Effect of Fertigation and Organic Manure on Growth and Yield of Maize (*Zea mays*) in the Northern Region of Ghana

ABSTRACT

Food insecurity in Ghana is major challenge in the country, with a significant portion of the population (5%) facing the risk of inadequate access to food. Whilst there is food insecurity, agricultural productivity in the country is not increasing. Additionally, farming in Ghana especially in northern Ghana fully depends on rainfall. Also, farmers are faced with climate crisis such as drought and high temperatures which affects productivity. Alternative ways such as fertigation have been demonstrated to increase agricultural productivity in many parts of the world. However, this technique is under-utilized in Ghana. Therefore,this study was conducted to evaluate the effect of fertigation and organic manure on maize growth and yield production in Northern Region of Ghana. Organic manure(OM) mainly compost was incorporated in soil together with fertigation and the effects on maize plant growth parameters (i.e., plant height, number of leaves, stem girth) and yield (i.e., number of grains, number of wet and dry grains) were measured. The study found that maize plants treated with OM and fertigation application had significantly higher plant growth parameters and yield compared to maize plants that were not given OM but were manually fertilized. The results showed that the combined use of fertigation and OM application holds immense potential for enhancing maize plant growth and yield. By maximizing the growth and yield potential of maize plants through fertilization and OM application, farmers can address the growing demand for this vital crop while promoting sustainable and environmentally responsible agricultural practices.

Keywords: Fertigation, Drip irrigation, Maize, Organic manure, Growth and yield parameters

1. INTRODUCTION

Agriculture is the largest consumer of water globally, accounting for ~70% of total freshwater withdrawals on average[1]. In some developing countries, this figure can be high as 95%. The demand for water in agriculture has been steadily increasing over the last century and is projected to continue, primarily due to population growth. [2]. Despite the vast amount of water on Earth (~1400 million cubic km), only a tiny fraction (0.003%) is considered freshwater suitable for various purposes such as drinking, hygiene, agriculture, and industry. Access to this freshwater are further limited by factors such as pollution and distribution [2], hence efficient utilization of the limited accessible water is eminent. Additionally, variability in precipitation patterns worldwide due to climate change further contributes to the water availability challenge. Some regions experience more intense rainfall, leading to flooding, while others suffer from decreased rainfall, causing droughts. These changes have implications for agriculture and water resource management [3].

Additionally, to water use in agriculture, mineral/inorganic fertilizers has also been used intensively to increase productively in the last century. Between 1965 and 2020, the use of these fertilizers more than quadrupled (46.31 to 201.83 million metric tons), with a substantial increase of approximately 46% between 1990 and 2020 alone [4];[5]. Despite increase yield productive achieved with the use of mineral fertilizers, these fertilizers also has the potential to create environmental pollution [6]. Many farmers over apply fertilizers, leading to the leaching and runoff of nutrients into water systems and ecosystems.

Organic manure (e.g., compost, animal manure, bone meal, and fish emulsion) similarly to mineral fertilizers contains nutrients essential for plant growth and development [7]. Organic manure has the potential to improve the soil structure hence retaining moisture and nutrients in soil [8]. This potentially can reduce leaching into ground water, hence reduced pollution. Despite the importance of OM in agriculture, there is reduced usage of OM due to limited availability, lack of knowledge on the types/usage of OMs and availability of inorganic fertilizers.

Increasing agricultural productivity while conserving and enhancing natural resources, including water, is essential for achieving long-term food security. Utilizing alternative methods to enhance water and fertilizer use while increasing yield productivity in crucial. One of such methods is drip irrigation,- this method apply water in precise amounts directly to the root zone and at the right times, minimizing water losses due to evaporation, runoff, and deep percolation/leaching, and also preventing nutrient leaching and loss [9].

Mixing fertilizer together with the drip irrigation water is term 'fertigation' (i.e. fertilization + irrigation). This integrated approach allows for the simultaneous delivery of water and nutrients, enhancing nutrient uptake by plants in the right amounts. However, fertigation is under-utilized especially in Africa.

Currently, only a small fraction of agricultural land in Africa is under irrigation, representing about 6% of the total cultivated land (i.e. ~13 million hectares) [10]. A large portion of food production in Africa relies on rainfed agriculture, which is highly susceptible to weather variability and climate change. This dependence on rainfall makes agriculture in the region vulnerable to droughts and other climate-related crisis. Studies have shown that the adoption of irrigation practices can boost crop yields by at least 50%, hence contributing to the food demands of a growing population [11]. Expanding irrigation in Africa, especially in Sub-Saharan Africa, can contribute to improved food security by reducing crop yield variability and the risk of crop failure due to erratic rainfall patterns. It can also enable farmers to diversify their crops and produce food throughout the year.

Agriculture plays a pivotal role in Ghana's economy, contributing a significant portion to the Gross Domestic Product (GDP) and providing employment for a substantial part of the labor [12];[13]. However, agriculture in Ghana, predominantly northern Ghana is mostly rain-fed [14], making farming vulnerable to climate-related disasters (e.g. droughts and floods). Climate change has led to shifts in rainfall patterns in Ghana, including late onsets, early endings, and inconsistent distribution of rains, making it challenging for farmers to predict when to cultivate [15].

Maize (*Zea mays* L.) is not only a globally important cereal crop (i.e., third most important cereal after wheat and rice but holds a special place in Ghana, where it is the most important cereal both in terms of production and consumption across different agronomic zones [16]. It plays a vital role in the country's food security and economy. Despite its significance, maize productivity in Ghana faces several challenges, primarily due to the dependence on rain-fed agriculture. Poor and variable rainfall patterns, coupled with prolonged droughts, can lead to low and unpredictable yields. Low soil fertility, particularly low soil nitrogen levels, is another contributing factor to low maize productivity [17];[16]. Frequent drought stress, which is common in rain-fed agricultural systems, significantly limits maize production in Ghana. Maize is known for its high-water requirements, and its sensitivity to water stress makes it vulnerable to yield reductions during dry periods [18]. Fertigation using drip irrigation system potentially can provide a consistent and uniform supply of water and nutrients to maize crops. This will mitigate the impacts of irregular rainfall and droughts. Studies from around the world have demonstrated the positive impact of drip fertigation on crop yields and water use [19];[20];[21]. Despite the potential benefits of drip fertigation, it's adoption in Ghana, particularly in the northern regions, is limited. To fill this knowledge gap, a field study has to be designed to evaluate the effect of fertigation and organic manure on maize production in northern Ghana. The study hypothesized that maize plant growth and yield parameters would be higher under fertigation than drip irrigation (with manual organic application). It was also hypothesized that, OM addition to soil will further increase maize yield.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was located in the Nyankala campus, under the Tolon District of the Northern Region of Ghana, at 9°24'39''N, 0°58'52''W; 161 m above mean sea level (Figure 1). Field experiment was conducted in a Research Demonstration Field of the West African Centre for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies (UDS). The soil at the site is sandy loam (76.2% sand, 20.3% silt, 3.5% clay) with a bulk density of 1.30 g/cm^3 (ranging between 1.28 -1.32 g/cm^3). The soil has a field capacity and permanent wilting point of 19.6% and 9.1% respectively. The chemical properties of the site soil and organic manure are presented in Table 1. The experiment site has a semi-arid climate characterized by hot dry rainless season between November and April, and a rainy season between May and October. The mean annual rainfall varies between 800 to 1200 mm. The mean day temperature ranges between 33 and 39°C, and at night the temperature between 20 -26°C. The experimental area is characterized by a mix of savanna and woodland ecosystems.

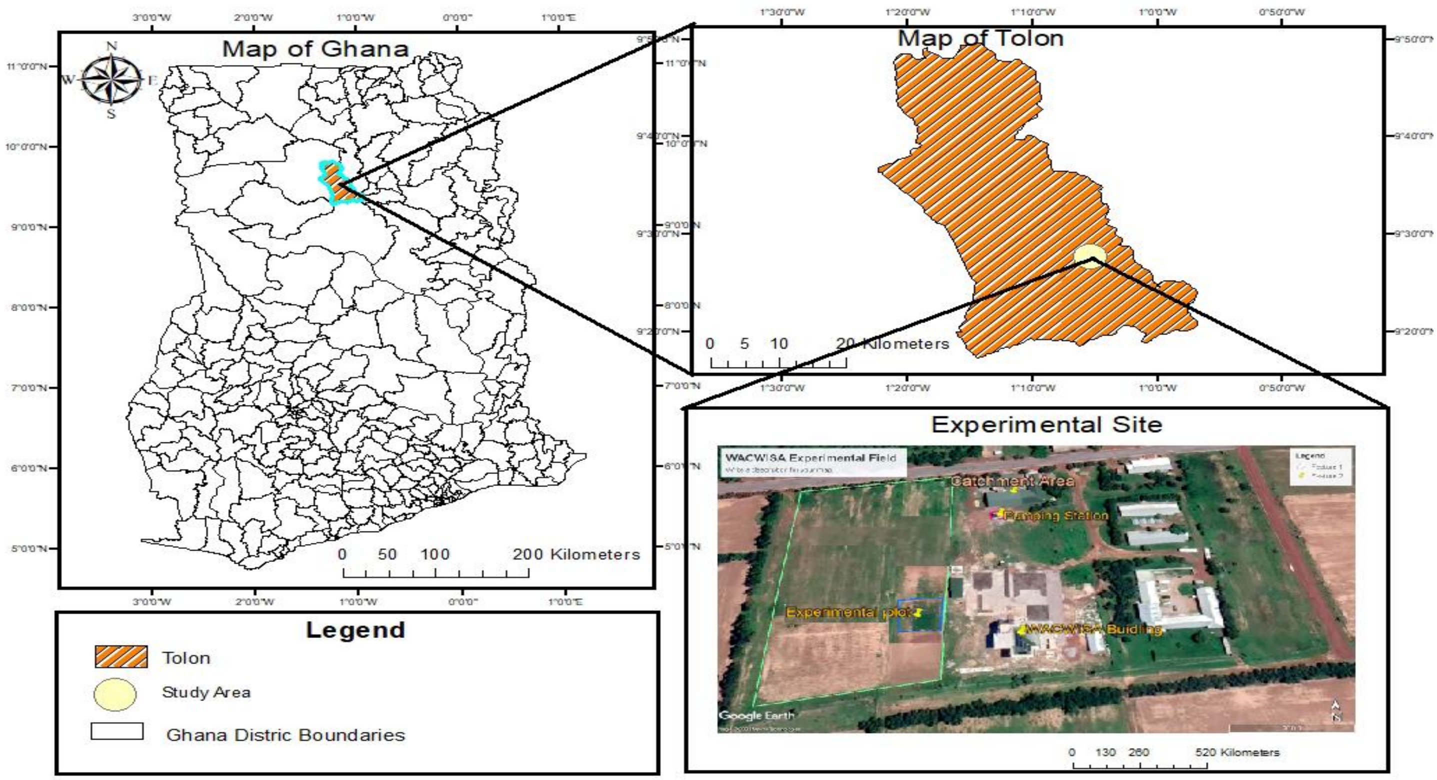

Fig. 1. Map of Ghana Showing Nyankpala and the Experimental Site

Table 1. Chemical Properties of Experimental Area Soil and Organic ManureUsed (OM)

Properties	Experimental Area Soil(15 cm depth)	OM (Compost)
pH (1:2.5)	6.18	8.11
Total organic C (%)	1.19	12.48
Total N (%)	0.11	1.15
Total P (mg/kg)	7.44	2360
Total K (mg/kg)	88	7000
Ca (Cmol+/kg)	1.40	1.80
Mg (Cmol+/kg)	0.60	1.20

2.2 Field Experimental Design and Layout

Manual tillage was done with a hoe, tilling was done twice (i.e., primary- initial losing of soil, and secondary- leveling and making of ridges) before seeding. The field experiment was laid in a Randomized Complete Block Design (RCBD). Six soil ridges were made (5 m long and separated from each other by 0.75 m). Driplines/laterals (5 m long) made of ¾ PVC pipes were placed on each soil ridge, laterals were separated from each other by 0.75 m (buffer zone). Three driplines (A, B, and C) were connected to one main line also made of PVC pipe. The other three laterals similarly were connected to a different main line (PVC pipe). Ten drip holes (2 mm) serving as emitters and equally spaced were drilled on the laterals. Each main line was then separately connected to 120 liters' container elevated to a height of one meter above the ground (to create gravitational flow) and serving as the water storage tank (Fig. 2). Main lines had valves to regulate water flow.

Fig. 2. Field Experimental Layout

2.3 Treatments

The study had four (4) treatments, which were; (1). Drip Fertigation (on lateral line 'A'), (2). Drip Fertigation + addition of OM to soil (On lateral line 'B' and 'C'), (3). Drip irrigation + Manual/traditional fertilizer application + OM to soil (on lateral line 'D' and 'E'), and (4). Drip irrigation + Manual/traditional fertilizer application (on lateral line 'F') (Fig. 2).

2.4 Fertilization and Irrigation

The organic manure used was a compost made of chicken manure mixed with decomposed neem tree litter (Table 1). OM with manually applied uniformly on the surface of soil ridges that had OM treatments. NPK 15-15-15 and Urea fertilizers were used, 3 kg of NKP and 1 kg of Urea was applied manually close to the base of plants under the drip irrigation treatment (soil ridges- lateral D, E, and F) two weeks and four weeks after seed germination respectively (i.e. NPK after two weeks and Urea after four weeks of seed germination). The irrigation was applied daily at a rate of 60 L/day (see section 2.6) which were applied through the drip holes at a controlled rate. However, irrigation was not given on rainy days. The total number of rainy days during this experiment were five. Storage containers were refilled every two days. However, with the drip fertigation treatment (on lateral line A, B, and C), 0.75 kg of NKP per week was mixed with irrigation water and applied through the drip holes in two consecutive days each week for four weeks (i.e., week two to five after germination). 0.5 kg of Urea per week similarly to NKP application, was applied with irrigation water on week six and seven after seed germination.

2.5 Planting, Management, and Plant Measurements

The maize (*Zea may* L.) variety used was Bihilifa maize. Seeds were planted at 5 cm depth into tilled soil. Two (2) seeds were planted per hole and planting holes were spaced 50 cm within rows and 75 cm between rows based on the recommended planting structure of this variety. Weeding was done two weeks after planting and mid stage by hoe to control weeds and also adding soil to base of plants to support plants.

Measurements of plant parameters started two (2) weeks after seed germination and on set of fertilization treatment. The parameters measured were; the plant height (cm), number of leaves, stem girth. These parameters were measured every two weeks until harvest. Yield was also measured at the end of the experiment. The plant height was measured using a measuring tape by placing tape on the edge of the soil close to the stem to the highest point of the maize plant and recording the height in cm. The number of leaves was measured by virtually counting the number of unfurled leaves on each plant. The stem girth measured by using a flexible rope round the stem of the plant and measuring the length of the rope on a measuring ruler. Data was collected on each plant from all treatments. Yield was measured after harvest. The fresh grains were counted per treatment and the fresh weight measured in kg. Grains were then dried and the dried weight also measured in kg to account for the moisture content of the grains.

2.6 Amount of Water Applied

The amount of water applied was calculated based on the various growth stages of the maize variety using the Equation 1:

Amount of water to irrigate = Df × (FC – PWP) × Dr × Wetted diameter ………………………….……….. Eq. 1

Where: Dr- Rooting depth, Df - Depletion factor, FC- Field capacity, and PWP- Permanent wilting point.

Depletion factor of our soil was not estimated and the rooting depth with a destructed sampling method was not applied in this study. Hence equal amounts (60 L/day) were applied the whole field for the entire experiment. However, we acknowledge that calculating the amount of water needed by maize plants at each developmental stage of the plant is important.

2.7 Data Analysis

Data was first checked for normal distribution. The stem girth and number of grains data were normally distributed and hence were analyzed using one-way ANOVA. Data on plant height, number of leaves, wet and dry grain weight were however not normally distributed and hence non-parametric analysis using Kruskal-Wallis Test were performed. Pairwise comparison of mean values between treatments were done using Turkey-Kramer LSD (P<0.05). All analyses were done using JMP 8 software and the graphs were drawn using SigmaPlot 12.5 software.

3.0 RESULTSAND DISCUSSIONS

3.1 Plant Height

Cumulative growth rate showed all plants increased monotonically over the growth period (Fig. 3). However, there was a significant difference (P < 0.0001) in the average plant height between the treatments measured during the peak growth stage (Fig 4). Fertigation + OM application had a significantly higher plant height compared to all other treatments. The pattern of the maize plant height measured was Fertigation + OM > drip irrigation + manual fertilization + OM > fertigation = drip irrigation + manual fertilization (Fig. 4).

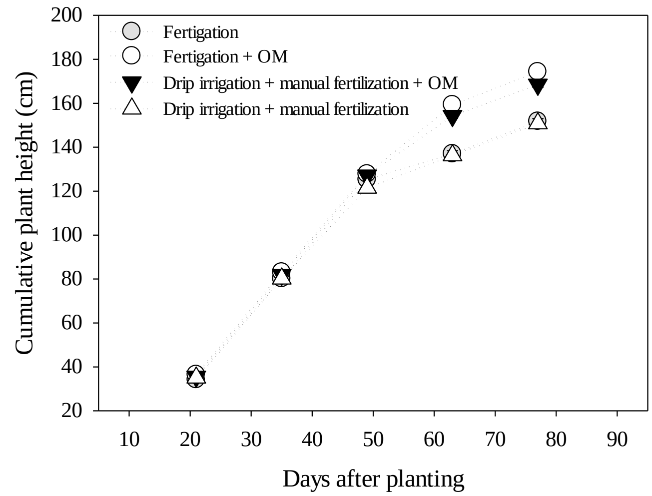

Fig. 3. Cumulative plant height of maize during the growth period different irrigation methods and fertilization (data points are means ± standard errors, SE; number of replicates for each point, n = 5 for fertigation, and drip irrigation + manual fertilization; n = 10 for fertigation + OM, and drip irrigation + manual fertilization + OM).

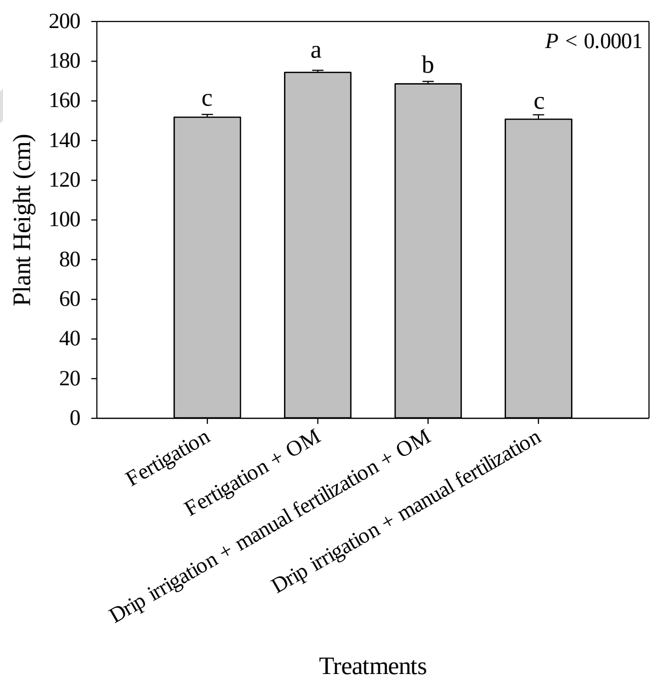

Fig. 4. Effect of different irrigation methods and fertilization on maize plant height during peak biomass (data points are means ± SE; n = 5 for fertigation, and drip irrigation + manual

fertilization; n = 10 for fertigation + OM, and drip irrigation + manual fertilization + OM)

3.2 Number of Leaves

Similarly, to the cumulative plant height, the cumulative number of leaves increased over the experimental period in maize plants under all the treatments (Fig. 5). However, the average number of leaves measured during the peak biomass stage was significantly (P < 0.0001) higher under Fertigation + OM application compared to the other treatments (Fig. 6). The pattern of treatment effect was Fertigation + OM > drip irrigation + manual fertilization + OM > fertigation > drip irrigation + manual fertilization (Fig. 6).

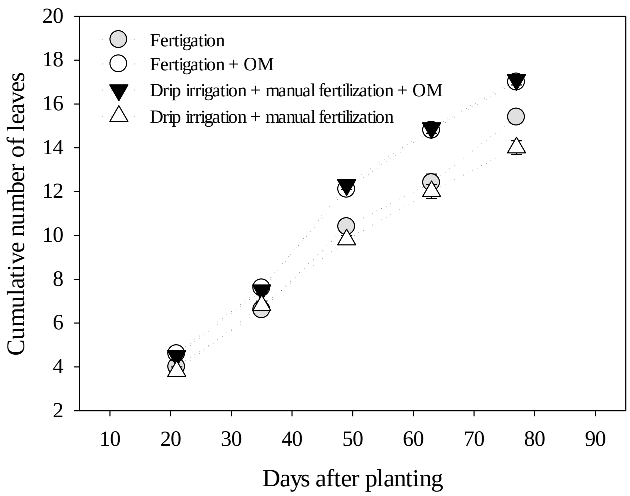

Fig. 5. Cumulative number of maize leaves during the growth period with different irrigation methods and fertilization (data points are means ± SE, n = 5 for fertigation, and drip irrigation + manual fertilization; n = 10 for fertigation + OM, and drip irrigation + manual fertilization + OM).

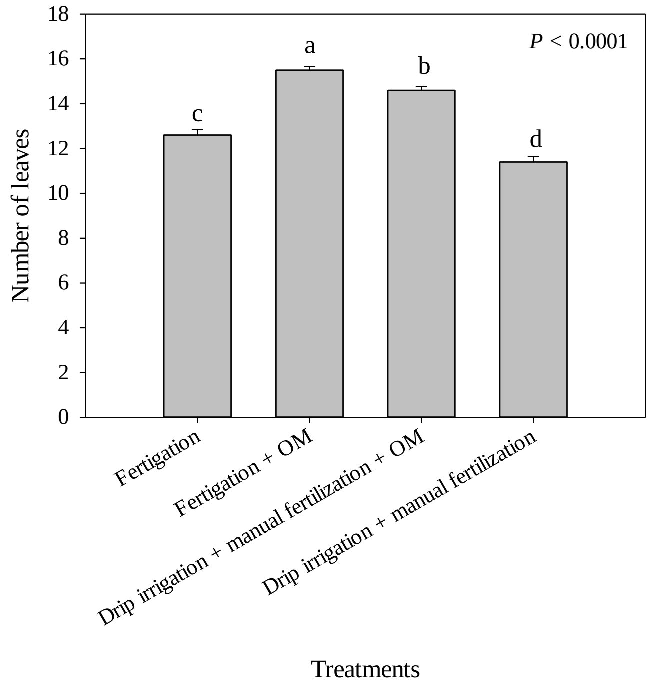

Fig. 6. Effect of different irrigation methods and fertilization on the number of leaves of maize plant during peak biomass (data points are means ± SE; n = 5 for fertigation, and drip irrigation + manual fertilization; n = 10 for fertigation + OM, and drip irrigation + manual fertilization + OM).

3.3 Plant Stem Girth

The cumulative stem girth measured over the whole experimental period showed continues increase in all plants under all treatments (Fig. 7). The average maize stem girth measured during the peak growth stage was significantly different (P = 0.0394) amongst maize plants exposed to different irrigation and fertilization treatments (Fig. 8). Fertigation + OM treatment had the highest stem girth (12.13 cm) and the drip irrigation + manual fertilization treatment had the lowest (11.26 cm) (Fig. 8).

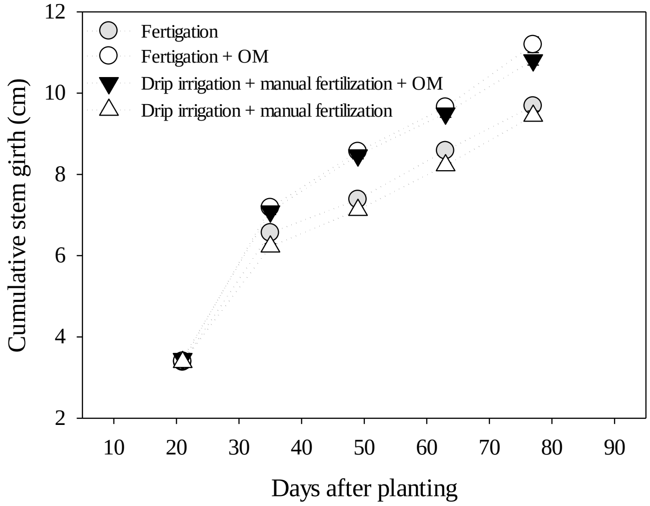

Fig. 7. Cumulative stem girth of maize plant measured during the growth period with different irrigation methods and fertilization (data points are means ± SE, n = 5 for fertigation, and drip irrigation + manual fertilization; n = 10 for fertigation + OM, and drip irrigation + manual fertilization + OM).

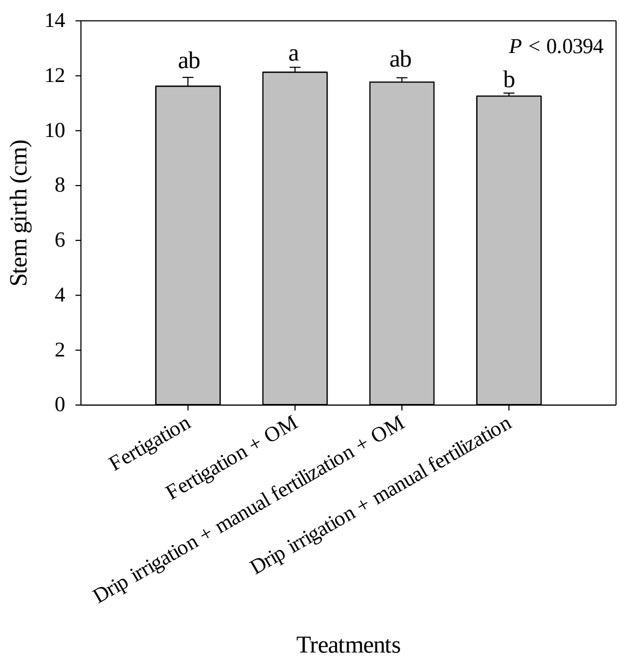

Fig. 8. Effect of different irrigation methods and fertilization on the stem girth of maize plant during peak biomass (data points are means ± SE; n = 5 for fertigation, and drip irrigation + manual fertilization; n = 10 for fertigation + OM, and drip irrigation + manual fertilization + OM).

3.4 Number of Wet Grains

Similarly, to all other measured parameters, there was a significant difference (P < 0.0001) between the treatment effects on the number of maize grains counted after harvest. Fertigation + OM application had a significantly higher number of grains compared to all other treatments. The pattern of the number of maize grains counted was Fertigation + OM > drip irrigation + manual fertilization + OM > fertigation > drip irrigation + manual fertilization (Fig. 9).

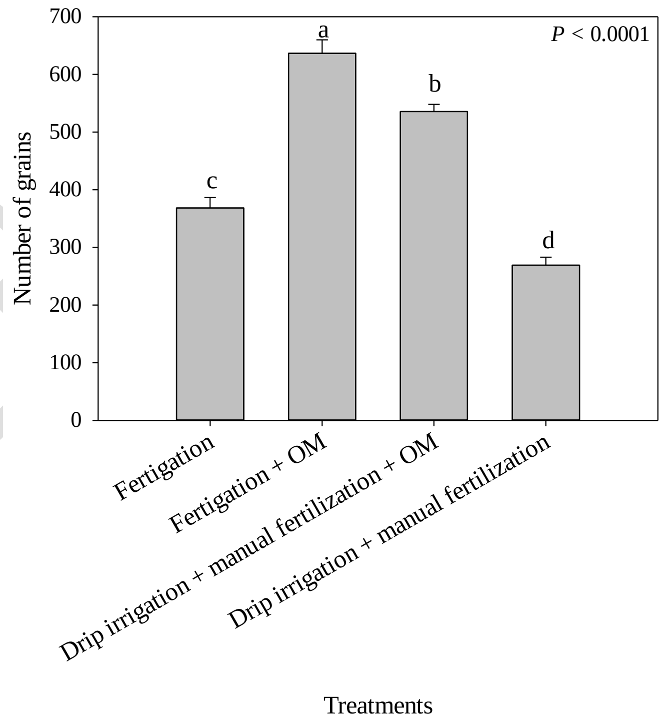

Fig. 9. Effect of different irrigation methods and fertilization on the number of maize grains counted after harvest (data points are means ± SE; n = 5 for fertigation, and drip irrigation + manual fertilization; n = 10 for fertigation + OM, and drip irrigation + manual fertilization + OM).

3.5 Fresh and Dry Weight of Maize Grains Harvested

There was a significant (p< 0.0001) effect of treatments on the weight of the maize grains harvested. The pattern of the weight of grains measured was Fertigation + OM > drip irrigation +

manual fertilization + OM > fertigation > drip irrigation + manual fertilization (Fig. 10). However, maize plants treated with Fertigation + OM had 14.4% of moisture in the grains which was lost after drying. Drip irrigation + manual fertilization + OM had 26.8% moisture, fertigation had 41.25% moisture, and drip irrigation + manual fertilization had 49.09% moisture.

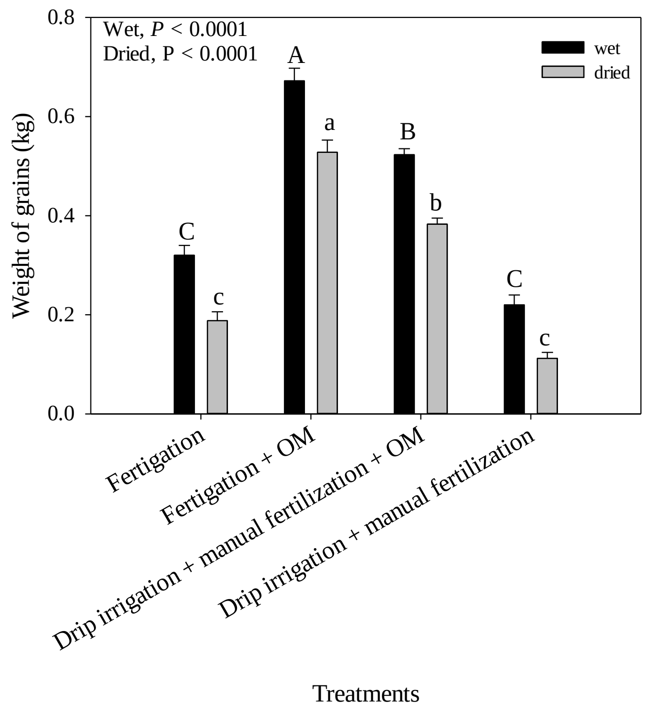

Fig. 10. Effect of different irrigation methods and fertigation on the wet and dry weight of maize grains after harvest (data points are means ± SE; n = 5 for fertigation, and drip irrigation + manual fertilization; n = 10 for fertigation + OM, and drip irrigation + manual fertilization + OM; upper case and lowercase letters show the significant effect of different treatments on the wet and dried grain weight respectively).

3.6Discussion of Plant Growth Parameters as Influence by Treatments

The study showed that the incorporation of fertigation + OM resulted in overall best growth performance of the maize cultivar (Bihilifa maize). Plant height, number of leaves, and stem girth were significantly increased under fertigation + OM treatment compared to the other treatments used in this study. Drip irrigation + manual fertilization showed the lowest impact on most of the maize growth parameters measured. Suggesting that slow addition of fertilizer to soil together with the incorporation of OM improves the overall health and growth of maize. Similarly, Bibe *et al.*[19] found increase maize growth parameters (such as; plant height, dry matter production, number of grains, etc.) under fertigation system compared to drip irrigation system. However, the study of Bibe *et al.*[19] did not incorporate OM together with the fertigation system. Incorporating organic matter into the soil complements fertigation by nurturing soil health and enhancing the growth of maize plants. Organic manure, such as the compost/well-decomposed manure that was used in this study, enriches the soil with essential nutrients and improves its water-holding capacity. This leads to healthier maize plants with increased height potential. Maize plants benefit from the precise nutrient delivery of fertigation while capitalizing on the improved soil fertility from OM. This synergy encourages remarkable height gains throughout the growth cycle.

Aside the water-holding capacity of soil improvement by OM [8], application of OM also helped to improve the soil structure [22]. The improved soil structure resulting from OM application facilitates better root development. Enhanced root systems can support a greater number of leaves, contributing to an increased leaf area for photosynthesis. The combination of fertigation's nutrient precision and OM's soil-enriching properties promotes lush foliage, resulting in a higher leaf count and increased photosynthetic potential.

Organic matter provides adequate carbon source which help to promote microbial activity in the soil [7]. Increase microbial activity aids in nutrient cycling and availability. Maize plants respond to these nutrient-rich conditions by developing thicker and more robust stems. Maize plants grown under these conditions develop sturdy and robust stems due to the optimized nutrient availability and improved soil structure, contributing to better overall plant health. Incorporating OM into the soil contributes to carbon sequestration, helping mitigate climate change by storing carbon dioxide in the soil [23].

The integration of fertigation and OM application presents a comprehensive approach to promoting healthy maize growth worldwide. This strategy aligns with the objectives of sustainable agriculture, bolstering food security and supporting the global maize industry.

3.7 Discussion ofYield Parameters as Influence by Treatments

The results showed that maize yields were significantly increase under fertigation + OM application than all other treatments (Fig. 9 and Fig. 10). Similarly, other studies have showed that fertigation application increases maize yield when compared to other irrigation systems [20];[21]. Maize, also known as corn, is one of the world's most vital staple crops, providing sustenance for billions of people and serving as a critical component of animal feed and industrial products [24]. To meet the growing global demand for maize, it is essential to optimize agricultural practices. Fertigation, the precise application of fertilizers through irrigation systems, when combined with OM application, offers a promising approach to significantly increase maize yields worldwide. Maize production in Ghana for instance is faced with several challenges such as rainfall, drought, soil fertility, pests and diseases, weed control, fertilizer use, and climate [25]. All these challenges to some extend can be managed with fertigation application, especially when adopted together with OM application as shown in this study.

4.0 CONCLUSIONS

This study showed that the incorporation of organic manure (compost) with fertigation can significantly increase maize production in northern Ghana. This suggest that using this method which is under exploited in Ghana can increase the overall food production in the country especially in northern Ghana where maize is the major stable food and its production faced with many challenges such as rainfall, drought, fertilizer availability, and climate change. This integrated approach will not only boosts individual plant vitality but also contributes to increased maize yields worldwide. By maximizing the growth potential of maize plants, farmers can address the growing demand for this vital crop while promoting sustainable and environmentally responsible agricultural practices.

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