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Productivity of onion (*Allium cepa* L.) as influenced by composted poultry manure and fishpond waste in an aquaponics-based food system

H.A. DWAMENA, K. TAWIAH, E.O. DANQUAH, S.K. DARKEY, M.D. ASANTE, C.O. PEPRAH, T. FRIMPONG, P. MARFO, A.K.A. SERWAA, P. MARNO, S.K. AMPONSAH, K. AGYEMAN, M.O.O. ASANTE, A. KARIM & F. FRIMPONG*

(H.A.D., E.O.D., S.K.D., M.D.A., C.O.P., T.F., P.M., S.K.A., K.A., M.O.O.A., A.K. & F.F.: Council for Scientific and Industrial Research - Crops Research Institute, P. O. Box 3785, Kumasi, Ghana; K.T.: Department of Mathematics and Statistics, University of Energy and Natural Resources, Sunyani, Ghana; H.A.D., K.T., P.M. & A.K.A.S.: Department of Statistics and Actuarial Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana)

**Corresponding author's email: felix.frimpong@yahoo.com*

ABSTRACT

Sustainable intensification of food production with aquaponics-based food systems requires conscious efforts of soil amelioration with the rich organic outflows to realize the closed nature of such integrated systems. This study assessed the effects of composted poultry manure and fishpond waste on the growth and yield of onion (*Allium cepa* L.) for sustainable production by smallholder farmers. A randomized complete block design on-station study was conducted in an aquaponics-based system at the CSIR-Crops Research Institute, Kumasi, in the 2016 minor season. The onion cultivar "Boko red" was grown under three treatments; 0 application (absolute control), 12 t/ha composted poultry manure, and 6 t/ha composted poultry manure plus 25 l/hill of pond water derived based on the crop nutrient requirements. Growth parameters (plant height and the number of leaves) were taken weekly from four weeks after transplanting, as well as yield parameters (total dry matter and total bulb weight). Among the treatments, the highest mean yield (25381 kg/ha) was attained with composted poultry manure and pond water combined. This shows the potential usage of organic waste as alternate sources of fertilizers for vegetable production, in integrated aquaculture systems. Organic waste such as poultry manure, droppings of small ruminants, fishpond waste, crop residues etc., are freely and abundantly available in integrated aquaculture systems, and can substitute inorganic fertilizers with considerably benefit to farmers by increasing yield.

Keywords: Composted manure; fishpond effluents; integrated soil fertility management; onion; vegetable production

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Introduction

Onions are nutrient-rich and contain various health-promoting compounds like amino acids, carotenoids, and phytochemicals. They offer medicinal benefits, including antioxidant and anti-inflammatory effects, cancer prevention, and relief from insect stings. In Ghana, onion production is vital for food security and

economic stability, providing diverse nutrition and livelihoods for farmers (Yahaya *et al*., 2010; Sami *et al*., 2021; Rodrigues *et al*., 2003; Zhao *et al*., 2021; Michalak-Majewska *et al*., 2020). Onion production holds a significant position in Ghana's agricultural landscape due to their production volume, economic value, and high demand. It ranks as the third-largest vegetable crop in terms of cultivated area after tomatoes and chilli peppers (DAI, 2014). Most onion production in Ghana relies on rain-fed conditions, constituting 75% of the annual crop output (Richards, 2023). Local onion production in Ghana consistently falls short of meeting local demand, necessitating imports to bridge the gap.

Various studies report varying estimates of onion yields in Ghana. For instance, yield figures for the Bawku red variety range from 3.3 mt/ha to 3.7 mt/ha (rainfed), and 12 mt/ha to 19 mt/ha (irrigated) (van Asselt *et al*., 2018; Balana *et al*., 2020; MoFA, 2019). However, these yields are notably lower than those seen in neighbouring countries like Niger, which can reach as high as 35 mt/ha (Baffour-Ata *et al*., 2021). Despite the abundance of land resources, Ghana is not self-sufficient in onion production necessitating huge foreign exchange annually basically from neighbouring countries like Niger and Burkina Faso to meet market demands (Hathie & Yiyugsah, 2013). A significant underlying cause of this problem is that soils in most of the onion-growing areas in Ghana have low nutrient properties and often require soil amendment to boost crop production (Laube *et al*., 2012).

The soil's physical and chemical properties continue to worsen in prolonged vegetable cropping without fallow due to the high demand fresh vegetables to feed the markets and also bad agronomic practices. Thus, appropriate soil nourishment is one of the variables which restrict onion cultivation. This is because Onions, characterized by their shallow root systems, significantly depend on rich soil nourishment to thrive and yield substantial bulbs, and therefore amelioration practices like the use of both organic and inorganic fertilizers can help maintain high soil fertility for higher yields. In many livestock production systems, the common feed nutrients are mainly poultry excreta and cattle waste (Islam & Hossain, 1990; Mahmoud, 2017) necessitating the need to explore waste from other livestock like rabbits as well.

Adding on to the problem is also the issue water scarcity as a result of irrational rainfall patterns caused by climate change which affects the water resources available for irrigation in the onion growing areas in Ghana (Dagar *et al*., 2020). In this regard recycling and re-use of effluent from aquaponic-based food systems for irrigation presents a viable solution, considering its richness in organic materials valuable for agricultural purposes. This practice not only boosts soil fertility but also enhances crop production while simultaneously reducing overall costs by minimizing the need for additional fertilizers (Essilfie *et al*., 2017; Opoku, 2020; Arndt *et al.*, 1979; Trujillo *et al*., 2014).

The benefits of using fish effluents as fertiliser have been studies on a wide range of crops; tomato, lettuce, beans, cucumber, and sweet potato (Abdelraouf, 2019; Delaide *et al*., 2021; Mangmang *et al*., 2016; McMurtry *et al*., 1990; Pickens *et al*., 2020). However, in Ghana, not much has been explored with regards to onion production to the best of our knowledge, and also most aquaculture systems in discharges their effluents as waste despite their great potential to be re-used to improve plant growth as demonstrated in previous studies. Also, combination of these organic fertilizers in bulb onion cultivation is yet to be explored in Ghana. Against this background,

this study was carried out to maximize the use of fish effluents and composted poultry and livestock manure to enhance onion production, maintain soil fertility, and promote the results of fish effluents for vegetable production while reducing environmental pollution.

Materials and Methods

Study area

The study was conducted on-station at the CSIR-Crops Research Institute, Fumesua, in the minor cropping season of 2016/2017. Fumesua is located at latitude (N) 6°41´, longitude (W) 1°28´and an altitude of 289 m in the forest zone of Ghana, with a mean annual rainfall of 1500 mm. The type of soil at the Fumesua site is coarse sandy loam Acrisol.

Source of fishpond effluents and composted poultry manure

The fishpond effluents and composted manure (made up of rabbit and poultry droppings) were sourced from the CSIR-Crops Research Institute's aquaponics research site. At the site, catfish, tilapia, poultry, and rabbits are raised using an integrated aquaponics-based food system approach (Frimpong *et al*., 2017). The manure from the aquaponics-based food system (mainly rabbit and poultry droppings) was composted anaerobically with the help of a black polyethene sheet cover. After collection, the mixture was mixed with water, covered up, and left to undergo further decomposition. The mixture was watered and overturned every two weeks and covered again until eight weeks after which manure could be used as a soil amendment. The initial soil physicochemical properties at a depth of 0-30 cm (Table 1), the elemental chemical composition of the composted poultry manure, and the fishpond effluents (Table 2) were adopted from Frimpong *et al*. (2017).

TABLE 1
Elemental compositions of the composted poultry manure, and the fishpond effluents

Fishpond wastewater/ effluent (mg/L)	Composted poultry manure (%)
Total N – 182.13	Total N – 2.44
Total P – 0.74	Total P – 1.39
Total K – 12.04	Total K – 0.51
Total S – 67.86	Total S – 0.71
Total Ca – 118.18	Total Zn – 0.13
Total Mg – 5.21	-
Total Zn – 0.12	-
Total Mn – 0.05	-
Total Cu – 0.10	-
Total Fe – 0.22	-
Total Cl – 28.50	-

Where; N-Nitrogen, P-Phosphorus, K-Potassium, S-Sulphur, Ca-Calcium, Mg-Magnesium, Zn-Zinc, Mn-Manganese, Cu-Copper, Fe-Iron, Cl-Chlorine

TABLE 2
Physico-chemical properties of soil analysis from 0 - 30 cm depth used for onion organic amendment trial

Soil properties	Unit	Value
pH (1:1; soil: water)	-	4.22
Organic Carbon	%	1.00
Total N	%	0.12
Organic Materials	%	1.74
PPmP	-	103.11
PPmK	-	48.77
Ca^{2+}	cmol/kg	1.59
Mg^{2+}	cmol/kg	0.55
K^{+}	cmol/kg	0.16
ECEC	cmol/kg	3.33
Base saturation	%	70.91
TEB	cmol/kg	2.39
Exchangeable A (Al + H)	cmol/kg	1.41
Texture	Loamy sand	

Where; N-Nitogen, P-Phosphorus, Ca-Calcium, Mg-Magnesium, K-Potassium, ECEC-Exchangeable Cations Exchange Capacity, T.E.B-Trace Elements, Al-Aluminium, H-Hydrogen

Experimental design and data collection

The experiment consisted of three treatments (control = T1, 12 t/ha composted poultry manure = T2, and 6t/ha composted poultry manure + 25 l/hill of pond water = T3). The experiment was set up in a randomized complete block (RCBD) with three replications. Seedlings of an onion cultivar called 'Boko Red' were raised on a seedbed of 1 m × 5 m, following the recommended agronomic procedures. T1, T2 and T3 were applied as a single application into the respective experimental plots. Watering was done and left for one week before transplanting. Healthy and vigorous seedlings of 12-15 cm height (at 3-4 true leaf stage) were carefully uprooted from a seedbed prepared for this purpose and transplanted at 23 cm × 11.5 cm spacing between rows and plants, respectively. Recommended cultural practices were adopted for all treatments and data on vegetative growth, yield and yield components were recorded.

Statistical analysis

Data recorded, namely; plant height (cm), number of leaves, single bulb weight (g), total bulb weight (kg ha^{-1}, total dry matter (g m^{-2}), total fresh weight (g m^{-2}) were statistically analyzed using the SAS computer software version 9.4 and Statistical Tool for Agricultural Research (STAR) Version 2.0.1. When ANOVA results showed significant differences, mean separation was carried out using Tukey's Honestly Significant Difference (HSD) test at a 5% significance level.

Results and Discussion

Plant height

The height of the onion varied from 30.60 cm to 39.75 cm due to the different treatments applied (Figure 1a). The tallest plant was found on composted poultry manure, followed by compost + pond water, whereas the control produced the shortest.

Number of leaves

The application of the different treatment combinations significantly increased the number of leaves per plant (Figure 1b). The composted poultry manure produced greater number of leaves (6), than the compost and pond water (5) and the control (5). However, there were no difference between all the treatments, namely, compost, pond water and the control treatments.

Single fresh bulb weight

Single bulb weight varied from 52.85 g to 96.22 g (Figure 2a) among the treatments applied. The poultry compost treatment produced heavier highest bulbs (96.22 g) than compost plus pond water, and control.

Fresh bulb yield

The fresh bulb weight of the onion varied from 13372 kg/ha to 25381 kg/ha (Figure 2b). The highest yield (25381 kg/ha) was found when compost + pond water field (Figure 2b) was applied while the lowest yield (13372 kg/ha) was recorded on the control field with significant differences observed between the treatments applied.

Total fresh bulb yield

The highest fresh weight (783.10 kg/ha) was recorded in the treatment compost and pond

water. The second highest was recorded in the treatment of compost poultry manure (701.37 kg/ha). However, the control recorded the least (394.93 kg/ha). A significant difference was observed between compost treatments and the control.

Total dry biomass

Dry bulb yield followed a similar trend as the fresh bulb yield, with significant variations in the total dry matter resulting from the different treatments (Figure 2c). The highest dry matter yield (70.23 kg/ha) was recorded on the compost + pond water field, followed by composted poultry manure (67.10kg/ha). However, the control had the least (36.17 kg/ha) dry matter yield

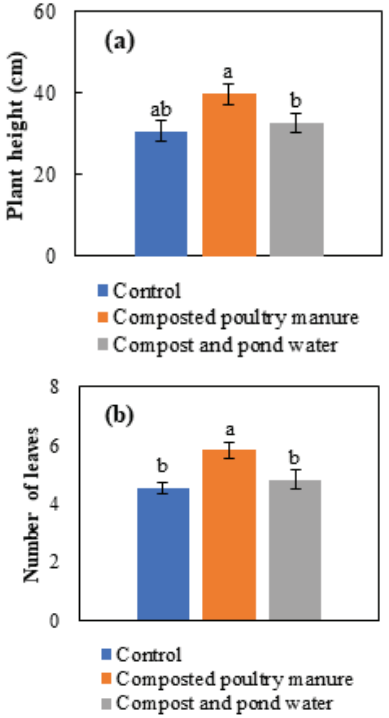

Fig. 1: Influence of organic fertilizer treatments on leave number and height of onion; a - influence of treatments on the number of leaves of onion; b - onion height as influenced by amendment treatments

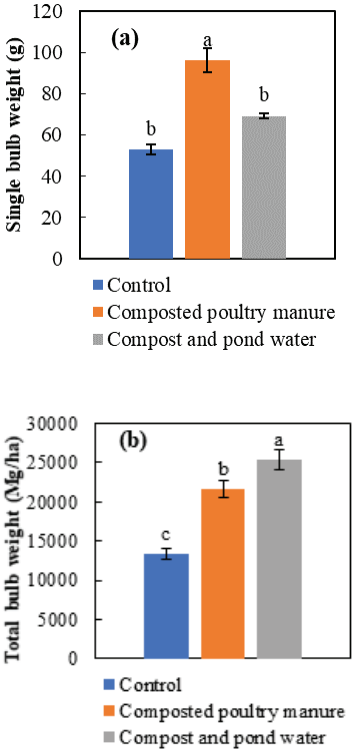

Fig. 2: Influence of organic fertilizer treatments on yield components of onion; a - influence of treatments on single bulb weight; b - influence of treatments on total bulb weight; c - total fresh weight as influenced by treatments; d - total dry weight as influenced by treatments

This study analyzed the effects of organic sources of macro and micronutrients on the productivity of Onion (*Allium cepa L.*) in a bio-circular system with aquaponics as the base component under various nutrient source combinations. The results demonstrated the benefits of reusing waste in a bio-circular system as an alternate source of soil fertility likely to enhance crop productivity and also reduce environmental pollution as well as the cost of synthetic fertilizer application to increase farmers' income. To produce an adequate yield

of onions that are of good size, improved soil fertility and timely utilization of nutrients are required to enhance the root growth of the onion (Soundy *et al*. 2001). This can result in a lower recovery rate of applied fertilizer (mainly mineral N), with reported values often being between 30% and 40% as reported in the literature (Greenwood & Hunt, 1986; de Visser *et al*., 1995; Sharma *et al*., 2012). When compared to the control, composted poultry manure fertilization significantly increased plant biomass in this study. The significant variation in the total dry matter might be due to differences among the sources of the nutrients available from the treatments. For instance, single bulb weight was significantly improved by the composted poultry manure fertilization and even in combination with the fish effluent significantly improved the overall total bulb yield.

Furthermore, our results obtained on plant height are supported by Baloch *et al*. (1991), who found that optimum nutrients could enhance plant height significantly in onion plants. Our findings corroborate that of Dixit (1997) that applying higher farmyard manure resulted in higher yields.. This effect is attributed to soluble and readily available nutrients from the pond water for uptake to enhance plant growth and development, as reported by Frimpong *et al*. (2017). The combined effect on the compost plus pond water on the yield may have also rsesulted from additional benefit of the irrigation water from the fish effluents even though that was not the focus of this study. Perhaps, that is regarded as a limitation of the study and will require future assessment in that regard.

Also, as observed from Figure 1(a) and 1(b), the significant difference in plant height and the number of leaves under the various growth conditions buttress the importance of composted poultry manure and pond water effluents in such a circular system, for increased biomass that can result in higher yields without falling on additional external inputs. As proven earlier by Cordell & white (2011), the high percentage of unused water in an aquaculture system poses an environmental threat due to the high percentage of mineral sources (70-80%) entering the water and turning it into waste (Palada *et al*., 1999). This is because the abundant nitrogen and phosphorus uptake by the fish is less than 10-50% and 15-45%, respectively (Shpigel *et al*., 1993; Holby & Hall, 1991).

Composted poultry manure produced the highest number of leaves. Therefore, the combined utilization of fishpond effluents and compost would be very beneficial to farmers in the provision of readily available macro and micronutrients in synchrony with the ontogenic nutrient demand that can reduce the negative environmental impacts. Thus to maximize yield, compost and pond water appeared to enrich soil nutrients, whilst poultry compost only promoted the growth of onion. The use of compost and pond water will considerably benefit farmers by reducing costs. Also, environmental pollution by these organic fertilizers will decrease completely.

Conclusion and Recommendation

The study assessed the effect of composted poultry manure and fishpond waste on the growth and yield of onion (*Allium cepa* L.) in an aquaponics-based food system**.** Treatments positively influenced growth and yield parameters. Among the treatments, the highest mean yield (25.38 mg/ha) was attained with composted poultry manure and pond water combined. This indicates the potential of organic effluents as alternate sources of fertilizers for vegetable production, especially for onion growth and development in an integrated aquaculture system. Further research

is, however, required to analyze the economics of scale of using such organic amendments versus inorganics and the shelf life of onion bulbs and other marketable yields.

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