ESJ Natural/Life/Medical Sciences Peer-reviewed

Performance Optimization of a Simple Drip Irrigation System with Used Plastic Water Bottles

Zakaria Issaka
Department of Agricultural Engineering,
Tamale Technical University, Northern Region, Ghana
Abdul-Latif Husein Alhassan
Department of Water and Environmental Engineering,
Tamale Technical University, Northern Region, Ghana

Doi:10.19044/esj.2024.v20n21p170

Submitted: 16 August 2021
Accepted: 30 July 2024
Published: 31 July 2024

Cite As:
Issaka, Z., & Alhassan, A.-L. H. (2024). *Performance Optimization of a Simple Drip Irrigation System with Used Plastic Water Bottles.* European Scientific Journal, ESJ, 20 (21), 170. https://doi.org/10.19044/esj.2024.v20n21p170

Abstract

Effects of perforation sizes and heights of used plastic water bottles on growth and yield components of *amaranthus spinosus L.* crop were analyzed in this study. The experiment was conducted on a 38 m^2 experimental field of Tamale Technical University using a Randomized Complete Block Design with four treatments and replications. Perforation sizes at different heights of bottles from the ground level combinations were: 3.2 mm, 5 cm (A); 3.2 mm, 10 cm (B); 3.2 mm, 15 cm (C); 3.2 mm, 20 cm (D), respectively. Data on growth and yield components of amaranthus crop were measured and analysed using ANOVA. Results showed a decreasing trend for both irrigation time and perforation size and height of the plastic bottle from the ground level. Significant differences were observed between the treatments A and D, B and C, B and D, and C and D for leaf area, number of leaves, plant height, stem girth, root length, and weight of amaranthus crop head. However, perforation size of 3.2 mm with the plastic water bottle raised at a height of 5 cm from the ground resulted in significant growth and yield of amaranthus crop, followed by B, C and D treatments. Small holder farmers can adopt used water plastic bottles with perforation size of 3.2 mm raised 5 cm from the ground level in order to boost the production of amaranthus crop.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Keywords: Plastic bottle, drip irrigation, perforation size, height of bottle from ground

Introduction

A major challenge in the 21st century is how to feed the growing world population in the face of climate change (Fróna et al., 2019; Foley et al., 2011). In addition to requiring institutional changes, global crop production needs to double to meet the demand by 2050 (Bahar et al., 2020; Tillman et al., 2014; Alexandrators and Bruinsma 2012; Valin et al., 2014). Global cereal production would decrease by 20 % without irrigation (Siebert and Doll, 2010), and climate change and population growth will further enhance the role of irrigation plays in the future of agriculture (Wang et al., 2018; Neumann et al.2011; Plusguellec 2002). In the past 50 years, irrigated area has doubled (Ngiah-Sah, 2021; FAO, 2018; Siebert et al., 2015) and about 24% of the total harvested cropland is irrigated, producing more than 40% of the global cereal yield (Mehta et al., 2024; Norain et al., 2019: Portman et al., 2010) irrigation is the single largest global freshwater user, accounting for ~70 % of water withdrawal and 80-90 % of water consumption (Gleick et al., 2009).

In Ghana, agriculture is vital for overall economic development since it is the largest contributor to the Gross Domestic Product (GDP) accounting for about 50 %. It also accounts for about 60 % of export earnings and directly or indirectly supports 80 % of the total population economically through farming, distribution of farm products, and provision of other services to the agricultural sector (MoFA, 2022). A vital area necessary for the modernization of agriculture in Ghana is irrigation. Unfortunately, the total area under irrigation as of 1996 was estimated at 11,000 ha which is only 0.44% of the total land area or just 0.26% of the area under cultivation (Sant Anna, 1997). This has barely changed and this goes to buttress the fact that Agriculture is mainly rain-fed, subject to the vagaries of the weather despite the fact that yields are greater and cropping is twice yearly on some irrigated schemes (MoFA 2022; Memuna and Cofie, 2005).

Current channel irrigation efficiencies in Ghana are generally below 50%, as much of the diverted water is lost in the conveyance system or through inefficient application to the plants. The magnitude of these losses is determined primarily not only by the irrigation system (eg. sprinkler, surface, drip) but also by metrological and other environmental conditions. However, only water that leaves the system without a benefit for crop growth, such as evaporation from bare soil and other non beneficial components (weed transpiration) should be considered a manageable loss, (Kelly and Keller, 1995). Since the beginning of crop production, irrigation has been used to reduce crop drought stress by compensating for low precipitation.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

The growing recognition of irrigation problems and their impact on the economy and environment have prompted the government of Ghana to implement plans and strategies to encourage new drip irrigation technologies to promote sustainable irrigated agriculture. One issue that generates a lot of pessimism about irrigation in Ghana is the issue of cost. Inadequate feasibility studies led to costly design changes during the construction of irrigation projects and hence the involvement of expensive expertise at all stages of the project cycle at the early stages of nationhood. Perforation size and height of the bottle from ground level determine the irrigation time and efficiency of the drip irrigation system. Hence, there is a need to research into these parameters and how they affect irrigation efficiency and crop parameters. In this study, a simple drip irrigation system with used water bottles was designed, and the performance parameters were optimized in order to meet the needs of small-holder farmers and sustain crop production.

Methodology

Study area

The experiment was conducted at the experimental field of Tamale Technical University located in the Northern Region of Ghana. It lies between latitude 9° 17’ and 10° 6’ N and longitude 1° 2’ and 1° 19’ W (Zakaria et al., 2014) as shown in Figure 1.

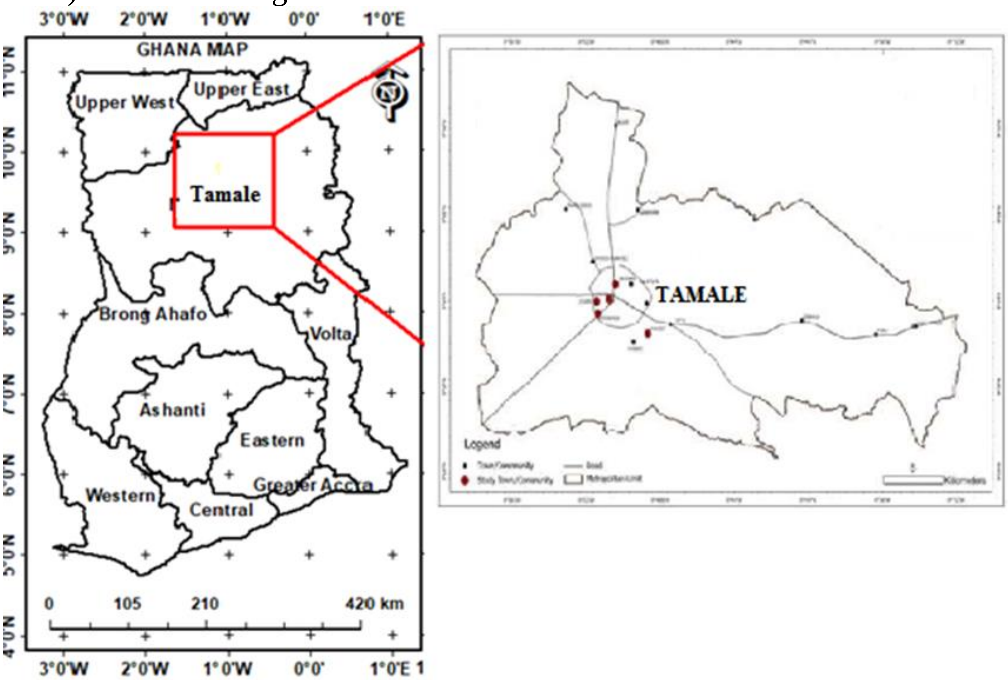


Figure 1. Location map of the study are

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

The climatic conditions in the are characterized by a mean annual rainfall of 1100 mm, a relative humidity of 75 %, and a temperature range of 15 °C to 42 °C, with an average annual temperature of 28.3 °C. The rainy season typically begins in May and extends through to October, with peak rainfall occurring between July and August. However, the dry season spans from November to March (Alhassan *et al*., 2014). Soils in the area are generally sandy loam and support the cultivation of various types of crops.

Land preparation

The land was prepared by clearing weeds using a cutlass, and hoe, and finally, a rake was used to convey the debris out of the field in order to make the land convenient to construct the bed. The area of the field was measured as 10 m x 3.8 m (38 m^2). Four beds were prepared and labeled with placards as Test 1, Test 2, Test 3, and Test 4 as shown in Fig. 1 below. Each test bed measured 3.8 m x 1.7 m (6.46 m^2). Seeds from the amaranthus crop were nursed before *t*ransplanting the seedlings into the field with two lines (Figure 2).

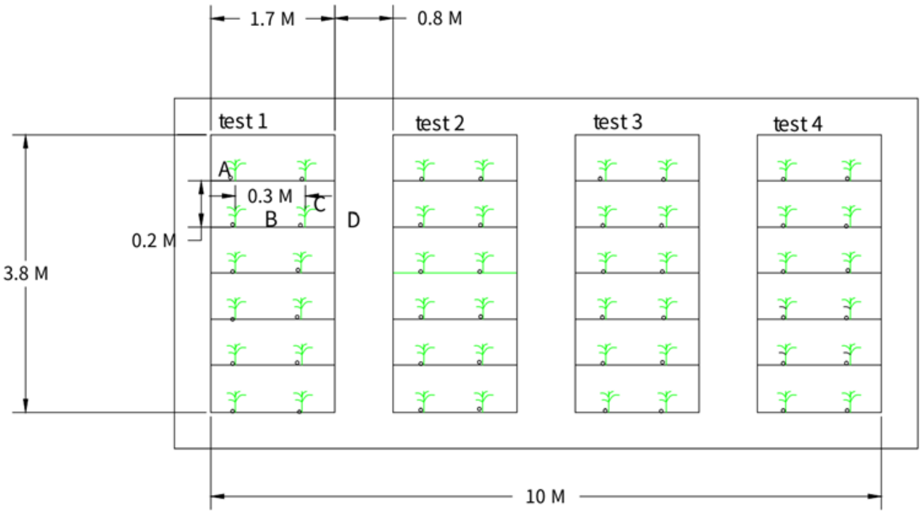


Figure 2. Field layout of used plastic water bottle drip irrigation system

Flow calibration for the drip system

Wooden posts were erected at the two ends of each bed, and a rope was tied to the top end of the wooden posts to enable the plastic bottles to be hung directly above the base of each plant. As can be seen in the schematic diagram (Figure. 3), the distance between the plastic bottles was based on the plant spacing of 20 cm x 30 cm. As shown in the figure below, the plastic bottles were placed close to the base of plants, holes of different diameters were perforated in the bottom part of the bottles and water was filled to maximum in each bottle.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

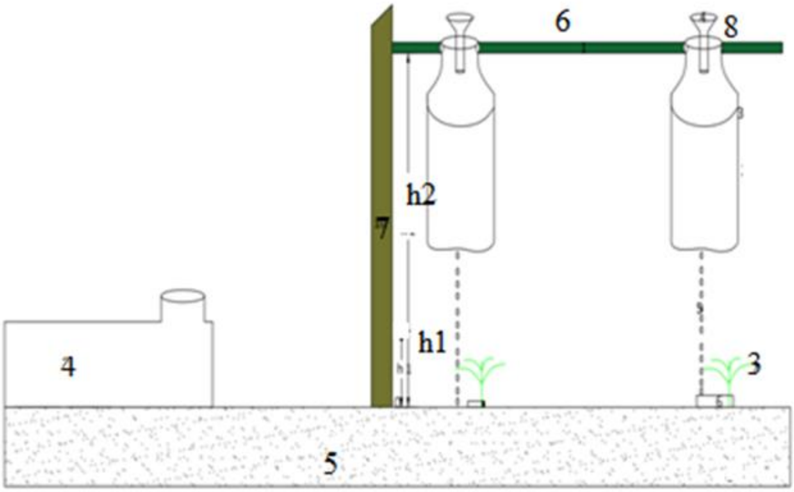


Figure 3. Flow calibration of used plastic bottle drip irrigation system: *2. used plastic bottle, 3. crop, 4. storage tank, 5. ground level, 6. rope, 7. stake, 8. funnel, h_1. height of bottle from ground, h_2. height of bottle*

Due to the force of gravity acting on the water in the plastic bottle, water drips continuously from the bottle and wets the base of the plant. The base of each crop was mulched with grass to prevent splashing of the soil at the base of the crop during the dripping of water. The pressure exerted by a static fluid or hydrostatic pressure, is the pressure in an equilibrium system that depends on the depth of the water in the used plastic bottle, the density of the water, and the acceleration of gravity. Hence, the pressure exerted by the water is given:

$$P = \rho g h \quad (1)$$

where; P is the pressure of water in the plastic water bottle (N/m^2), p is the density of water (kg/m^3), g is acceleration of gravity (m/s^2), and h is the depth of water in the plastic bottle (m)

Measurement of flow parameters

Infiltration rate

Flow rate and irrigation time

Irrigation time is the time taken for the required amount of water to wet the root zone of the crop. It plays a key role in determining the optimum perforation size and height of the plastic bottle to achieve maximum irrigation efficiency. Irrigation time was determined by closing the hole punched at the bottom part of the plastic bottle and filling it with water, then opening the hole for the water to drip. The time was recorded with a stopwatch when the bottle had emptied all the water. This was repeated for all the four treatments.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Distance a droplet of water cover from the bottom of the bottle to the ground and the time taken to empty the plastic water bottle for each treatment. The experiment was repeated three times to calculate the average velocity and wetted cross-section area. The flow rate, q was calculated using Equation 2 below.

$$q = vA \tag{2}$$

where; q is the flow rate (m^3/s), v is the average velocity of flow (m/s), and A is the cross-section area of the perforation (m^2)

Depth of water application

The depth of water applied during irrigation is the amount of water is stored within the root zone between field capacity and minimum allowable balance for a given crop and soil. Net depth of irrigation was calculated using Equation 4.

$$dnet = p(FC - PWP)d \tag{4}$$

where; *dnet is the net depth of irrigation (mm), p* is depletion fraction, *FC* is Field capacity (mm), *PWP* is permanent wilting point (mm) and *d* is root depth (mm).

Measurement of growth and yield components

Plant height

Plant heights were measured in a week interval from the ground level to the end of the terminal bud using measuring tape, and this was repeated and the mean was calculated and recorded.

Stem girth

The stem girth of the tagged plants from each net plot was determined using an electronic digital venire caliper, their mean was calculated and recorded also in weekly intervals.

Leave area

The leave area of the whole sampled plant was determined every week by measuring the individual leaf length and width and multiplying by 0.64 (Kolawole and Sarah, 2009) and the result obtained was recorded. This is the ratio of the total area of leaves to the ground area occupied by the crop (Forbes and Watson 1992). Thus.

$$LAI = \frac{LA}{GA} \tag{6}$$

where; *LAI* is Leaves area index, *LA* is leaf area (m^2), and *GA* is ground area (m^2)

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Statistical analysis

The data collected was scanned, edited, and fed into the computer, where Microsoft Excel software was used to perform t-tests on the treatments in order to select the optimum combination of perforation sizes and heights of the used plastic water bottle for optimum growth and yield of *Amaranthus crop*.

Results and discussion

Characteristics of experimental soil

Characteristics of experimental soil are summarized in Table 1. Sandy loam soil is the most dominant soil in the area and is generally suitable for growing lettuce crops. The experimental site has 25.0 6% and 11.16 % FC and PWP, respectively. The average volume percentage of TAW was 126 %.

Table 1. Characteristics of experimental soil

Soil Characteristic	Value
Sand	9.33 %
Silt	9.33 %
Clay	25.3 %
Organic Matter, OM	0.84 %
Field Capacity, FC	23.2 %
Permanent Wilting Point, PWP	11.16 %
Total Available Water, TAW	139.10 mm/m
Electrical conductivity, EC	0.68 dS/m
pH	7.24

Infiltration rate of soil

Infiltration rate is the speed at which water enters into the soil and it is measured by the depth (mm) of the water layer that can enter the soil in one hour. In this study, the infiltration rate of the soil in the study area was calculated from the graph by calculating the gradient which was 1.92 mm/min as shown in Fig. 3. Infiltration rate is how fast water moves from the soil surface into the soil. Different types of soils have different rates of infiltration. Results from the field tests give a calculated value of infiltration rate of 1.9 mm/hr. In Figure 4, it can be seen that the infiltration rate was more rapid at the beginning of the test, which slowed down after 40 minutes of the test. This happened because the type of soil found in the study area is predominately sandy loam. However, as more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

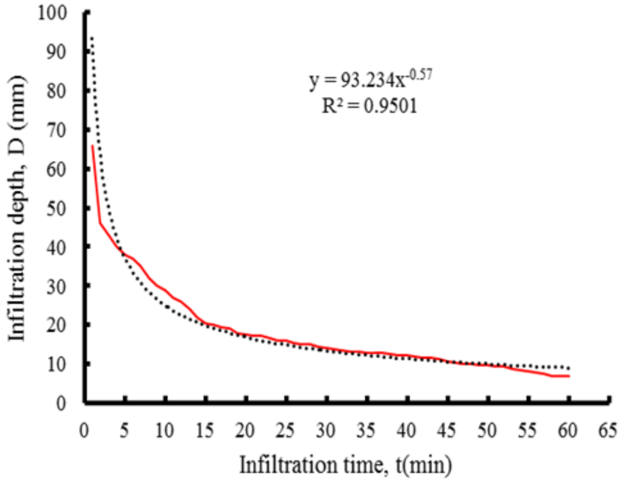


Figure 4. Infiltration rate of sandy loam soil in the study area

It can be observed that at the early stage, the infiltration rate was very high within one minute but as it gets along to the last part of the infiltration curve, the rate of infiltration gradually declines. Based on the result obtained, the infiltration rate of the soil in the study area could be good for the production of amaranthus crop.

Application rate

Application rate is the depth of water that the irrigation system applies to crops at a specific time. Results of the application rates are presented in Table 2. It can be observed from the table that the application rate and the wetted area increased with the increase in the perforation size of the bottle.

Table 2. Application rates of different treatments

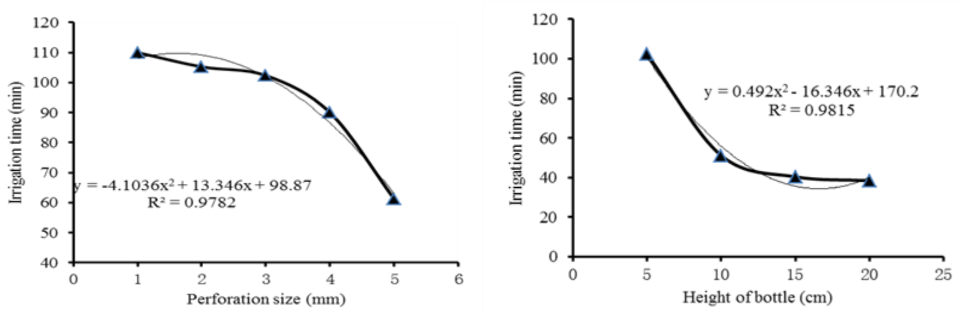
Treatment	Application rate, q (cm/min)	Wetted Area, A_w (cm^2)
A	0.17	0.1018
B	0.19	0.1256
C	0.22	0.1075
D	0.31	0.1256

However, the results show that there was no statistical difference among the treatments A, B, C, and D. This means that treatment A could also give a better application rate with a large wetted area which is necessary for meeting crop water requirements.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Effects of perforation size and height of bottle on irrigation time

Figure 5 below shows the relationship between different perforation sizes and irrigation time. The effect of perforation size (mm) and irrigation time (mm) can be observed when the perforation size of the bottle is small; it takes a longer time for the water to drip off from the bottle. However, it takes a shorter time for the water to drip off when the perforation size is large. It can be seen that the optimal perforation size was 3 mm with an irrigation time of 104 min.



(a) (b)

Figure 5. Effect of used water bottle on irrigation time: (a) Relationship between perforation size bottle and irrigation time: (b) Relationship between height and irrigation time

A mathematical model was developed that can be useful for determining the irrigation time when the perforation size and height of the bottle from the ground level is known. The perforation size and height of the bottle remain constant, it is only when the pressure acting on the bottle decreases. This means that the water in the bottle is also finishing which will reduce the speed of flow of the water, indeed the height may change little but it does have an effect on the perforation size and that of time.

Leave area index

The mean leaf area index was 0.948, 0.882, 0.759, and 0.521 for treatments A, B, C, and D respectively (Figure 6). Results of the analysis of variance showed that the effects of different water levels influenced leaf area index significantly between treatments A and B (0.05, $p>0.05$), A and C (0.189, $p>0.05$), A and D (0.427, $p>0.05$), B and C (0.123, $p>0.05$), and C and D (0.238, $p>0.05$). This might have led to increasing the level of water, and as the plant continues to grow, an adequate amount of water would be required to carry out chemical activities such as cell division and as the cell divides multiple smaller cells are formed.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

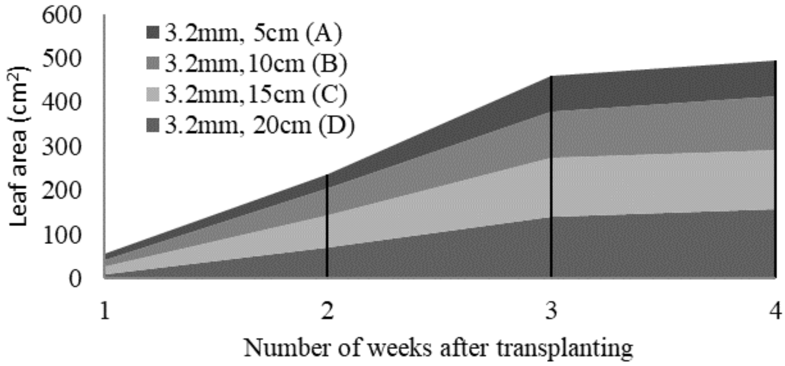


Figure 6. Effects of the treatments on leaf area

The process of increasing the number of cells increases also the leaf area and hence the area index with respect to the water uptakes. These analyses are in agreement with the results reported by Karam et al. (2002) and Bozkurt and Mansuroğlu (2011) who obtained higher head diameters at full irrigation treatment (Steven L. Peter et al., 2019). It is important to avoid water stress during the period of head formation, the most critical period of amaranthus crop for irrigation.

Plant height

Results for the mean values were 42.7 cm, 43.25 cm, 41.0 cm, and 38.5 cm for treatments A, B, C, and D respectively (Figure 7). The effects of watering on plant height showed a significant difference between treatments A and C (1.7, $p > 0.05$), A and D (4.2, $p > 0.05$), B and C (2.25, $p > 0.05$), B and D (4.75, $p > 0.05$), and finally C and D (0.2.5, $p > 0.05$). Amaranthus crop requires a sufficient amount of water for growth because it is sensitive to any small amount of water, it begins to respond in accordance to the water intake, and as the water increases, so as the plant increases especially from the initial stage to maturity.

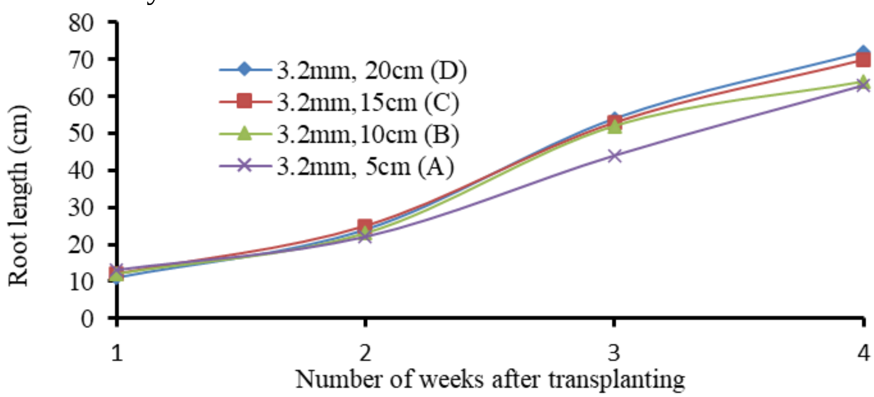


Figure 7. Effects of the treatments on plant height

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

During this period, photosynthetic life processes take place where water is transported from the soil through the stem to the leaves and various plant parts for chemical processes, leading to plant increment or growth. Yazgan et al. (2008) reported that the irrigation water level in amaranthus crops had significant effects on plant height and obtained the highest plant height values from full irrigation levels. Kirnak et al. (2002) also pointed out that plant height for amaranthus crops increased significantly with increasing irrigation water applied. However, there was no significant difference between A and B (0.032, p>0.05). Amaranthus crop is very sensitive to small amounts of irrigable water and will increase as the water level increases, so will it decrease as the water decreases, this is to say that water stress should be avoided in Amaranthus crop production because of heavy dependency on water.

Stem girth

Mean values of stem girth were 5.9 cm, 5.2 cm, 5.1 cm, 4.2 cm for treatments A, B, C, and D, respectively (Figure. 8). The analysis of variance showed that there was a statistical difference in the effects of perforation size and height of bottle on stem girth between treatment B and D (1.0, p>0.05), A and C (0.8, p >0.05), A and D (1.7, p >0.05), B and C (0.100, p>0.05). We also observed an incremental trend in stem girth for all the treatments in this study (Figure 8).

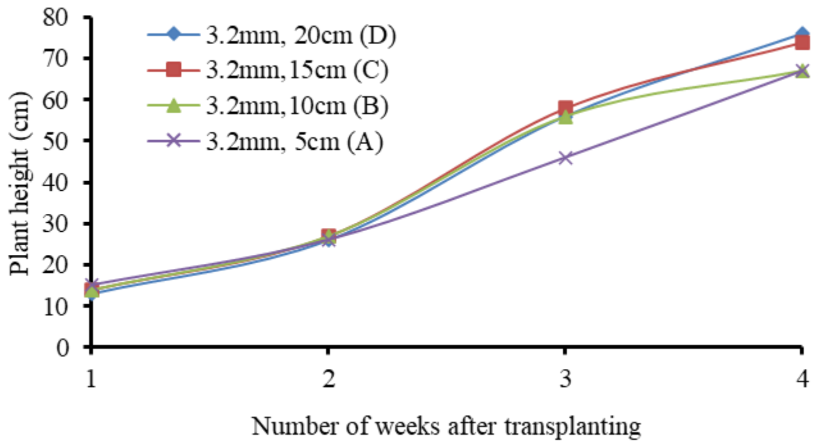


Figure 8. Effects of the treatments on stem girth

In plant cells where the cell sap is immersed in pure water, inward osmosis of water into the cell sap ensures. This results in the exertion of turgor pressure against the protoplasm, which in turn is transmitted to the cell wall. The pressure also prevails throughout the mass of solution within the cell. If the cell wall is elastic some expansion in the volume of the cell occurs as the

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

result of pressure which may also increase stem girth. However, there were no significant differences between A and B (0.045, $p>0.05$). These occurrences might be associated with water stress, when plants lack water pressure begins to pile up at the root and this will be transmitted via the stem since there will be demand at the leaves zone for photosynthesis and other physiological activities this demand might cause shrinkage of the stem.

Root length

Mean values for root length from the analyzed data were 40.25 cm, 40.0 cm, 37.75 cm, and 35.75 cm for treatments A, B, C, and D respectively (Figure 9). Results from the statistical analyses showed significant differences in terms of root length between treatments B and C (2.25, $p>0.05$), B and D (4.25, $p>0.05$), C and D (2.0, $p>0.05$). It can be seen from Figure 9 that the length of the root increased with the number of weeks after transplanting.

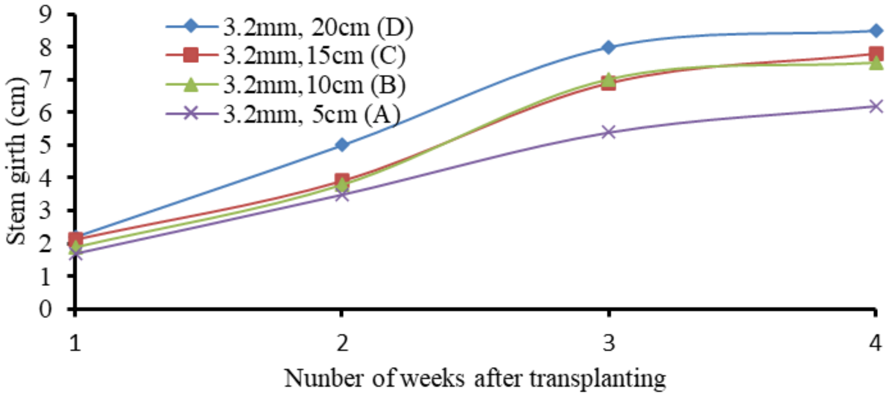


Figure 9. Effects of the treatments on root length

Whenever the water potential in the peripheral root is less than that of the soil water, movement of water from the soil into the root cells occurs. This occurrence might enable the roots to absorb some chemical element from the soil in the form of nutrients which may result in either increasing the length or the weight.

Weight of amaranthus crop head

Average values were 2.4 g, 1.7 g, 1.3 g, 1.1 g for treatments A, B, C and D, respectively (Figure 10). The analysis of variance observed a significant difference between the treatments in terms of head weight of amaranthus crop A and B (0.7, $p>0.05$), A and C (1.1, $p>0.05$), A and D (1.3, $p>0.05$) and B and C (0.4, $p>0.05$). However, we observed a decreasing trend in the weight of amaranthus crop head after transplanting. This could be due to the fact that the amaranthus crop tends to lose water at maturity.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

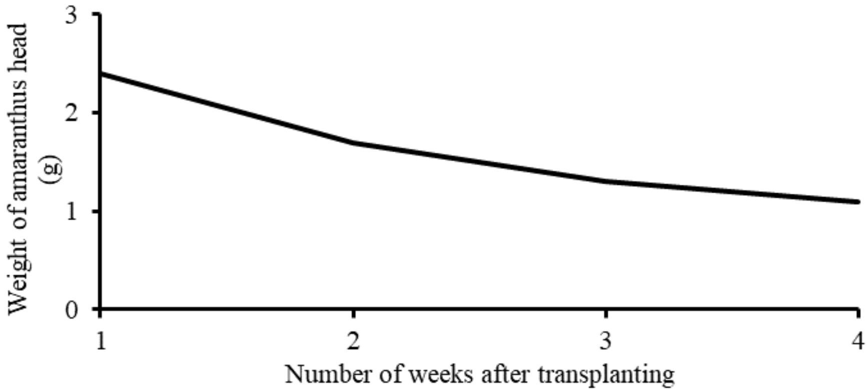


Figure 10. Effects of the treatments on weight of amaranthus head

Water is the most abundant constituent of all physiologically active plant cells. Leaves for example have water content that lies mostly within a range of 55- 85 % 0f their fresh weight. Amaranthus crop is very sensitive to small amounts of irrigation water this might have led to the increase in the amount of water contained within the leaf. More so, the more you apply water the higher the leaves absorb the water and hence increasing the amaranthus crop head weight. Our results disagree with that of Acar *et al*. (2008) which states that there was no significant variation in head and marketable head weight in all irrigation levels.

Number of leaves per plant

The mean values from the analysis were 14.5, 12.5, 9.5, 8.5 for Treatment A, B, C, and D respectively (Figure. 11). Results of the statistical analysis showed significance between treatments A and B (2.0, $p>0.05$), A and C (5.0, $p>0.05$), A and D (6.0, $p>0.05$), B and C (3.0, $p>0.05$). The number of amaranthus leaves also decreased with the number of weeks after transplanting. It is possible for the amaranthus crop to lose some leaves throughout its entire growth period, particularly at the maturity stage.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

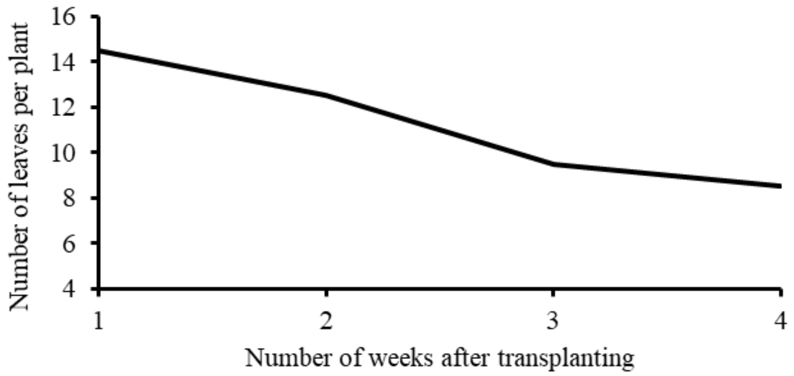


Figure 11. Effects of the treatments on the number of leaves per plant

In the case of a number of leaves, a decrease in irrigation level may result in a reduction in the mean leaf number per plant. However, Increasing the level of irrigation might increase the number of leaves as a result of gradual progression in the growth stages, as the plant grows the leaves might also increase and as the leaves increase, weight also increases this means that the higher the leaves the heavier the amaranthus crop head weight all things being equal. In contrast with our results, Acar et al. (2008) reported that different irrigation levels did not significantly affect mean leaf number.

Conclusion

Different amounts of water application levels had significant effects on the growth parameters and yield parameters of amaranthus crop. The results showed that a used plastic bottle with a perforation size of 3.2 mm raised to a height of 5cm resulted in an increase and growth and yield parameters of amaranthus crop. However, other perforation sizes and heights of bottles from the ground combinations (3.2 mm, 10 cm), (3.2 mm, 15 cm), and (3.2 mm, 20 cm) resulted in marginal increment in growth and yield parameters of the *amaranthus* crop. A used plastic water bottle with a perforation size of 3.2 mm raised at a height of 5 cm is recommended for smallholder farmers in the study area, particularly those who cannot afford the commercial drip irrigation system.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All data are included in the content of the paper.

Funding Statement: The authors did not obtain any funding for this research.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

References:

1. Bahar NHA, Michaela Lo, Sanjaya M, Van VJA, Alexander P, Ickowitz, A, Sunderland T (2020). Meeting the food security challenge for nine billion people in 2050: What impact on forests? Global Environmental Change, 62, 102056.
2. FAO Food and Agriculture Organization of the United Nations (2018). Global crop water Model Environmental Research letters, 8 (2): 302-309.
3. Foley J. A., Ramankutty N, Bruinman K.A, Cassidy E.S. (2011). Increasing population and consumption are placing unprecedented demands on agriculture and natural resources. Nature.com. University of California, California.
4. Forbes, J.C and Watso, R.D. (1992). Plants in Agriculture 1st Edn. Irrigation practices in high rainfall area. Press syndicate of the University of Cambridge, Cambridge, New York. No. 04-90-St. Joseph. Mich: ASAE Pub. 355.
5. Fróna D, Szenderá J, Harangi-Rákos M. (2019). The challenge of feeding the world. Sustainability, 11(20), 5816.
6. Karam, K. F. Karam N, Tarabey (2002) Paticipatory water saving management and water cultural heritage: Lebanon country report. Lebanese Agricultural research Institute, Irrigation and Agro-Meterology Department, Zahleh, Lebannon.
7. Karata, A. (1995). An Investigation on Determination of Suitable Plant Growth, Yield, Sowing Date, and Some Quality Characteristics of lettuce. Azizona, USA.
8. Kelly, A and Keller (1995). Effective Efficiency: A water use concept of allocating freshwater resources. Water resources and irrigation division Discussion paper 22. Arington, Virginia winrock International, USA.
9. Kirnak H, Demir S, Tas I, Cakmakli M. (2002). Response of different irrigation water applications on yield and growth of lettuce grown in greenhouse. J Agric Fac Harran Uni, 6 (1-2): 4754.
10. Mehta P, Siebert S, Kummu M. (2024). Half of twenty-first century global irrigation expansion has been in water-stressed regions. Nat Water 2, 254–261.
11. Ministry of Food and Agriculture (2020). Ghana agricultural survey fpr minor season. Accra, Ghana
12. Ministry of Food and Agriculture-MoFA (2022). Transforming Ghana beyond aid. Annual report, Accra, Ghana.
13. Neumann K. Stehfest E, Verburg P, Siebert H, Muller S, Veldkamp. T. Exploring global irrigation patterns: A multi levels modelling approach, Agriclt. Syst., 104, 703-713.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

14. Ngiah-Sah Kah K. (2021). Effects of vareity, deficit drip irrigation and rice straw mulch on flowering, fruiting and yield of tomato (*Lycopersicon esculentum l.*). Master's Thesis, University for Development Studies, WACWISA, Tamale, Ghana.
15. Norain, J, Festo, J, Massawe, R, Symonds, C. (2019). Transpiration efficiency of Amaranth (*Amaranthus sp.)* in response to drought stress, The Journal of Horticultural Science and Biotechnology, 94(4): 448-459,
16. Siebert. S, Doll P (2010). Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. J. Hydrot., 384, 198-217.
17. Steven, L. Peter, M.S. Ayyangowdar, B.Maheshwara Bahu, Y. Pampanna, B.S. Polisgowdar and G. Ramesh (2019). Evaluation of drip irrigation on *amaranthus* (*Amarathus hybridus L*) yield and water use efficiency under shade-Net. Department of soil and water Engineering, College of Agricultural Engineering, Raichur University of Agricultural Science, Raichur- 584 104, India.
18. Wang J, Vanga SK, Saxena R, Orsat V, Raghavan V. Effect of Climate Change on the Yield of Cereal Crops: A Review. Climate, 6, 41.
19. Yazgan S, Ayas S, Demirtas C, Buyukcangaz H, Candogan, B.N. (2008). Deficit irrigation effects on lettuce (*Lactuca sativa var. Olenka*) yield in unheated greenhouse condition. J. Food Agric Environ. 6(2): 357-361.
20. Zakaria H, Abujaja AM, Adam H, Nabila AY (2014). Factors affecting farmers willingness to pay for improved irrigation service : A case study of Bontanga Irrigation Scheme in northern Ghana. International Journal of Agricultural Economics and Extension, 2(1), 68–76.