

EFFECTS OF DEFICIT IRRIGATION USING GRAVITY-DRIP SYSTEM AND NUTRIENT SOURCES ON BIOMASS YIELD AND WATER USE EFFICIENCY OF ARTEMISIA IN SAMARU, NIGERIA

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ABSTRACT

Artemisia plant produces artemisinin, a potent medication for malaria disease which is hazardous globally. In Nigeria, however, it is exclusively produced under rain-fed conditions, hardly produce under irrigation in the country. Additionally, it is not yet known whether the crop may be impacted by water stress due to the country's worrying water shortage, particularly in the northern region. As a result, this study assessed the crop response in terms of water use and production to the administration of fertilizers under drip irrigation. An on-field experiment was conducted at the Institute for Agricultural Research (IAR) farm in Samaru, from February to June 2022. The irrigation treatment levels were: 100, 80, and 60% of reference evapotranspiration (ET_o) while fertilizer treatment had levels: poultry manure and inorganic fertilizer. These treatments were replicated three times and laid out in a randomized complete block design (RCBD). For the gravity drip irrigation, two plastic tanks with a combined capacity of 3000 liters were erected on a stanchion at a height of 3.2 m above the ground and two additional tanks were positioned at the ground level to feed the overhead tanks. Mainline pipes and drip kit set were used for precise water conveyance while access tube installed at different depths was use for moisture monitoring. The highest biomass yield obtained was 8.85 t/ha at 100% irrigation level using inorganic fertilizer and irrigation water use efficiency was 9.10 kg/m³ at 60% irrigation level using inorganic fertilizer. While the lowest obtained was 3.25 t/ha at 60% irrigation level and 4.55 kg/m³ at 100% irrigation level using poultry manure, respectively. The water application rates (100, 80, and 60% ET_o) have a big impact on *Artemisia annua*'s biomass yield. *Artemisia annua*'s biomass output obtained was higher under 100% irrigation level compared to 60% irrigation level by 4.91 t/ha to 1.33 t/ha respectively. Therefore, biomass yield dropped as deficit irrigation increases, indicating that the plant is susceptible to water stress and that; irrigation deficit affects its yield, particularly when the stress is severe.

Keywords: *Artemisia*; Deficit Irrigation; Gravity-drip, Water Use Efficiency

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INTRODUCTION

One of the deadliest parasites in the world, the malaria parasite *Plasmodium falciparum* is responsible for over a million fatalities annually. Sub-Saharan Africa accounts for 90% of cases, 85% of which involve children under five. *Artemisia annua* (Sweet Wormwood) is an annual shrub. *Artemisia annua* L., is native to China and a member of the Compositae family, flourish in a variety of subtropical and temperate climates. The artemisia plant produces artemisinin, a potent anti-malarial medication. It has been used to treat malaria in China for more than 2000 years [1]. The crop is however, exclusively produced under rain-fed conditions in Nigeria, hardly produce under irrigation in the country.

Water scarcity at a global scale is increasing, making it hard to achieve sustainable agricultural production [2]. Agriculture is one of the major sources of revenue for the average person, also serves as a means of supplying necessities including food, protein, clothing, and housing. Irrigation agriculture has been a component of adaptation methods to offset the consequences of climate change in various locations, including the Guinea, Sudan, and Sahel Savannah regions [3, 4]. Hand pumps, canal water,

and rainfall were formerly the main sources of irrigation water supply from upstream to downstream or with only pumps to convey the irrigation water to the irrigation field. These techniques have had serious problems such under- and over-irrigation, which result in leaching and loss of the soil's nutrient contents [5].

A system that effectively regulates field irrigation is required due to changing environmental circumstances and a lack of water [6]. Drip irrigation has generated interest due to its capacity for modest, frequent irrigation treatments and potential for enhanced production. In the drip irrigation systems, the plant develops well with little but frequent applications without suffering from water stress between successive irrigations [7]. In the system water is applied precisely and gradually, drop by drop, grid of points on or just below the soil's surface close to a plant's root zone. This technique is popular because it makes it possible to manage both fertilizer and water effectively [6].

Deficit irrigation aims to save enough water without significantly affecting the economic production and quality of the crop. Deficit irrigation, means application of irrigation water at lower irrigation rates than the whole crop water need, is another water-saving irrigation technique that is employed in various regions of the world [7]. This technique increases water use efficiency (WUE). All

plants need adequate water supply especially within the rooting zone. In case it is insufficiently by rain, it can be covered through irrigation. The ability of farmers to control rain is highly limited if not impossible. This demonstrates that we cannot rely solely on rainfall. Consequently, irrigation is needed.

When making decisions about how to increase yields and improve quality, effective irrigation is crucial [7]. Scheduling irrigation calls for an understanding of crop water need. That is how much water a crop needs at a specific developmental stage, and how should it be applied? In addition to these, the consideration of water usage efficiency (WUE) comes to account [8]. WUE refers to economic or biomass yield per unit of water consumed. It can improve agricultural water management strategies that can lead to an improvement in crop yields, such as deficit irrigation, irrigation technology, and irrigation scheduling. It is a tool for plant management that can be used to increase crop productivity and product quality [8]. Therefore, it is essential to boost WUE while reducing the applied

water volume without impacting crop yield, especially in areas with a limited supply of water.

Despite the significance of the test crop (*Artemisia annua*) the treatment of Malaria, it is not being grown as a priority crop under irrigation. As such, it is yet unknown whether the crop is impacted by water stress due to the country's worrying water shortage, particularly in the northern guinea. As a result, this study assessed how the crop's response to in terms of production and water utilization under gravity drip irrigation system.

MATERIALS AND METHODS

Site of the experiment

The field experiment was carried out in the 2022/2023 dry season at Ahmadu Bello University's irrigation field of the Institute for Agricultural Research (I.A.R.), in Zaria, Kaduna State. It is situated in the Northern Guinea Savanna (NGS) ecological zone of Nigeria in latitude 11° 11' N, longitude 7° 38' E, and 686 m above mean sea level (Figure 1) [9].

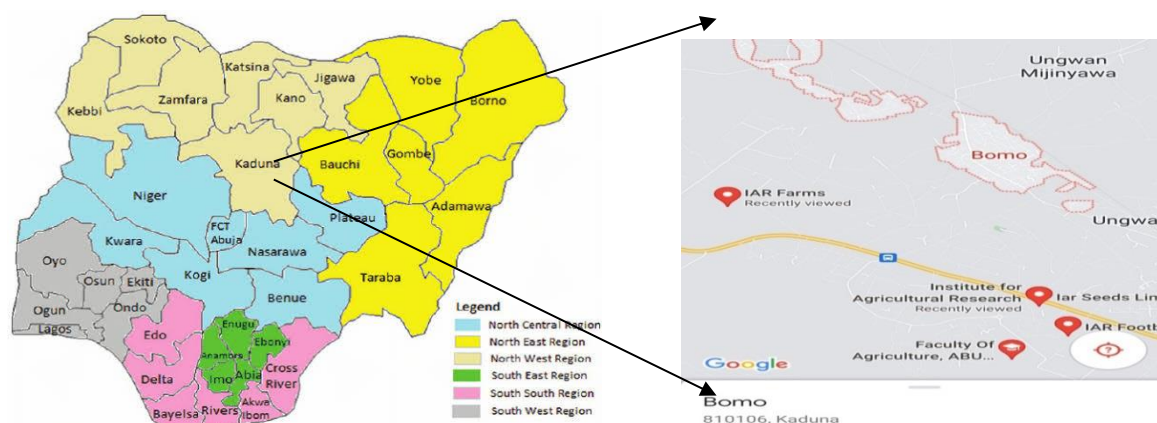


Figure 1: Location of the study area
Source: GIS analysis 2022

Soil laboratory analyses

Prior to planting, sampling within the study area was randomly conducted for various measurements. While determining bulk density, moisture content, and soil texture in the laboratory, the samples were taken at depth intervals of 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm using a theta probe moisture meter and access tubes buried below the soil surface.

Field activities

The experimental field was harrowed to provide suitable growth condition for the crop. The experimental crop (*Artemisia*) was grown in a nursery for six weeks before being transferred to a 1 × 1 m plots laid in a randomized complete block design. The field was irrigated to field capacity after pegging, using drip irrigation method, mulching was also done to minimize evaporation.

Measurement soil moisture

Using a theta probe moisture meter (ML2x), the moisture lost from the soil in increments of 60, 40, and 20 cm was measured by putting the instrument through access tubes that were previously placed in each hole, readings were taken in-situ, and the values were appropriately recorded.

Experimental design

The experiment included three irrigation levels (100, 80, and 60% of ETo) and two nutrient sources (poultry manure, PM, and inorganic fertilizer, IF), forming a total of six treatments that were replicated three times (3x2x3 = 18 plots) (Table 1).

Table 1: Treatment description of one replicate for the experiment

| S/No | Treatments | Description |
|------|----------------------|--|
| 1 | 1 ₁₀₀ +IF | (Irrigation at 100% ETo with inorganic fertilizer) |
| 2 | 1 ₁₀₀ +PM | (Irrigation at 100% ETo with poultry manure) |
| 3 | 1 ₈₀ +IF | (Irrigation at 8% ETo with inorganic fertilizer) |
| 4 | 1 ₈₀ +PM | (Irrigation at 80% ETo with poultry manure) |
| 5 | 1 ₆₀ +IF | (Irrigation at 60% ETo with inorganic fertilizer) |
| 6 | 1 ₆₀ +PM | (Irrigation at 60% ETo with poultry manure) |

Drip system design

Two sets of plastic tanks each with a capacity of 3000 liters were mounted on a stanchion and utilized as the construction materials for the gravity drip irrigation configuration (Plate 1). Each stanchion was raised to 3.2 meters height. A 1.25" (one and a quarter inch ($2.0484 \times 10^{-5} \text{M}^3$)) sub-mainline pipes, 0.25" (one-quarter

inch ($4.0967 \times 10^{-6} \text{M}^3$)) laterals, and mainline pipes with diameters of 2" (two inches ($3.2774 \times 10^{-5} \text{M}^3$)) and 1.5" (one and a half inches ($2.4581 \times 10^{-5} \text{M}^3$)) were attached and well connected. This drip kit was set up in the field, spanning a 2500 m² area with lateral lengths of 25 m and sub-main lengths of 100 m. The water was transferred from the main canal to the plastic storage tanks using a two-inch centrifugal pump.



Plate 1: Layout of experimental plots and pipe installation

Determination of emission characteristics of drip system

To assess the homogeneity of the drip irrigation components, a methodology similar to that described by [10, 11, 12] was utilized. Therefore, four emitters were chosen for each lateral pipe at four separate points along its length: at the start, a ¼, ½, marks, and at the terminal end. A pressure gauge that was mounted along the submains just before the filter was used to measure the operating pressures for each test. From the emitters, the water emitted during a period of 5 minutes were collected and its volume determined by means of a graduated measuring cylinder. These data were used in calculating the average flow for each emitter, and hence, the average emission rates.

The emission uniformity (EU) was determined using equation 1 [13]:

$$EU = \frac{q_{25}}{\bar{q}} \times 100 \quad (1)$$

The coefficient of variation of the emitter flow (CV_q) was determined using equation 2 [14]:

$$CV_q = \frac{Sd(q)}{\bar{q}} \times 100 \quad (2)$$

and the emitter flow variation (q_{var}) was determined using equation 3 [15-16]:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \times 100 \quad (3)$$

Where,

q_{25} : average discharge of 25% of the emitters with the lowest flow (l/h).

\bar{q} : average discharge of all the emitters (l/h);

q_{max} : maximum emitter discharge along the line (l/h)

q_{\min} : minimum emitter discharge along the line (l/h)

$Sd(q)$: typical deviation of the emitters discharge (l/h); emitter discharge was determine using equation 4

$$a = \sqrt{\frac{\sum (x_i - v)^2}{N}} \quad (4)$$

Where:

a = emitter discharge deviation

N = number of the emitter discharge

X_i = each value from emitter discharge

v = emitter discharge means

Determination of water application per irrigation

The water amount applied (Q_i) per irrigation was computed as a function of periodical reference evapotranspiration (ET_o , mm) for the study area and the drip wetted area (A_{dw} , m^2) for the soil sampled. Hence:

$$Q_i = A_{dw} \times ET_o \quad (5)$$

Where,

Q_i is the amount of water to be applied per irrigation (l)

A_{dw} is the drip wetted area (m^2) determined using equation 6

$$A_{dw} = \pi d^2 / 4 \quad (6)$$

The depth of water applied through irrigation, d_n , was considered as a function of the reference evapotranspiration (ET_o) for the study area [17].

The gross irrigation depth, d_g , was obtained by dividing the net irrigation depth by the system application efficiency (drip emission uniformity). Hence:

$$d_g = \frac{d_n}{E_a} \quad (7)$$

Where,

d_g = gross irrigation requirement, cm

E_a = irrigation application efficiency, %

d_n = net irrigation requirement, cm

The volume of water (m^3) equivalent to d_g was calculated as a function of an estimated percentage of wetted area as compared to the whole irrigated area, and this depends on emitter discharge, spacing and the soil type [18].

Irrigation scheduling

According to earlier studies [19] irrigation intervals were set at seven days per irrigation circle, and the volume of water applied was determined by reference evapotranspiration data for the study area. Thus, equation 8 was used to calculate the amount of water applied for irrigation:

$$V_i = A_{dw} * 7 * ET_o \quad (8)$$

Where,

V_i is the irrigation volume (m^3)

A_{dw} is the drip wetted area (m^2)

ET_o is the reference evapotranspiration (mm)

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (9)$$

Where,

ET_o = reference evapotranspiration [$mm \ day^{-1}$],

R_n = net radiation at the crop surface [$MJ \ m^{-2} \ day^{-1}$],

G = soil heat flux density [$MJ \ m^{-2} \ day^{-1}$],

T = air temperature at 2 m height [$^{\circ}C$],

u_2 = wind speed at 2 m height [$m \ s^{-1}$],

e_s = saturation vapour pressure [kPa],

e_a = actual vapour pressure [kPa],

$e_s - e_a$ = saturation vapour pressure deficit [kPa],

Δ = slope vapour pressure curve [$kPa \ ^{\circ}C^{-1}$],

γ = psychrometric constant [$kPa \ ^{\circ}C^{-1}$].

Mean weather data (Daily Maximum and Minimum Temperature, Humidity: daily Average Relative Humidity [%] or Vapour Pressure [kPa], Sunshine hours and Average daily speed in km/day or m/sec) for 10 years was used for the computation of reference evapotranspiration

Determination of irrigation running time

The drip irrigation running time (time taken to apply the required amount of water) used in administering water according to the treatments were determined as expressed by Kumari *et al.* [20]:

$$T_{drip} = \frac{N_p V}{N_e Q \times EU} \quad (10)$$

Where,

T_{drip} = Drip Irrigation time (hours)

N_p = Number of plants served by one lateral

V = Volume of water applied per plant in drip irrigation system (litre)

N_e = Number of emitters in one lateral

Q = Average emitter discharge (litre/hr)

EU = Emission uniformity (fraction)

RESULTS AND DISCUSSION

Hydraulic performance of gravity drip irrigation system

Emission uniformity in this study varied from 70% to 93% with average of 84% (Table 2). Kumari *et al.* [21] reported emission uniformity below 95% and stated that, it could be due to ageing of the drip lines, which affects emitter discharge and emission uniformity. This also confirmed the findings of Bralts *et al.* [22] who reported general rating of emission uniformity from 80 to 90% as good. The average coefficient of variation is 17.67% and the average emitter flow variation is 18.68% (Table 2). Therefore, increase in emitter flow variation is an indication of greater magnitude between minimum and maximum emission rate. Ramalan *et al.* [23] stated that, in drip irrigation, the variation average should not exceed 20%. Further, it could be observed that, the discharge emitter

decreased linearly with the operating pressure from 6.15 l/hr to 6.10 l/hr and 2.36 kPa to 2.10 kPa respectively. This could be due to elevation of the field which might have influenced the gravitational force.

The distance from the main point to the different junction could also be another reason for the decrease in pressure and emitter discharge.

Table 2: Emitter discharge, coefficient of variation and emission uniformity at different operating pressures levels

| Junction number | Emitter discharge (l/h) | Operating pressure (kPa) | Coefficient of variation (%) | Emission uniformity (%) | Emitter flow variation (%) |
|-----------------|-------------------------|--------------------------|------------------------------|-------------------------|----------------------------|
| J1 | 6.15 | 2.36 | 16 | 93 | 18.32 |
| J2 | 6.14 | 2.36 | 15 | 89 | 21.20 |
| J5 | 6.14 | 2.24 | 18 | 74 | 16.21 |
| J6 | 6.13 | 2.20 | 17 | 75 | 20.00 |
| J9 | 6.11 | 2.15 | 20 | 90 | 16.32 |
| J10 | 6.10 | 2.10 | 20 | 80 | 20.00 |

From Figure 3, the relationship between the operating pressure and the emitter discharge expressed as:

$$Q = 0.1625 * H^{0.4132}$$

Where:

Q= emitter flow rate (l/hr)

H= operating pressure (kPa)

The coefficient of determination (r^2) obtained was 0.8905, and was considered good. It shows that the expression is an appropriate model to describe the relationship between the discharge and the operating pressure of the emitters. The values of emitter discharge coefficient (k_e) and the emitter discharge exponent (x) of the drip system evaluated were found to be 0.1625 and 0.4132 respectively. The emitter is classified as PC (laminar flow regime) because it had an emitter exponent value less than 0.5 based on Jensen [24].

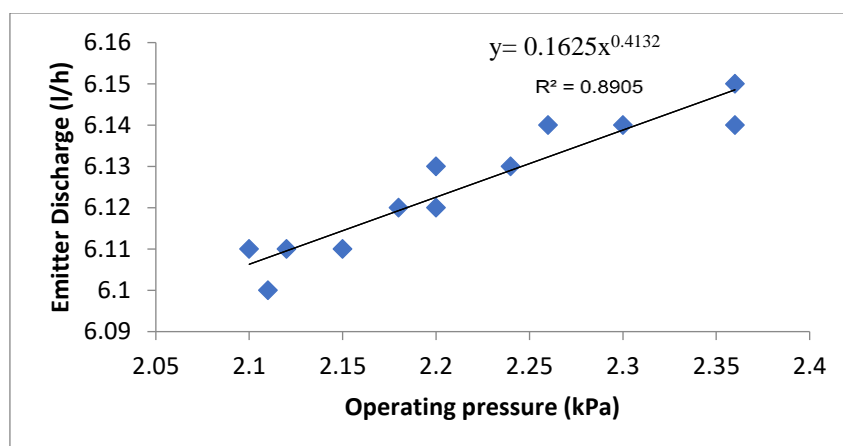


Figure 3: Means of measured emitter discharge rates at different pressure

Irrigation water use and water applied

Table 3 presented the variation of seasonal irrigation water used and water applied to the tested crop. It could be observed that, both irrigation water applied and crop water use decreased with increase in deficit irrigation (100% to 60% ETo) from 3461.17, to 3326.28 for $I_{100}+IF$ to 2057.33 to 1816.64 liters for $I_{60}+PM$, respectively. The decreasing pattern of water applied and crop water use as a result of deficit irrigation was expected, because deficit irrigation

reduces the amount of water in the soil for the crop to use without or with minimum ill effect on the yield economic quality and quantity [25]. Also, treatment with poultry manure was noticed to conserve more water than inorganic fertilizer. This is due to the fact that, poultry manure naturally conserves more moisture for a longer period of time as well as reduces the rate of evaporation from the soil around the crop [26].

Table 3: Irrigation water applied and water used (liters) for *Artemisia annua*

| S/No | Treatments | Water applied | Water use |
|------|----------------------|---------------|-----------|
| 1 | 1 ₁₀₀ +IF | 3461.17 | 3326.28 |
| 2 | 1 ₁₀₀ +PM | 3431.23 | 3251.71 |
| 3 | 1 ₈₀ +IF | 2776.75 | 2585.17 |
| 4 | 1 ₈₀ +PM | 2740.11 | 2412.84 |
| 5 | 1 ₆₀ +IF | 2111.64 | 1931.93 |
| 6 | 1 ₆₀ +PM | 2057.33 | 1816.64 |

Effects of irrigation levels and nutrient sources on the biomass yield of *Artemisia annua*

The water application rates (100, 80 and 60% ETo) and nutrient have significant effects on the biomass yield of *Artemisia annua* (Tables 4 and 5). Biomass yield of *Artemisia annua* decreased with increase in water deficit. The highest yield was obtained when irrigated fully (100% ETo), while least yield was obtained at 60% deficit. This indicates that, *A. annua* is sensitive to water stress. A recent study by Jigo *et al.* [27] found that, artemisinin content of *Artemisia annua* is higher when the crop is fully irrigated and lower at water stressed condition. These also correspond with the findings of Igbadun *et al.* [28], which reported that, the least yield of onion was obtained from the least irrigated treatment with no mulch in both seasons, and the highest yields, was

obtained from the full irrigated treatments with rice straw mulch. Similar results have been obtained by Bekele & Tilahun [29] when onion crop was irrigated using drip irrigation system. However, since surface irrigation methods such as basin and furrow, etc., flood more water, the *Artemisia annua* crop might not be as severely stressed as under deficit irrigation. Therefore, the need to further study on the artemisia response to deficit irrigation under different irrigation on similar soil and climate condition is recommended. And in this study biomass yield of 4.91 to 1.33 tons per ha was obtained which is higher than that obtainable by farmers for rain-fed system. Jha *et al.* [30] reported *Artemisia* cultivated under rain-fed, to have leaf dry weight yield ranges from 2596.12 to 3141.21 kg ha⁻¹ at pre-flowering stage.

Table 4: Effects of irrigation levels and nutrient sources on biomass yield of *Artemisia annua*

| Treatment | Biomass yield t/ha |
|---------------------------------|--------------------|
| Irrigation level (I) (%) | |
| 100 | 7.81a |
| 80 | 6.09b |
| 60 | 3.67c |
| SEt | 0.21 |
| Nutrient Source (PMI) | |
| PM | 4.59b |
| IF | 7.12a |
| SEt | 0.17 |
| Interaction | |
| I*PMI | ** |

** significant at 1% level

Table 5: Irrigation level and nutrient application interaction on biomass yield (t/ha) of *Artemisia annua*

| Nutrient | Irrigation level (%) | | |
|----------|----------------------|-------|-------|
| | 100 | 80 | 60 |
| PM | 7.77b | 5.58d | 3.25f |
| IF | 8.85a | 6.91c | 4.06e |
| SEt | 0.42 | | |

Effect of irrigation levels and nutrient source on irrigation water use efficiency of *Artemisia annua*

The irrigation water use efficiency indicates how good a yield could be obtained using efficient irrigation water. The water application rates (100, 80 and 60 %

ETo) and fertilizer types (Inorganic and poultry manure) have significant effects on the IWUE as presented in Table 6. Although, poultry manure is expected to improve the water retention capacity of the soil. However, in this study, the best water management was obtained when irrigated at 60% ETo and by applying inorganic fertilizer. This is because the poultry manure was applied around the wetted area (for drip irrigation), which is a small portion compared to the net cropping area, resulting in minimum water saving from evaporation. Further, the yield obtained using the 100% inorganic fertilizer was higher thereby resulting in higher IWUE.

Generally, irrigating the crop at 60% ETo using inorganic fertilizer, gives higher irrigation water use efficiency. This is expected because deficit irrigation aimed at minimizing the water use without

much effect on the yield. This corresponds with findings of [31, 32, 33]. Therefore, about 40 % of irrigation water could be saved when a deficit irrigation of 60% ETo is used to cultivate the crop. Biomass yield of *artemisia annua* is affected by water stress as reported earlier; however, deficit irrigation of 60% ETo is a good strategic option for *artemisia annua* crop in areas where there is water scarcity. Research have shown that higher crop water productivities are sometimes recorded with deficit irrigation practice, if the moisture stress resulting from the deficit is not much [34-37]. They further reported that under conditions of scarce water supply, deficit irrigation could provide greater economic returns than maximizing yields per unit of area. There is a growing interest in deficit irrigation as a means of improving water productivity.

Table 6: Irrigation level and nutrient application treatment interaction on IWUE

| Nutrient | Irrigation level (%) | | |
|----------|----------------------|--------|-------|
| | 100 | 80 | 60 |
| PM | 4.55e | 5.19d | 5.71b |
| IF | 5.66bc | 5.66bc | 9.10a |
| SEt | 0.28 | | |

CONCLUSION

The water application rates (100, 80 and 60% ETo) and nutrient source have significant effects on the biomass yield and irrigation water use efficiency of *Artemisia annua*. The highest biomass yield obtained was 8.85 t/ha at 100% irrigation level using inorganic fertilizer and irrigation water use efficiency was 9.10 kg/m³ at 60% irrigation level using inorganic fertilizer. While the lowest obtained was 3.25 t/ha at 60% irrigation level and 4.55 kg/m³ at 100% irrigation level using poultry manure, respectively. Biomass yield of *A. annua* decreases with increase in deficit irrigation, which indicates that, *A. annua* is sensitive to water stress. Although, the biomass yield of *artemisia annua* is affected by water stress as reported earlier, however, deficit irrigation of 80% ETo is a good strategic option for *Artemisia annua* crop in areas where there is water scarcity.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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