as nitrogen is a key component of chlorophyll (Mondal, 2023) [28]. In contrast, during the dry season, reduced soil moisture and higher temperatures may have limited microbial activity and slowed nutrient mineralization (Maslov, *et al*, 2021; Dietterich *et al*., 2022) [25, 11]. Consequently, nitrogen release from sheep droppings may have been insufficient at later growth stages, resulting in lower chlorophyll content at harvest. Furthermore, differences in decomposition rates among organic materials may explain the improved performance of compost under dry conditions, as compost tends to provide a more stable and gradual nutrient release (Fan *et al*., 2019; Sun *et al*., 2021) [12, 38].

Table 7: Effect of organic fertilizer on chlorophyll content at 4 WATP, 6 WATP and at harvest of beetroot

Organic fertilizers (Treatments)	4 WATP (spad)	Weeks 6 WATP (spad)	At harvest
CTR	41.62a	51.72a	54.02b
CMT	39.74a	50.86a	62.84a
CWD	35.311b	41.53b	58.83ab
SHD	44.06a	54.38a	50.20b
P-value	0.015	< 0.001)	0.033

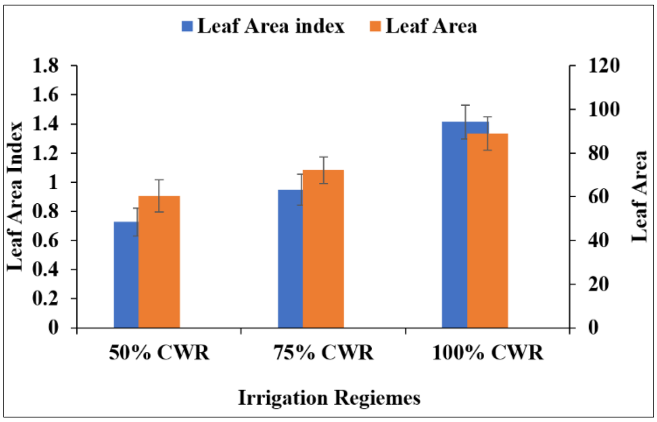
(Means that do not share a letter are significantly different) CNTRL - Control, CMPT - Compost, CWD - Cow dung, and SHD - Sheep droppings

3.2.4 Leaf area

ANOVA revealed no significant difference (p>0.05) between the effects of organic fertilizer on leaf area at the end of the rainy season. At harvest, the leaf area ranged from 40.3 to 76 cm2, with the pot with no organic soil addition having the smallest area and the pots with compost having the largest leaf area. In the dry season, there was no significant difference ($p>0.05$) in the effect of organic fertilizer on leaf area, and at harvest, the leaf area ranged from 68.7 to 78.96 cm2, with the pots treated with sheep dropping having the smallest area and the pots treated with compost having the largest area. ANOVA revealed a statistically significant difference ($p=0.033$) in the effect of irrigation regimes on the leaf area of beetroot at harvest, with the broadest leaf area of 89.1 cm2 observed at 100% CWR irrigation regimes, followed by 72.2 cm2 at 75% CWR and the smallest leaf area of 60.5 cm2 at 50% CWR (Figure 5). At the end of the dry season, there was no significant difference ($p>0.05$) between irrigation regimes and organic soil amendment, with pots treated with sheep droppings having a leaf area of 98.2 cm2, control pots with no treatment having a leaf area of 85.7 cm2, and plants in pots treated with compost having a leaf area of 84.0 cm2.

3.2.5 Leaf area index

The study's ANOVA results revealed that there was no significant difference ($p>0.05$) in the effect of organic soil amendment on leaf area index during the rainy season, but at harvest, the leaf area index ranged from 0.34 to 0.81, with the lowest recorded in pots with no organic soil amendment and the highest recorded in pots treated with compost. During the dry season, there was no significant difference ($p>0.05$) in the effect of organic soil amendment on beetroot leaf area index. However, at harvest, the leaf area index ranged from 0.951 to 1.15, with the lowest recorded in the plant pot with organic soil amendment and the application of compost. ANOVA revealed a statistically significant difference ($p=0.001$) in the effect of irrigation regimes on the leaf area index of beetroot harvested during the dry season. The maximum leaf area index of 1.41 was found at 100% CWR irrigation regimes, followed by 0.945 LAI at 75% CWR and 0.73 LAI at 50% CWR (Figure 5). At the end of the dry season, the interaction between irrigation regimes and organic soil amendment showed no significant difference ($p>0.05$). The highest LAI of 1.66 was achieved in compost-treated potted plants under a 100% CWR irrigation regime. At a 75% CWR irrigation regime, LAI was 1.25 in control pots and 0.97 in plant pots treated with compost at 50% CWR.



(Means that do not share a letter are significantly different)

Fig 4: Effect of irrigation regimes on leaf area and leaf area index of beetroot

The effect of organic soil amendment on beetroot growth characteristics was beneficial, as the plants treated with compost, sheep droppings, and cow dung had the highest plant height and the lowest performance during the rainy season. In the dry season, the experimental setup did not show a significant difference between 4 and 5 WATP for the interactive effect of organic soil amendment and plant height, though plant pots treated with sheep droppings had the highest plant height, followed by compost soil amendment and cow dung. Dlamini *et al.* (2020) [45] obtained similar results for cow dung fertilizer applied at a rate of 60 tonnes per hectare. During the dry season, the plant height of beetroot was affected by irrigation regime. The plant height was highest at 100% CWR irrigation regime and lowest at 50% CWR irrigation regime. Topak *et al*. (2011) [45] observed similar results, indicating that a 100% CWR regime provides adequate soil water supply during crop growth. During the rainy season, the plant containers treated with compost produced the most leaves, whereas those treated with cow dung produced the fewest. In the dry season, more leaves were observed in pot plants treated with compost, sheep droppings, and cow dung soil amendments, in that sequence. At 5 WATP, the 100% CWR irrigation regime produced the most leaves for the control treatment unit, but with deficit irrigation, sheep droppings had a greater benefit due to the increased leaf count. Chlorophyll concentration was highest in plant pots treated with organic soil amendment of sheep droppings during the wet season, and lowest in plant pots treated with compost during the dry season. Irrigation and fertilizer delivery at 100% CWR irrigation yielded the maximum chlorophyll concentration in compost-treated plant pots. The findings are consistent with those published by Jabeen *et al.* (2018) [47], who found that increasing the rate of manure application increased the chlorophyll content of chili leaves. However, the findings differed from those of Dlamini *et al.* (2020) [45], who found that control plants with no soil amendment had the maximum chlorophyll concentration. Chlorophyll is related with nitrogen levels, hence increasing nitrogen application can enhance the chlorophyll content of sugar beets and boost plant photosynthetic rate (Tsialtas and Maslaris, 2012) [48]. The higher chlorophyll content in some plants can be related to an increase in soil nutrients, particularly nitrogen. In the wet season experiment, plants treated with compost and sheep droppings for soil amendment had the highest leaf area and leaf area index values. During the dry season, the compost and sheep droppings had the maximum leaf area. The 100% CWR irrigation regime was found to have the highest leaf area and leaf area index, indicating that the interaction of irrigation regimes and organic fertilizer application on leaf area and leaf area index resulted in plants treated with sheep droppings having a high leaf area.

3.3 Effect of organic fertilizers and irrigation regime on beetroot yield parameters

3.3.1 Root development

In the wet season experimental period, beetroot root length ranged from 9.67 to 11.7 cm, with the shortest measured in control pots with no soil amendment and the longest in pots supplemented with sheep droppings. ANOVA revealed no significant difference ($p>0.05$) between the addition of organic soil amendment and beet root length. Furthermore, the ANOVA findings revealed no significant difference ($p>0.05$) between the influence of organic soil amendment on beet root length during the dry season. Beetroot lengths varied from 10 to 11.06 cm, with the shortest measured in compost-treated pots and the longest in soil modified with sheep droppings. The irrigation regime had a statistically significant effect (p=0.047) on beetroot length, with the 100% CWR irrigation regime producing the largest root length of 11.69 cm, followed by 10.48 cm at 75% CWR and the shortest length of 9.67 cm from 50% CWR. The interactive effect of organic soil amendment and crop water requirements on the beetroot length was not statistically significant (p>0.05). At 100% CWR irrigation regime the longest root length of 12.27 cm was recorded in pots treated with sheep droppings, at 75% CWR irrigation regime the longest beetroot length of 10.67 cm was recorded in pots treated with sheep droppings while at 50% CWR irrigation regime the longest root length of 11.67 cm was recorded in the pots treated with cow dung The interaction between organic soil amendment and crop water requirements on beetroot length was not statistically significant (p>0.05). At 100% CWR irrigation, the longest root length of 12.27 cm was recorded in pots treated with sheep droppings; at 75% CWR irrigation, the longest beetroot length of 10.67 cm was recorded in pots treated with sheep droppings; and at 50% CWR irrigation, the longest root length of 11.67 cm was recorded in pots treated with cow dung (Table 8).

Table 8: Effect of organic soil amendment and irrigation regime on beetroot's root length

Treatments	Root length (cm)
Organic fertilizers	**At harvest**
CTR	10.78a
CPT	10.00a
CWD	10.61a
SHD	11.06a
p-value	0.697
Irrigation regimes	
100% CWR	11.69a
75% CWR	9.67b
50% CWR	10.48ab
p-value	0.047

Irrigation (% CWR) levels	At harvest (cm)			
	Organic fertilizers			
	CTR	**CPT**	**CWD**	**SHD**
50% CWR	10.50ab	9.50a	11.68ab	10.25ab
75% CWR	10.00ab	9.33ab	8.67b	10.67ab
100% CWR	11.83ab	11.17ab	11.50ab	12.27a
	p- value		0.827	

(Means that do not share a letter are significantly different)

3.3.2 Bulb weight

Beetroot bulb weight varied from 19.95 to 40.72 g throughout the rainy season, with the lowest recorded in pots treated with cow dung and the greatest recorded in pots treated with compost. ANOVA revealed no significant difference (p>0.05) between the effects of organic soil amendment on beetroot bulb weight. In the dry season, ANOVA revealed a significant difference (p=0.007) between the influence of organic soil amendment on beetroot bulb weight, which ranged from 31.33 to 65.30 g. The pots treated with cow dung had the lowest bulb weight, while those treated with compost had the highest (Figure 6). Similarly, irrigation regime was significantly different (p=0.017) on beetroot bulb weight, with 100% CWR recording the highest bulb weight of 59.32 g, followed by 37.35 g at 75% CWR, and the lowest weight of 36.30 g at 50% CWR, as shown in Figure 7. The interaction between organic soil amendment and irrigation regime on beetroot bulb weight was significant (p=0.035). At 100% CWR irrigation, the pots treated with compost had the maximum bulb weight of 107.48 g, while the control pots had the highest bulb weight of 57.53 g. At 50% CWR irrigation regime the highest bulb weight of 53.16 g was recorded in the plants treated with compost (Figure 8).

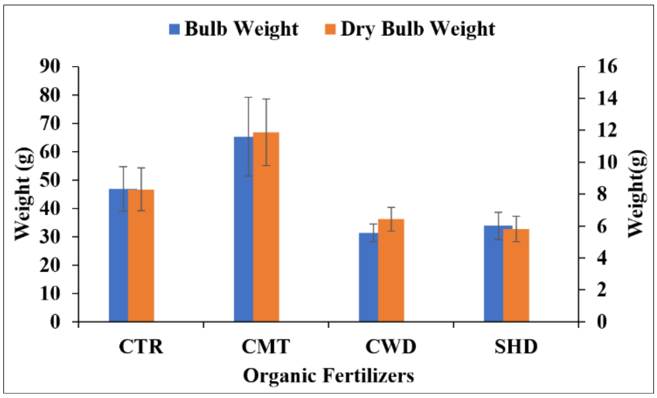


Fig 5: Effect of organic fertilizer on fresh and dry bulb weight (2nd season)

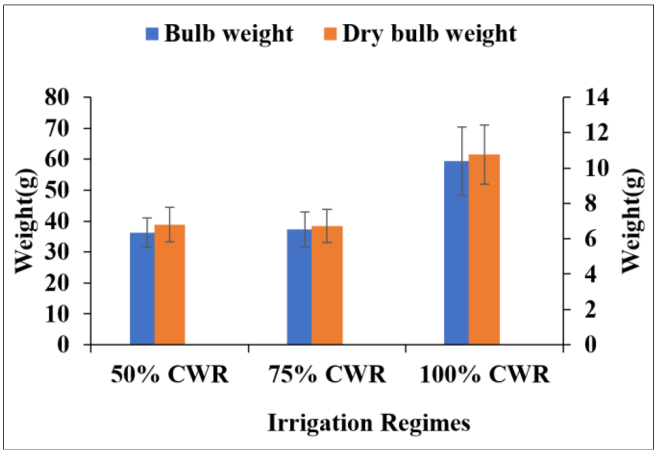


Fig 6: Effect of irrigation regimes on fresh and dry bulb weight

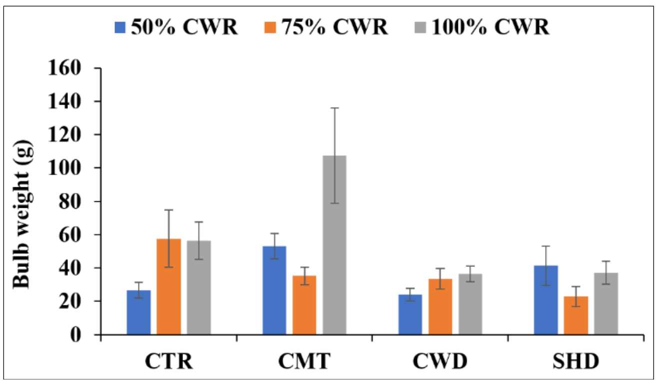


Fig 7: Interactive effect of irrigation regimes and organic fertilizer

Effect of organic soil amendment and irrigation regimes on beetroot

3.3.3 Dry bulb weight

The dry weight of beetroot during the wet season ranged from 4.06 to 6.69 g, with the lowest measured in cow dung experimental pots and the greatest in compost enriched soils. There was no significant difference (*p*>0.05) in organic supplemented soils during the wet season, but a significant difference (*p*=0.004) was seen in the dry season for beetroot dry bulb weight. Figure 6 represents the dry bulb for treatments applied as soil amendments. The effect of irrigation strategy on dry bulb weight of beetroot was significantly different (*p*=0.009) across the experimental setting, as shown in Figure 7. The combined effect of organic soil amendment and irrigation regime on dry bulb weight of beetroot was not significant (*p*>0.05). At 100% CWR, compost enhanced soils had the maximum dry bulb weight of 17.8 g, followed by control pots at 75% CWR and 10.85 g for treatments with 50% CWR and compost amendments.

3.3.4 Bulb diameter

During the wet season, beetroot bulb diameters ranged from 34.9 to 42.7 mm, with the lowest and greatest values obtained in pots with no organic soil amendment (control) and compost. ANOVA for dry season findings revealed no significant difference at *p*>0.05, however at *p*=0.001, soil amendment had a significant effect on beetroot bulb diameter. Bulb diameter in the dry season ranged from 29.0 to 36.3 mm, with the smallest in pots with no organic soil amendment and the largest in pots treated with cow dung (Figure 9). Similarly, the interaction between organic soil amendment and irrigation regime had no significant influence (*p*>0.05) on beetroot bulb diameter.

Zhao *et al*. (2019) [49] observed similar results, stating that applying organic fertilizer promotes soil aeration, allows for root growth development, and results in higher root development in the organically treated plant than the control. In addition, Dlamini *et al.* (2020) [45] found that cow manure application increased the fresh weight of beetroot compared to the control.

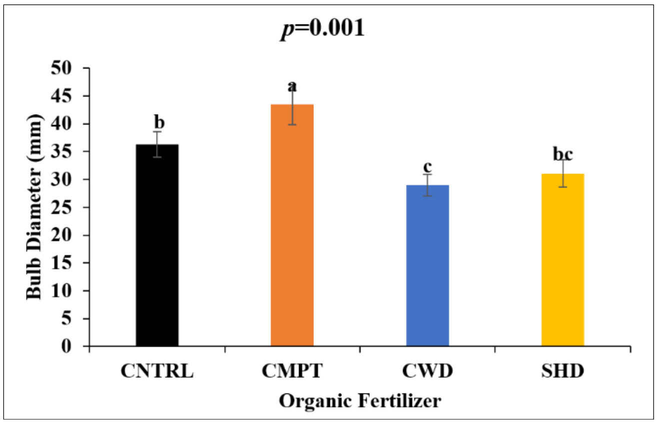


Fig 8: Effect of organic fertilizer and irrigation on yield parameters of beetroot

3.3.5 Yield of beetroot

Beetroot yields varied from 2.02 to 3.19 t/ha during the wet season and from 2.19 to 4.90 t/ha during the dry season. ANOVA revealed no significant difference (*p*>0.05) in the influence of organic soil amendments on beetroot output during the wet season, however organic soil amendment caused a significant difference (*p*=0.004) during the dry season (Figure 10). This is consistent with the findings of Piskin (2019) [32], who observed enhanced sugar beet yield with the application of sheep dung.

The irrigation regime had a significant influence (*p*=0.011) on beetroot output, with 100% CWR producing the maximum yield (4.45 t/ha), followed by 75% CWR (2.80 t/ha) and 50% CWR (2.46 t/ha) (Figure 11). This suggests that adequate water supply is critical for increasing beetroot productivity, as soil moisture improves nutrient availability, root development, and assimilate accumulation (Fereres and Soriano, 2017) [14]. The influence of organic soil amendment and irrigation scheme on beetroot yield was not statistically significant (*p*>0.05). However, numerical differences were found between treatments, with 8.06 t/ha documented in compost-amended soils at 100% CWR, 4.32 t/ha in the control at 75% CWR, and 3.99 t/ha in compost-amended soils at 50% CWR. These variations indicate that, while the overall impacts were not statistically significant, certain treatment combinations may nevertheless influence yield performance.

Overall, the yields achieved in this investigation were lower than the usual values published in the literature. This could be attributable mostly to the high temperatures encountered during the experiment. Beetroot is a cool-season crop with ideal growth temperatures ranging from 15 to 25 °C, and higher temperatures can have a negative impact on physiological activities as photosynthesis and assimilate partitioning (Khan *et al*., 2024; Yadav *et al*., 2023) [17, 44]. The maximum temperature of 41.2 °C observed in the research location most likely caused heat stress, limiting carbohydrate buildup in storage roots and hence diminishing yield. High temperature stress has been shown to diminish production by increasing respiration and decreasing photosynthetic efficiency (Sarker and Oba, 2020) [33]. Furthermore, the usage of pots containing around 12 kg of soil may limit root expansion, which is crucial for root crops like beetroot. Limited rooting capacity can limit water and nutrient uptake and inhibit store root formation, decreasing yield potential. Container-based experiments have been demonstrated to underestimate yield due to limited root growth and changed soil-plant interactions when compared to field conditions (Poorter *et al*., 2019) [31].

3.3.6 Crop water use efficiency

The average amount of water utilized for beetroot irrigation under 50%, 75%, and 100% CWR irrigation regimes was 811.5 L, 1217.25 L, and 1,836.75 L, respectively (equation 1). The average crop water usage efficiency of beetroot ranged from 1.19 to 2.671 kg/m3, with the lowest measured in pots treated with sheep dropping and the greatest in pots treated with compost. ANOVA findings revealed a significant difference (*p*=0.004) due to the effect of organic soil amendments on crop water usage efficiency in beetroot (Figure 10). Similarly, the results revealed a significant difference (*p*=0.011) in the influence of irrigation regime on the crop water use efficiency of beetroot. Crop water consumption efficiency was best at 100% CWR (2.42 kg/m3), followed by 1.53 kg/m3 at 75% CWR and 1.34 kg/m3 at 50% CWR. There was no significant difference (*p*>0.05) in the interplay of irrigation regimes and organic soil amendment on beetroot water use efficiency. At 100% CWR, greater WUE was found in plants treated with compost at 4.39 kg/m3. At 75% CWR, compost augmented soils had the greatest value of 2.35 kg/m3, whereas compost-treated pots had the maximum WUE of 2.17 kg/m3. Water supply is a major limitation on crop productivity in modern agriculture, particularly in water-scarce locations, therefore efficient water usage through irrigation is becoming increasingly crucial (Abd El-Kader *et al*., 2010) [50]. Pots treated with sheep dropping had the highest WUE in terms of organic soil amendment. Ye *et al*. (2020) [51] showed a similar large rise in WUE for pear jujube treated with sheep droppings. The results could also be attributed to the potential of organic soil amendments to improve aeration and moisture conservation. The tendency of a plant to retain moisture would result in increased water consumption and yield per unit applied (Beheshti & Behboodi, 2010) [53]. Subhan *et al*. (2017) [52] found that plants fed with organic fertilizer had higher water use efficiency than control plants in wheat farming.

$WUE = \frac{YLD}{ETc}$ ……………...Equation 1

Where:

WUE - crop water use efficiency (kg/m^3)

YLD - crop yield (kg/ha)

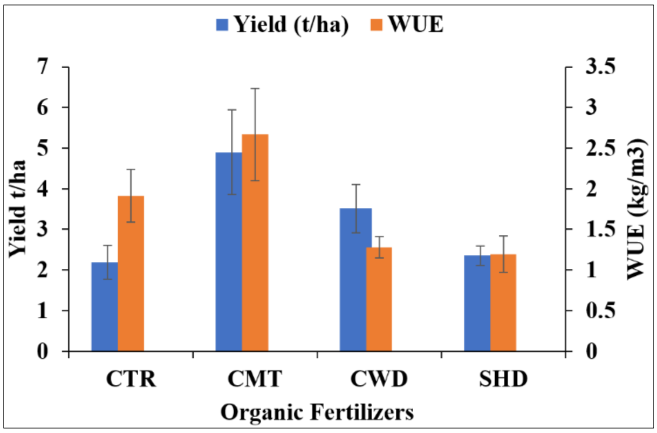
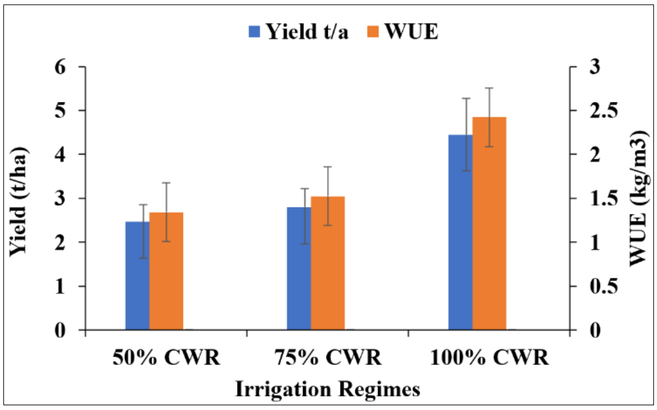


Fig 9: Effect of organic fertilizer on beetroot's yield and WUE (2nd season)



(Means that do not share a letter are significantly different)

Fig 10: Effect of irrigation regimes on yield and WUE

Effect of irrigation and organic fertilizer on yield and water use efficiency

4. Conclusion

This study has contributed to sustainable agriculture by examining the interaction between irrigation regimes and organic fertilizers in vegetable production. Regarding soil moisture dynamics, the results demonstrated that organic amendments significantly improved water retention. Sheep droppings consistently recorded the highest soil moisture content across both rainy and dry seasons, outperforming cow dung and compost at all irrigation levels (100%, 75%, and 50% CWR). This indicates that sheep droppings are the most effective amendment for improving the water-holding capacity of soils in this semi-arid environment. However, superior moisture retention did not directly translate to the highest yield. Compost proved to be the most effective fertilizer for crop performance, resulting in the highest leaf area, bulb diameter, fresh bulb weight, and overall yield (t/ha), particularly during the dry season. While sheep droppings improved vegetative height, compost appeared to provide a better nutrient balance for bulb development. In terms of water management, the 100% Crop Water Requirement (CWR) regime produced the highest plant height, chlorophyll content, and yield (4.45 t/ha). Implementing deficit irrigation (75% and 50% CWR) resulted in significant yield reductions (2.80 t/ha and 2.46 t/ha, respectively), suggesting that beetroot is sensitive to water stress in this region, likely aggravated by the recorded high ambient temperatures (up to 41.2°C). Furthermore, the interaction of 100% CWR and Compost yielded the highest Water Use Efficiency (WUE) and maximum yield (8.06 t/ha).

Therefore, these findings highlight that while sheep droppings are recommended for maximizing soil moisture retention, the application of compost combined with 100% CWR irrigation is recommended for maximizing beetroot yield and water use efficiency in the ecological conditions of Northern Ghana. Future research may focus on optimizing the nutrient release of sheep droppings or exploring a mixture of sheep droppings (for moisture) and compost (for yield) to harness the benefits of both amendments and across diverse locations in controlled environments to improve agricultural sustainability in water-scarce regions.

Author contributions

O.O.O was responsible for the conceptualization, methodology, formal analysis, investigation, and original draft preparation of this research study. F.K.A and TAA were responsible for reviewing and editing the manuscript and for visualization both F.K.A. and TAA provided supervision for the project. All authors have reviewed and approved the manuscript.

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Data availability statement

Data will be made available on request through corresponding author.

Declaration of conflicts of interest

The authors confirm that they have no conflict of interest to declare.

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