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Full Length Research

Assessment of Aquaponics-based Food Production System Effluents on the Performance of Maize.

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Farmers heavily rely on inorganic sources of fertilizers to replenish their farmlands, which in turn increase production and management cost further with subsidies removal. The cost and environmental implications of these inorganic fertilizers on farmlands calls for innovative technologies for alternate options to sustain soil fertility. The goal for this study therefore was to ascertain the best alternative means of sustaining yields of three improved CSIR-Crops Research Institute of Ghana maize varieties if not increase it and the economic implications using effluents from an aquaponics-based food production system. To achieve this, an on-station study was conducted using effluents from aquaponics-based food production system. The treatments were laid in a 3×3 factorial experiment in a randomized complete block design of maize varieties (*Obatanpa*, *Omankwa* and *Aburohemaa*) and effluents (absolute control, 2L/hill pond water and a combination of half rates of pond water and composted poultry manure recommended). Overall grain yield, cob number, plant height, chlorophyll content varied significantly ($P \leq 0.05$) due to the application of the treatments. Grain yield of 4 t/ha, 3 t/ha and 2 t/ha was realized for *Obantanpa* maize variety under pond water and composted poultry manure combination, pond water only and control respectively as compared to the potential yield of 4.6t/ha for the *Obatanpa* variety. Economic analysis proved that application of freely available effluents in an aquaponics-based food production system did not only increase maize yields to about 50% over the control but also reduced total production costs; thereby leading to improved farmer income and food security.

Keywords: *Aquaponics-based food system; effluents; maize*

INTRODUCTION

Maize is a cereal crop grown as a component of an Aquaponics Based Food System (AFS) popularly known as integrated aquaculture agriculture (IAA) system in many parts of the world including Ghana and Brazil in a range of agro-ecological environments (Muendo et al., 2011). Aquaponics based food system is a refined branch of aquaculture. It is a bio-integrated system linking recirculating aquaculture with the production of plants such as vegetables, cereals, roots and tuber crops, tree crops, ornamental flowers and culinary or medicinal herbs, etc. and/or animals (Jones, 2002). Manure from the fish pond (effluent and algal water) and/or livestock may be used to fertilize and irrigate ('fertigate') crops. Maize, often grown as a component crop in an aquaponics based food system is produced annually worldwide than any other cereal crop (Paliwal et al., 2000). However, maize production in Ghana is usually characterized by poor soil fertility because of continuous mono-culture and shifting cultivation (FAO, 1983). This leads to soils under such production highly impoverished (Tulu, 2002) resulting in lower actual yields of (1.7t/ha) in Ghana compared to other maize growing countries like Italy (9.5t/ha), Canada (6.6 t/ha), China (4.6 t/ha) and Argentina (5.7 t/ha) (Tahir et al., 2009). Based on synthetic fertilizers calculations, maize nutrient requirement is 90Kg N, 45KgP and 45Kg K per ha respectively (Mucheru-Muna et al., 2007). FAO (2015) fertilizer trends and outlook report suggests that fertilizer use has soared five-fold, globally in the past five decades despite no substantial gains in yields. In 2012, about 180 million tones of fertilizer were applied, at an average application rate of 115 kg of nutrients per hectare of arable land and crops. Fertilizer use varies widely across the globe, from relatively low rates in sub-Saharan Africa to high levels in East Asia. Although there is the challenge due to its excessive moisture, bad odour, transportation, inconsistent nutrient contents and phytotoxic substances, which may adversely affect the health of those who handle it; nonetheless, applying poultry manure to agricultural fields is potentially beneficial to agro-ecosystems. Furthermore, it has been observed that composting as an agricultural best management practices (BMPs), could address the above issues with poultry manure (Farhad et al., 2013). Organic waste increases soil organic carbon, nitrogen, available phosphorus, exchangeable bases and acidic soil pH (Vanluawe et al., 2001). Fish ponds accumulate organic matter, nitrogen and phosphorus in their effluent via regular artificial feeding. Studies show that only 25% of N and 20% of P of the feed is recovered in harvested fish and the rest accumulated in pond effluent (Avnimelech, 1995; Avnimelech, 1998). Composted poultry manure (CPM) and fish effluent on the other hand is abundantly available in an AFS which may be used to ameliorate poor soils under maize production (Frimpong et al., 2015). The rising cost of inorganic fertilizers coupled with their inability to sustain organic carbon and soil structure has directed attention to organic manure use in recent times (Boateng et al., 2006; Lopez-Real, 1995). Farmers rely heavily on inorganic sources of fertilizers to replenish the soil nutrients, which in turn increase production and management cost. This is expected to further increase as subsidies are being removed from inorganic fertilizers in most developing countries (FAO, 1995). Also, FAO reported in 2012 that nutrient imbalance, soil acidity and increased greenhouse effects were some of the adverse effects of inorganic fertilizers (FAO, 2012). Tabur et al., 2009 also reported on it cytological defects and chromosomal abnormalities in plant cells. Despite all these negative effects, inorganic fertilizer has been found to only sustain crop and increase yield for only few years (Ojeniyi, 2000).

AFS on the other hand is a coined name for a technology firstly developed by the Brazilian Agricultural Research Cooperation (EMBRAPA), which integrates fish farming, crops and/or animal production such as small ruminants, grass cutter, rabbit, sheep and goat etc. as a comprehensive unit usually on 1ha parcel of land (Frimpong et al., 2015). It is a closed system which involves at least two to several units such as aquaculture, snailery, compost unit, livestock/poultry, vegetables, worms rearing, and crop production where either the output or effluent from one of these components becomes an input of the other. According to (Amponsah et al., 2014), the objective of the Aquaponics-based Food System is to increase smallholder food production through implementation of water conserving aquaponics-based food systems ensuring all-year-round food production for enhanced nutrition to the smallholder farmer. The project was implemented by the CSIR-Crops Research Institute with affiliates CSIR-Water research and Animal Research Institute`s as collaborating partners. Effluents such as rabbit droppings (20Kg/week on average from keeping 35-40 rabbits), poultry manure (60 Kg/week on average from keeping 200 birds) and fish pond waste water (100L/week) on the average was freely abundant from the AFS setup. Despite the intensification and closed nature of this integrated system, crop production occurs continuously on designated permanent fields as a result of promoting efficient utilization on 1ha. This calls for the efficient usage of soil amendments the system’s effluents for sustainable crop productivity. Therefore, there is urgent need to conduct research to ascertain the best alternative means of sustainably replenishing the soil using effluents (pond water and compost) or in combination on maize production in an aquaponics-based food production system. This is to increase yields, maintain soil fertility and reduce farmer’s production cost thereby leading to a higher farmer income and food security. The main objective of the study was to evaluate the effect of fish pond effluents and compost from the aquaponics-based food system on the yield of three (3) improved maize varieties in Ghana.

MATERIALS AND METHODS

Site Description and Land Preparation

The experiment was conducted during the 2014 minor season at the CSIR-CRI Fumesua station. Table 1 illustrates the agro-ecological characteristics of the study area. Planting was done on 20th September, 2014 at three seeds per stand and later thinned to two stands per hill at 31,250 plants/ha following spacing recommendations from CSIR–CRI maize improvement program (reference). Land preparation was done using traditional cutlass, hoe, spade and rake, measuring

Table 1: Agro-ecological characteristics of the study site (DAR, 2014)

Location	Fumesua(6^{o}41' N, 1^{o}28' W)
Agro-ecological zone	Humid forest
Soil type	Ferric Acrisol; Asuansi series upper top soil consisted of 5cm greyish brown sandy loam topsoil of dark brown gritty clay loam
Temperature (Min-Max. ^{o}C) 2010-2014	25-32
Wet season	Bimodal rainfall pattern
Major season	March-Mid August
Minor season	September-November; peak in October.
Total annual rainfall (mm)	2014 (1200 -1500 mm)

tapes and pegs. Cultural practices like weeding, thinning out and filling in were done two weeks after planting. Weedicide (Nicosulforon 40 OD) was applied to control the growth of weeds five weeks after planting.

Experimental Design

The experiment was laid in a 3×3 factorial randomized complete block design (RCBD) with 3 replications. The factors were three (3) improved CSIR-Crops Research Institute's released maize varieties; *Aburohemaa*, *Obatanpa* and *Omankwa* (Table 2) and effluents (figure x) from the AFS; Pond water only, composted poultry manure (CPM) + pond water at ratio of 0.5:0.5 recommended and control (no fertilizer). The effluents were used as organic fertilizers starting two weeks after planting and applied every fortnight up to the eighth week. The quantity of fertilizer applied were 2L per hill for the pond water only treatment (applied in 4 splits at two weeks interval, i.e. 500ml at each application) equivalent to 364 mg N, 1.5 mg P and 24.1 mg K. In the case of the combined treatment, half rates (3 t/ha) of the recommended CPM of 6 t/ha according to Farhad et al. (2013) and added to 1 L/hill of pond water treatment applied in 4 splits at two weeks interval.

Table 2: Characteristics of the released improved CRI varieties.

Name of variety	**Year of formal release**	**Origin (institute)**	**Maturity period (days**	**Potential (tons/ hectare)**	**Selected characteristics**
Obatanpa	1992	IITA/CIMMYT	105	4.6	Yield, quality protein maize, kernel type, tolerance to pests and diseases (blight, rust, streak, stem borer), lodging resistant
Aburohemaa	2010	IITA	90	5.0	DT, Striga tolerant, QPM; all 2010 varieties are drought resistant and mature early, were suitable for the forest and coastal zones, as well as that of Northern and Sudan savannah zones.
Omankwa	2010	IITA	90	4.7	DT, Striga tolerant; QPM

NB: CRI= CSIR-Crops Research Institute, CIMMYT = International Maize and Wheat Improvement Center, IITA = International Institute of Tropical Agriculture; QPM = quality protein maize; DT = drought tolerant.
Adapted from Ragasa et al., 2013.

AFS Composted Poultry Manure

Pond water from AFS

Figure X: Illustration of AFS effluents

Field layout

The layout consisted of three blocks with each block measuring 23 m x 5 m with a 1.5 m space in between blocks. Each block consisted of nine plots, 2 m x 5 m with 0.5 m space in between plots as alleys.

Source of effluents

Composted poultry manure and pond water were sourced from the Aquaponics-based food system (AFS) Fumesua on-station project site. Manure from the AFS was composted anaerobically with the help of black polyethylene sheet cover. They are firstly mixed with water after collection, covered up and left to undergo initial decomposition. The mixture was watered and overturned every two weeks and covered again until eight weeks after which the manure can be used for soil amendment.

Water and soil sampling

Sample of the composted poultry manure sourced from the aquaponics set up was also analyzed by CSIR-Soil Research Institute to determine their physico-chemical properties (Table 3).Initial soil samples were also taken on all three blocks at 3 different locations (upstream, midstream and downstream) at a depth of 0-30cm and their fresh and dry weights measured and analyzed by CSIR-Soil Research Institute for various physico-chemical properties (Table 4). Pond water samples were taken for analysis from three points of each 3 m x 4 m AFS pond on-station. The two raised fish ponds are 1m high and filled up to 0.75 m. The three water samples for each pond were then bulked and analyzed by CSIR-Water Research Institute (Table 5).

Table 3: Some chemical properties of poultry manure used in the experimental field

Chemical Properties	Analytical value
Total N **(%)**	2.44
Total P **(%)**	1.39
Total K **(%)**	0.51
Total S **(%)**	0.71
Total Zn **(%)**	0.13

Table 4: Soil analysis of the experiment field for the various physico-chemical properties

Soil Properties	**Unit**	**Soil**
pH (1:1; soil: water)		4.22
Org Carbon	%	1.00
Total N	%	0.12
Org Material	%	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
E.C.E.C	cmol/kg	3.33
Base Sat.	%	70.91
T.E.B	cmol/kg	2.39
Exch. A (Al+H)	cmol/kg	1.41
Texture		Loamy sand

Table 5: Results of Aquaponics based Food System pond water quality analysis.

Element (mg/L)	**Pond 1**	**Pond 2**
N	184.923	179.328
P	0.593	0.879
K	10.59	13.49
S	70.168	65.546
Ca	118.00	118.35
Mg	4.032	6.384
Zn	0.064	0.180
B	-	-
Mo	-	-
Mn	0.005	0.052
Cu	0.089	0.103
Fe	0.185	0.246
Cl	30.0	29.0

Data Collection and Analysis

Growth parameters such as number of plant stand and chlorophyll content (using the SPAD meter) were taken three (3) weeks after establishment at an interval of two (2) weeks till maturity. Plant height was also taken on the third, fifth, seventh and ninth weeks after planting. Data on 50% tasselling was also recorded. Yield parameters such as Number of Cobs and Grain yield were also collected and tabulated after harvest. Grain yield was calculated based on the formulae below according to (University of Maryland Cooperative Extension, 2001). Digital moisture meter was used to record the moisture content of grains at harvest to enable calculation of grain yields. Data was then subjected to analysis of variance using Genstat version 9.0 to determine significant differences between and among treatments.

$$\text{Grain yield} = \frac{\{\text{Cob weight} \times 10000\text{ha} \times (100 - \text{Moisture content}) \times 0.8\}}{\text{Harvested Area} \times 8.5}$$

Where; 0.8 is the shelling percentage, 8.5 is a constant.

RESULTS AND DISCUSSION

Soil physico-chemical properties and pond water analysis

Soil used for the experiment was loamy-sand in texture, slightly acidic and low in total Nitrogen (N) and slightly lower in potassium (K) as depicted in Table 4. However, the soil had high available phosphorus (P) (103.11 mg/kg) above the 10 mg/kg recommended for optimum maize growth in the tropics (Okaleboet al., 2002). This was consequently due to the topography and previous history of the field resulting in leaching and residual deposition of phosphorus. The soil can be described as a poor soil for maize production due to its low level of total Nitrogen (0.12), organic matter and pH of (4.22).

According to Mucheru-Muna et al., 2007, maize nutrient demand is 90 kgN/ha, 45 kgP/ha and 45 kgK/ha however, analysis of the water quality of the two ponds (Table 5) used for fertigation indicates very low N, P and K below the critical essential macro and micro nutrient requirements for maize. Though the nutrient levels of the pond water was lower than required, it was similar to the content discovered by Challam and Chaturvedi 2013, in brewery effluent at various levels which was averagely 250 ppm, 0.506 ppm and 0.75 ppm for N, P and K respectively. Despite the low levels of N-P_2O_5-K_2O in the fish pond water, fertigation of maize resulted in vigorous growth and total plant development than the control. This might be due to soluble and readily available nutrients from the pond water (applied in split) for uptake to support plant growth and development.

Effect of different effluents on the height (cm) of maize

Maize height at 3WAP, 5WAP, 7WAP and 9WAP showed significant differences ($P < 0.05$) due to the application of the different fertilizer levels i.e., control, pond water only and combined compost and pond water (Figure 1). On the whole, height at 9WAP averaged at 113 cm, 127 cm and 170 cm for control, pond water only and the combined treatment respectively. This signifies a 50.44% increase over the control for the combined treatment. Confirming these results is poultry manure amendment work done by (Ewulo et al., 2015) where maize plant height increased from 21 to 63 days after planting. Again, their highest value of plant height was obtained in the interaction of irrigation and poultry manure at 4 t/ha (Ewulo et al., 2015). Studies by Komakech et al., 2015 also observed similar result trends where significant difference ($P < 0.05$) in both crop growth and yield was noted when the organic fertilizers were compared with the control. Howbeit, the different varieties i.e. Obatanpa, Aburohemaa and Omankwa showed no significant differences in plant height (Figure 2). This shows similarity to Osaigbovo and Orhue (2006) who reported that plant height was averagely around 100 – 120 cm after applying different content of pharmaceutical effluent to soil for 8 weeks. Research has shown that effluent from fish pond and other sources like rubber, brewery, dairy positively affect plant height compared to control treatments (Challam and Chaturvedi, 2013; Ojobor and Tobih, 2015; Mounke et al., 2014, Orhue et al., 2005; Orhue and Osaigbovo, 2012).

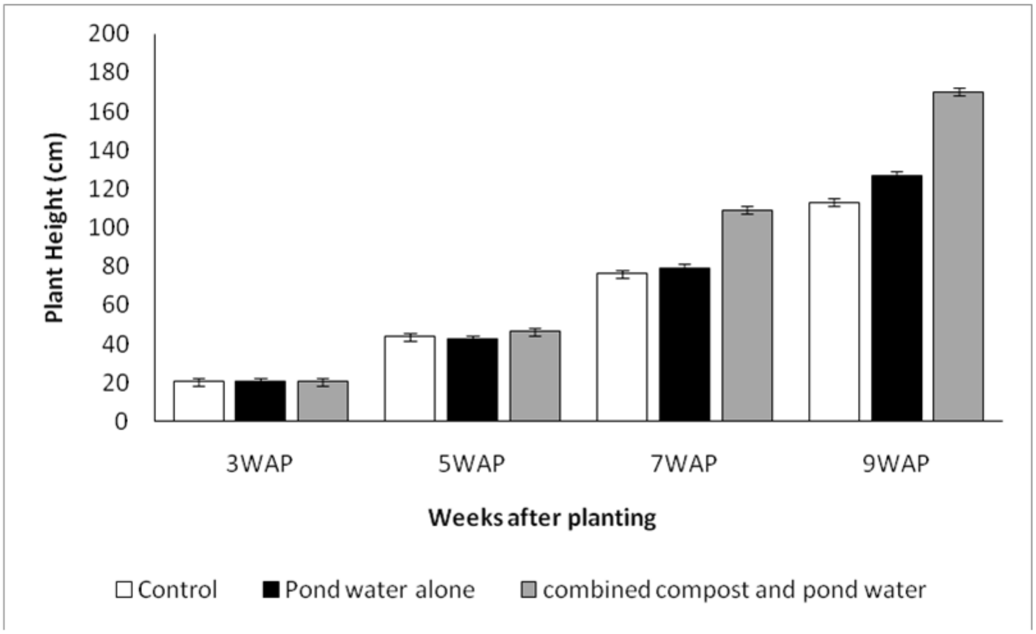

Figure 1: A graph showing plant heights at different Weeks after planting (WAP)

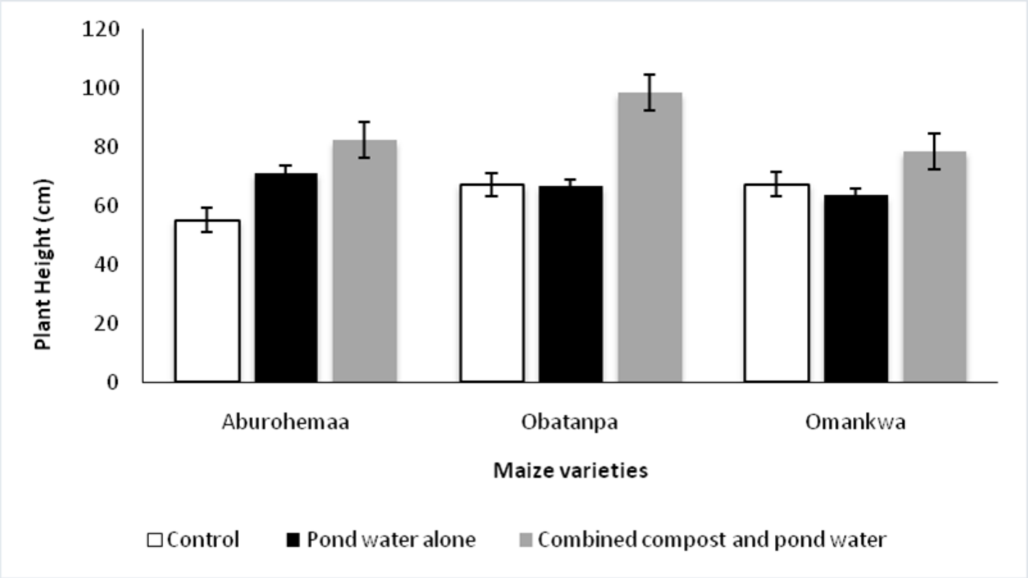

Figure 2: Maize varietal heights with respect to the types of treatments.

Saeed et al. (2001) also reported a positive correlation between plant height and it productive potential. Interaction effect between the fertilizer treatments and maize varieties was also not significant. Generally, the significant difference (*P*< 0.05) in maize height (Table 4) due to the application of effluents from an aquaponics based food system reaffirms the importance of composted manure and pond water effluents in such systems for soil amelioration and how close it can be without external inputs. For example, (Muendo et al., 2011) argues that development of IAA-systems in African farming would improve nutrient use efficiencies and enable increased food production while reducing soil fertility losses. These positive impacts are achieved because of the possibility of the aquaculture component to (i) utilize available farm residues/effluents (ii) trap and retain nutrients in pond sediments and (iii) operate all year round.

Effect of different effluents on chlorophyll content of maize leaves

Application of AFS effluents had significant effect (*P*< 0.05) on the chlorophyll content of maize leaves based on the analysis of SPAD readings (Table 4). However, there was no significant difference in terms of chlorophyll content among the different improved maize varieties. Combined ½ pond water and ½ compost treatment plots had much greener leaves compared to the control or even pond water alone treatment (figure 6) for all varieties evaluated. Similar to the findings of Osaigbovo et al., 2006; that the higher the treatment application of effluent, the higher the chlorophyll content in the plant. This implies that the combination of composted poultry manure and pond water made readily available both macro and micro nutrients for plant uptake i.e. ensuring synchronization with plant nutrient demand. The results is in accordance with Amujoyegbe et al., 2007 who demonstrated that combined application of inorganic fertilizer and poultry manure (IFPM) resulted in very green coloration of maize than the control leading to an overall higher grain yield. They concluded that, while significant improvement is usually deserved in the use of organic and inorganic nutrient sources in crop production, the improvement in yield, biomass and chlorophyll due to IFPM suggested that its use in crop production would aid both the vegetative and the post-anthesis development of the crop. There was significant impact of the nutrient source, evident in dark coloration and that subsistence farmers could use such nutrient source to reduce high fertilizer cost.

Effect of effluents on maize stands and tasseling

Results on maize tasseling indicate no significance for days to 50% tasseling for all the varieties irrespective of treatment or its combination (Table 4). This suggests that, none of the treatments had a competitive advantage over the other in terms of tasseling by the 50th day after planting (figure 3). Similarly, there was no significant difference among plant stands three weeks after planting. This suggests equal treatment of all plots before the commencement fertilizer application. Thus, affirming the statistical significance of growth parameters and yield

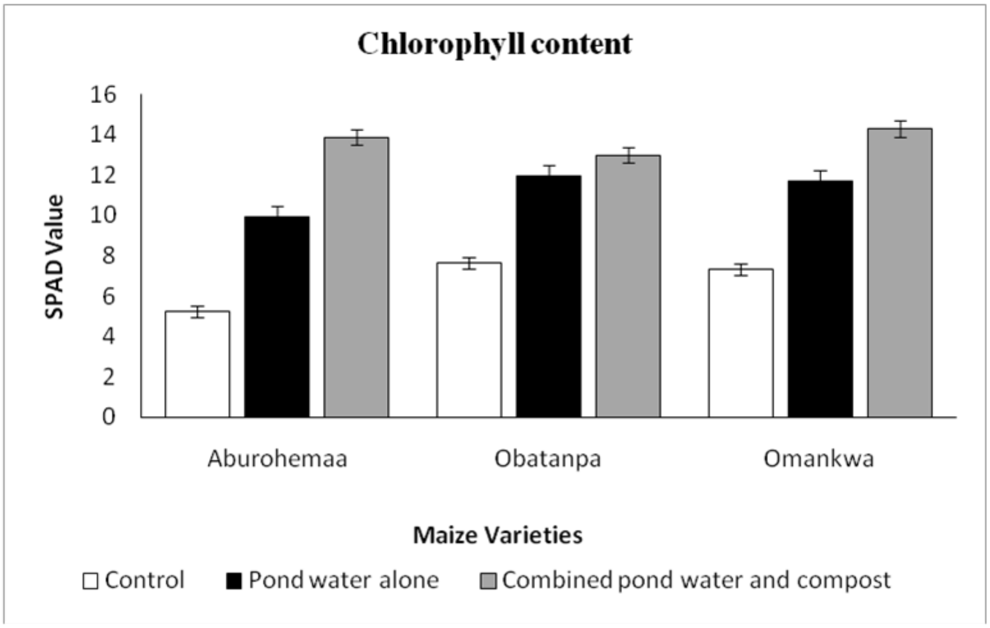

Figure 3: Effect of fertilizer treatments on Chlorophyll content of different maize varieties

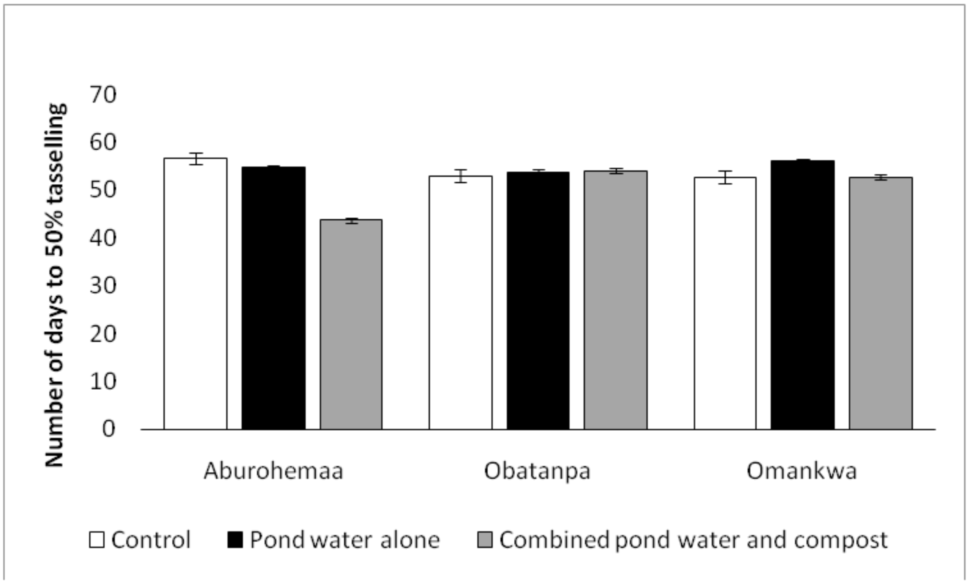

Figure 4: Number of days to 50% tasseling of the maize varieties under different fertilizer treatments

eventualities during harvest was due to fertilizer levels and/or varietal differences.

Effect of effluents on the yield of maize

Results from the ANOVA showed significant difference (*P*<0.05) in the different effluents application on the grain yield and cob number of maize (Table 4). However, there was no significant difference in yield among the three improved varieties. Achievable grain yields of maize reported for Ghana from 1993-2011 are in the range of 1.5 to 1.7 t/ha (Ragasa et al., 2013). Figure 6 shows that, grain yield averages for this study were in the range of (0.7: 2: 2.8 t/ha) for control, Pond water alone and combined compost and pond water treatments respectively across all varieties used. Again, from Figure 7, Cob number averages were in

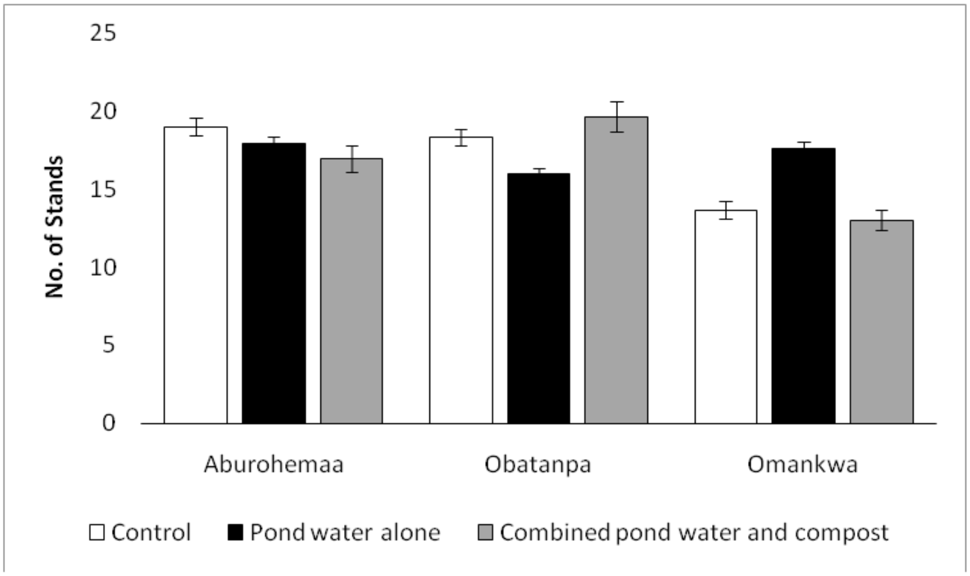

Figure 5: Plant stand at 3 weeks after planting (WAP) for the various fertilizer treatments

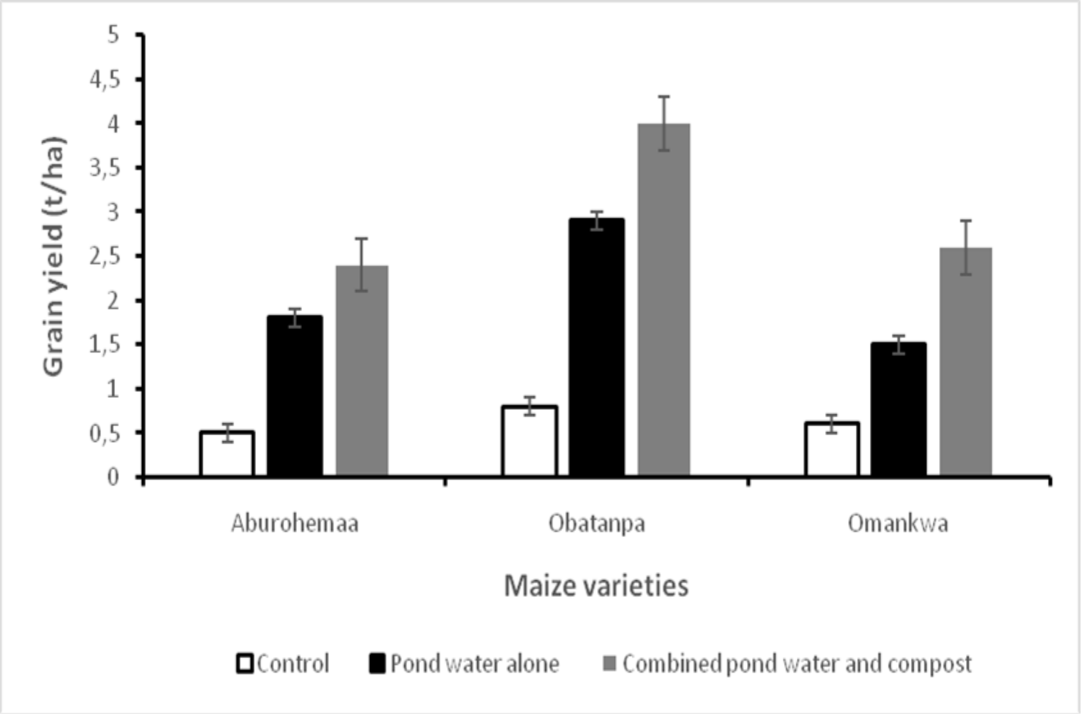

Figure 6: Maize varietal grain yield with respect to treatments

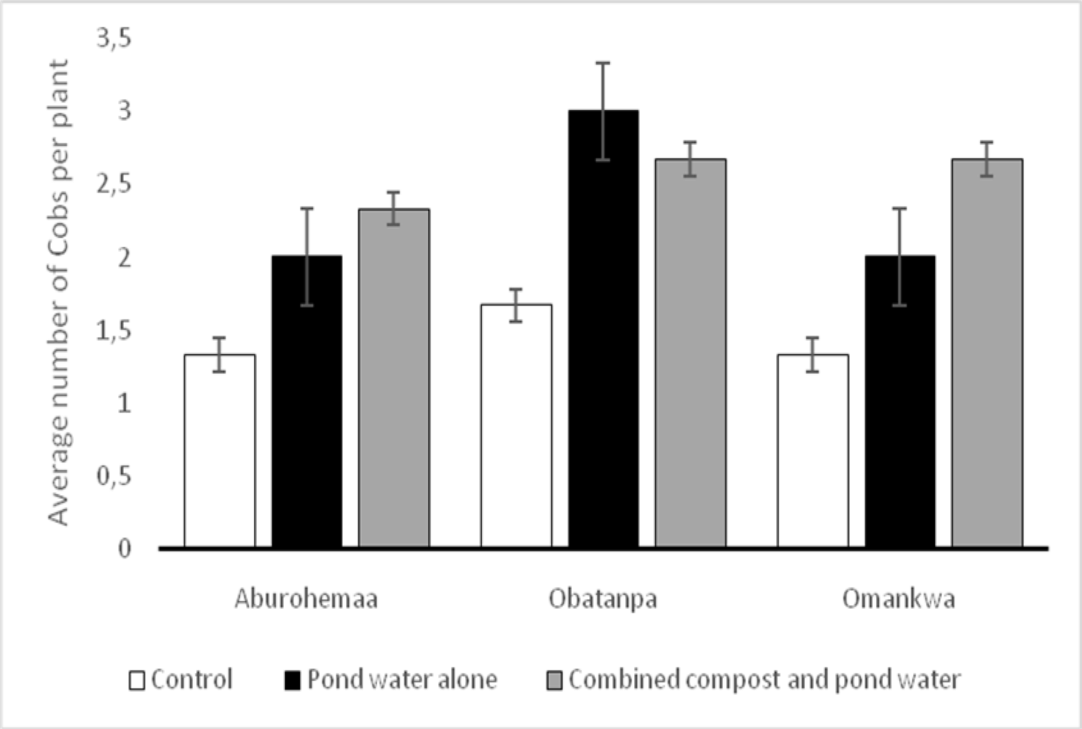

Figure 7: Maize varietal cob number with respect to treatments

the range of (1.5: 2.3: 2.53 t/ha) for control, pond water alone and combined compost and pond water treatments respectively across all varieties used. Although statistically not different from the other varieties, it should be noted that, Obatanpa maize recorded the highest mean grain yield of 4 t/ha and cob number of 3 for combined and pond water alone treatments respectively (Figures 6 and 7). It can therefore be inferred from the results that, application of aquaponics based food system effluents (particularly the combination of the compost and pond water) can be used as an alternate fertilizer in the production of maize while ensuring no compromise on production quantity. This is in line with research work by Boateng et al.(2006) and Agyeman et al. (2012) who concluded that organic fertilizers such as composted poultry manure (pm) and agroforestry biomass could serve as alternative to chemical fertilizers. This was based on results that 4 t pm/ha rate produced maize grain yield of 2.07 t/ha which was statistically not different from that of the chemical fertilizer rate (2.29 t/ha) and 6 t pm/ha (2.60 t/ha), while the 6 t pm/ha was not statistically different from the 8 t pm/ha rate. Similar conclusions also in line with studies on effluent from palm oil, brewery and dairy on maize yield which recorded higher tonnes compared with control (Challam and Chaturvedi, 2013; Ogboi et al., 2010; Orhue and Osaigbovo, 2012).

Benefit cost Assessment

The highest BCR (1.29, 2.43, and 1.24) was achieved with the combined treatment option of compost and pond water for *Aburohemaa*, *Obatanpa* and *Omankwa* respectively (Table 6). Significantly lower BCR (-0.23, 0.23, and -0.08) was recorded with the control option for all maize varieties (Table 6). It can be inferred that investing 1 Ghana cedis using the combined treatment, a farmer would gain 0.29, 1.43 or 0.24 plus the additional cedi invested compared to the control in which case a loss of 0.23 or 0.08 would be incurred except for *Obatanpa* maize. Generally, Obatanpa performed better in terms of growth and yield thereby affecting its overall economic outlook to even be somewhat good in the case of the control treatment. Bamire et al., 2004 studies confirms that yield levels (kg/ha) and mean net income earnings (/ha) per annum were significantly higher for users of manure. The results of the BCR's further reiterate the importance of using the combined treatments across the three improved maize varieties in an aquaponics based food system.

Table 6: Partial budget and economic analysis of effluent options on 3 maize varieties

	Aburohemaa			*Obatanpa*			*Omankwa*		
Parameter	**C**	**PW**	**CPWC**	**C**	**PW**	**CPWC**	**C**	**PW**	**CPWC**
Average yields(kg/ha)	500	1900	2400	800	2600	3600	600	1500	2350
Adjusted yield*	450	1710	2160	720	2340	3240	540	1350	2115
Gross benefit(₵/ha)	1035	3933	4968	1656	5382	7452	1242	3105	4865
cost of effluent(₵)	0	500	583	0	500	583	0	500	583
Labour cost for effluent(₵/ha)	0	240	240	0	240	240	0	240	240
land clearing(₵/ha)	250	250	250	250	250	250	250	250	250
Cost of seed (₵)	120	120	120	120	120	120	120	120	120
Labour cost of planting(₵/ha)	400	400	400	400	400	400	400	400	400
Labour cost of thinning out(₵/ha)	30	30	30	30	30	30	30	30	30
Cost of weed control (5 times) (₵/ha)	300	300	300	300	300	300	300	300	300
Harvesting cost(₵/ha)	250	250	250	250	250	250	250	250	250
Total cost that vary	1350	2090	2173	1350	2090	2173	1350	2090	2173
Net benefit	-315	1843	2795	306	3292	5279	-108	1015	2692
Benefit cost ratio	**-0.23**	**0.88**	**1.29**	**0.23**	**1.58**	**2.43**	**-0.08**	**0.49**	**1.24**

NB: 1 ₵=$4, C – Control; PW – Pond Water Only and CPWC – Combined Pond Water and Compost

CONCLUSION

Proper fertigation maximizes economic yield and minimizes risks of over-fertilization and nutrient losses. Resulting in tremendous increase in grain yield (4 t/ha) for *Obatanpa* maize from the Pond water + Compost treatment compared to a yield of 2 t/ha for the control treatment. Thus, translating into a 50% maize yield increase over the control when effluents are applied in aquaponics-based food production system. Therefore, application of free available effluents hitherto regarded as waste in an aquaponics-based food system will not only increase maize yields but promote nutrient balance for sustained crop production and reduce farmers' production costs leading to an enhanced farmer income, livelihood and food security.

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REFERENCES

Adu S. V., and Asiamah R. D. (1992). Soils of the Ayensu-Densu Basin, Central, Eastern and Greater Accra Regions of Ghana. Council for Scientific and Industrial Research (CSIR) – Soil Research Institute Memoir
(No. 9, p. 117).

Agboola A. A. (1990). Organic matter and soil fertility management in the humid tropics of Africa. IBSRAM Proc., 10: 231–44.

Agyenim Boateng S., Zickermann J., KornahrensM. (2006). Poultry Manure Effect on Growth and Yield of Maize. West Africa Journal of Applied Ecology –ISSN: 0855-4307, Volume 9.www.wajae.org.

Amponsah, S.K., Dankwa, H.R., Amoah, K. O., Bessah, E., Frimpong, F., Adu-O. J., Agyeman, K., and Tetteh, E. N. (2014). Fact Sheet: Aquaponics-based Food Systems Project. CSIR-Crops Research Institute, Kumasi.

Amujoyegbe B. J., Opabode J. T., Olayinka A. (2007). Effect of organic and inorganic fertilizer on yield and chlorophyll content of maize (Zea mays L.) and sorghum Sorghumbicolour(L.) Moench). African Journal of Biotechnology Vol. 6 (16), pp. 1869-1873

Avnimelech, Y. (1998). Minimal discharge from intensive fish ponds. World Aquaculture, Vol. 9, pp. 32 – 37.

Avnimelech, Y., Mozes, N., Diab, S. and Kochba, M. (1995). Rates of organic carbon and nitrogen degradation in intensive fish pond. Aquaculture, Vol. 93, pp. 1156 - 1163

Aweto, O.A. (1981a). Fallowing and soil, soil fertility restoration in South Western Nigeria. Malaysia Journal of Tropical Geography, 3: 1-7.

Bamire A. S., Amujoyegbe B. J. (2004) Economics of Poultry Manure Utilization in Land Quality Improvement Among Integrated Poultry-Maize-Farmers in Southwestern Nigeria. Journal Of Sustainable Agriculture Vol. 23 , Iss. 3. DOI: 10.1300/J064v23n03_04

Challam, B. S. and Chaturvedi, S. S. (2013). Effect of treated dairy effluent on height and yield of zea mays L. RASAYAN J. Chem. Vol. 6(2), pp. 153-157.

District Analytical Report. (2014). 2010 Population and Housing Census. Ejisu-Juaben Municipal. Ghana Statistical Service, Accra, Ghana.

Ewulo, B.S., Omoju O.J. (2015) Effect of poultry manure and irrigation interval on soil properties and maize performance in Akure, southwest Nigeria. Journal of Organic Agriculture and Environment Vol. 3, December 2015.

Farhad W., Cheema M. A., Saleem M. F., Radovich T., Abbas F., Hammad H. M. and Wahid M. A. (2013). Yield and Quality Response of Maize Hybrids to Composted Poultry Manure at Three Irrigation Levels International. Journal of Agriculture Biology, 15(2).

Food and Agriculture Organization. (2012). World food and Agriculture. FAOSTAT. Available at http://www.fao.org

Food and Agriculture Organization. (1995). The state of food and agriculture. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Food and Agriculture Organization. (1983). Integrating Crops and Livestock in West Africa. FAO Document Repository, Assessed from:http://www.fao.org/docrep/004/x6543e/x6543e03.htm

Food and Agriculture Organization. (2015). Worlds Fertilizer Trends and Outlook to 2018. Assessed from: http://www.fao.org/3/a-i4324e.pdf. 66 p. Job Number: I4324. ISBN 978-92-5-108692-6

Frimpong Felix, Shadrach Amponsah., Kennedy Agyeman, Kwame Owusu Amoah, Hederick Dankwa, Jonas Osei-Adu. (2015) Aquaponics based food system project. Interdisciplinary AGEP Winter School, University of Hohenheim-A World without Hunger Conference.DOI: 10.13140/RG.2.1.1605.5127

Jones S. 2002. Evolution of aquaponics. Aquaponics Journal, 6: 14-17.

Komakech A. J., Zurbrügg C., Semakula D., Kiggundu N. and Björn Vinnerås. (2015) Evaluation of the Performance of Different Organic Fertilizers on Maize Yield: A Case Study of Kampala, Uganda. Journal of Agricultural Science; Vol. 7, No. 11; 2015, ISSN 1916-9752 E-ISSN 1916-9760, Published by Canadian Center of Science and Education.

Lopez-Real J. M. (1995). Organic wastes and peri-urban horticulture. Report to Natural Resources Institute. A visit to Kumasi, Ghana.

Mouneke, C. O., Okpara, D., Ofor, C., Orji, R., Onwuka, J., Ibiam, N. (2014). Organic/inorganic leaf amaranth production: the case of poultry manuew, fish effluent and npkfertliser. Rahman G andAksoy U (Eds). Proceedings of the 4th ISOFAR Scientific conference from 13 – 15 October 2014, Istanbul, Turkey.

Mucheru-Muna, M, Mugendi D., Kung'u J, Mugwe J, Bationo A. (2007) Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. Agroforestry System, 69:189–197

Muendo P. N., Stoorvogel J. J., Verdegem M. C. J., Mora-Vellejo A., Verreth J. A. J. (2011) Ideotyping integrated aquaculture systems to balance soil nutrients. Journal of Agriculture and rural development in the tropics and subtropics, 112(2), 157-168.

Ogboi, E., Kperegbeyi, J.I., Nmor, E.I., Odeh, H.O (2010). The performance of maize (Zea mays) in soil contaminated with palm oil effluent (POME) in South, South Central Nigeria. African Journal of General Agriculture, Vol. 6(1), pp. 19 – 24.

Ojeniyi, S. O. (2000). Effects of goat manure on soil nutrients and okra yield in a rain forest area of Nigeria. Applied Tropical Agricultural Journal, Vol. 5, pp. 62 – 67.

Ojobor, S. A. andTobih, F. O. (2015). Effect of fish pond effluent and inorganic fertilizer on Amaranthus yield and soil chemical properties in Asaba, Delta State, Nigeria. Journal of Agriculture and Environmental Sciences, Vol. 4(1), pp. 237 – 244.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (2002). Laboratory methods in soil and plant analysis: Aworking manual. Second edition. TSBF-CIAT and SACRED Africa, Nairobi, Kenya.

Orhue, E. R. andOsaigbovo, A. U. (2012). The effect of rubber effluent on some chemical properties of soil and early growth of maize (Zea Mays L). Bayero Journal of Pure and Applied Sciences, Vol. 6(1), pp. 164 – 168.

Orhue, E.R., Osaigbovo, A.U., Vwioko, D. E. (2005). Growth of maize (Zea mays L.) and changes in some chemical properties of an ultisol amended with brewery effluent. African Journal of Biotechnology, Vol. 4(9), pp. 973 – 978.

Osaigbovo, A. U. andOrhue, E. R. (2011). Effect of palm oil mill effluent on some soil chemical properties and growth of maize (Zea mays L). Nigerian Journal of Agriculture, Food and Environment, Vol. 7(3), pp. 51 – 54.

Osaigbovo, A. U andOrhue, E. R. (2006). Influence of pharmaceutical effluent on some soil chemical properties and early growth of maize (Zea mays L). African Journal of Biotechnology, Vol. 5(12), pp. 1612 – 1617.

Paliwal R. L., Granados G., Lafitte H. R., Violic A. D. (2000). *Tropical Maize: Improvement and Production*. Paliwal R. L., Granados G., Lafitte H. R., Violic A. D (eds). Food and Agriculture Organization, Rome, Italy.

Ragasa Catherine, Dankyi Awere, Acheampong Patricia, Nimo Wiredu Alexander, Chapoto Antony, Asamoah Marian, and Tripp Robert (2013). Patterns of Adoption of Improved Maize Technologies in Ghana. Working paper 36, Ghana strategy support program, International Food Policy Research Institute.

Rebecca L. Nelson and John S. Pade. (2008). Aquaponic Food Production: raising fish and plants for food and profit. www.aquaponics.com/ShopAFPBook.htm

Saeed, N., Abbasi, K., Kazim, M. (2001). Response of maize to nitrogen and phosphorus fertilization under agro-climatic condition of Rawalokot Azad Jammu and Kashmir. Pakistan Journal of Biological Sciences, Vol. 4, pp. 53 – 55.

Tabur, S. and Oney, S. (2009). Effects of artificial fertilizer on mitotic index and chromosome behavior in Viciahybridal. Journal of Agricultural Resources, Vol. 47(1), pp. 1 – 7.

Tahir M., M. R. Javed, A. Tanveer, M. A. Nadeem and A. Wasaya, S.A.H. Bukhari and J. U. Rehman (2009).Effect of different herbicides on weeds, growth and yield of spring planted maize (Zea mays L.). Pak. J.

Life Soc. Sci., 7(2): 168-174.

Tulu, T. (2002). Soil and water conservation for sustainable agriculture. Mega publication Enterprise, Addis Ababa, Ethiopia.

University of Maryland Cooperative Extension (2001) https://extension.umd.edu/sites/default/files/_images/programs/anmp/Grain_Yield_Calc.doc.

Vanluawe, B., Wendt, J. and Diels, J. (2001). Combined application of organic matter and fertilizer. In G. Tian et al (ed.) sustaining soil fertility in West Africa. SSSA Special Publication. 58. SSSA and ASA Madison. WI. Pp 247 – 2.