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RESEARCH ARTICLE

NUTRIENT CONCENTRATION IN SURFACE WATER FROM CROP LANDS IN THE TOLON DISTRICT, GHANA

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ABSTRACT

The study assessed plant nutrient loads in water of a pond and irrigation dam in the Tolon District of Ghana. The pond is located downstream of croplands used mainly for rice and maize cultivation whilst the irrigation dam is located further downstream of the pond and used for irrigation of a developed area of 40 ha. Water samples were taken from each location and laboratory analysis determined the concentrations of NH_3, NO_3^-, NO_2^-, PO_4^{3-}, P and K. The results indicated that irrigation dam water recorded grand mean concentration of 0.877 mg/l, 0.284 mg/l, 0.020 mg/l, 0.379 mg/l, 0.139 mg/l and 4.620 mg/l for NH_3, NO_3^-, NO_2^-, PO_4^{3-}, P and K respectively. In the pond water however 1.290 mg/l, 0.033 mg/l, 0.167 mg/l, 0.404 mg/l, 0.063 mg/l and 4.757 mg/l were recorded for NH_3, NO_3^-, NO_2^-, PO_4^{3-}, P and K as grand mean concentration respectively. Farmers used mainly nitrogen and phosphorous based fertilizers and the wash-off effect is as exhibited in the laboratory results. The nutrient concentration of the irrigation dam and pond water resulted in it being oligotrophic and risk eutrophication with potential to reduce reservoir capacity. Nutrient concentration reduction methods will largely contribute to an increase lifespan of the water harvesting systems.

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INTRODUCTION

FAO (2014) reported that, agriculture contributed 30 % to GDP and employed 42 % of the total labour force in Ghana in 2010. In June 2008, the Government of Ghana introduced a nation-wide fertilizer subsidy programme covering three types of inorganic fertilizer i.e. Sulphate of Ammonia, Urea, and Compound fertilizer. The programme was a rapid intervention to help increase food production at the peak of the global financial, food and energy crisis that was adversely affecting poor countries. The goal was to help farmers increase fertilizer application for increased crop production. The target was to increase the country's fertilizer application rate to at least 50 kg per hectare (ha) as recommended in the Medium-Term Agricultural Sector Investment Programme (METASIP) of the Ministry of Food and Agriculture (MOFA). A total of 724, 493 metric tons (mt) of fertilizer was subsidized at a cost of GHS 345,244 million from 2008 to 2015. Government in 2015 projected to import 180,000 mt of subsidized fertilizer.

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As at December, the Government of Ghana imported 90,000 mt of fertilizer which represents half of the target for the year (Northern Ghana CSOS Platform Survey Report, 2015). Maatman *et al.,* (2007) and Morris *et al.,* (2007) noted that fertilizer usage in SSA is the lowest in the world, estimated at only 8 kg/ha in 2002 – 10 % of the world's average. Yet much of the projected growth in crop production in SSA is anticipated to be a result of intensification in the form of yield increases (Druilhe, and Barreiro-Hurlé. 2012). Chapoto, Sabasi and Asante-Addo (2015) also observed that policies aimed at helping smallholder farmers to intensify their use of inputs such as nitrogen fertilizer and the reduction of barriers to access of nitrogen as well as educating households on the gains from intensifying nitrogen usage was very important. Growing plants require nutrients, especially nitrogen and phosphorus. These are applied as fertilizers to compensate for soil nutrient deficits and to enhance plant growth. According to a report published in 1990 by the Environment Protection Agency (EPA), > 50 % of the water pollution of streams and rivers occur due to leaching and mixing of chemicals from agriculture practices (Chen, Hu and Liu, 2008). According to Goel (2006) modern agriculture uses large quantities of chemicals called agrochemical, in the form of fertilizers, organic manure, pesticides, growth hormones, nutrient solution and others.

All the residual forms of these chemicals along with debris from the remains of the harvested crops are trapped by run-off water causing pollution problems in the receiving waters.

Almost all the crop balances in Ghana show a nutrient deficit, i.e. the difference between the quantities of plant nutrients applied and the quantities removed or lost (FAO, 2004). The agricultural runoff is considered rich in nutrients like nitrogen, phosphorus, organic matter and pesticide. Water pollution occurs when a body of water is adversely affected due to the addition of large amounts of materials to the water. The sources of water pollution are categorized as being a point source or a non-source point of pollution (Global Environment Centre, 2008). Internal loading generally refers to the phosphorus (P) released from anoxic sediment surfaces. Under anoxic conditions, phosphorus may escape from the sediment into the water column and become a nutrient source for algae (Brönmark and Hansson, 2005). The study assessed the intra-seasonal variation in plant nutrient load in a pond located in a lowland/downstream used for rice and maize cultivation during the wet (rainy) season and an irrigation dam used for dry season food crop production in the Tolon District of the Northern Region of Ghana.

MATERIALS AND METHODS

Study Area

The study areas were Nyankpala and Golinga located in the Tolon District of the Northern Region of Ghana. Figure 1 is the map of the study areas. The topography of the area is generally undulating with a number of scattered depressions. The area has an annual uni-modal rainfall of about 1000 mm and falls within the Guinea Savannah vegetative zone interspersed with short drought resistant trees and grassland.

The soil is generally of the sandy loam type except in the lowlands where alluvial deposits are found. The levels of organic carbon, nitrogen and available phosphorus are generally very low. The soil fertility status in Northern region of Ghana as reported by the Soil Research Institute (2003) is 4.5 to 6.7 pH, 0.6 % to 2.0 % organic matter, 0.02 to 0.05 % nitrogen, 2.5 mg/kg to 10.0 mg/kg of soil for phosphorous and 45 mg/kg to 90 mg/kg of soil calcium levels. Considerably more plant nutrients are being removed and lost than are being applied, with a consequent progressive impoverishment of soils. Traditional, soil exhausting cultivation practices are still used extensively (Gerner *et al.*, 1995).

Data Collection and Laboratory Analysis: Water samples were taken from the study area at four (4) periodic intervals. The first sample was collected before crop planting (in the month of May 2012); second sampling was at initial crop development stage (in the month of July 2012); third sampling was at mid-crop growth stage (in the month of September 2012) and fourth sampling was after crop harvesting (in the month of December 2012). Fifteen (15) water samples were analyzed for each water source per season. Spectrophotometric analysis was done in determining ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), phosphorus (P), and potassium (K) in the water samples. The laboratory procedure and analysis used the Nessler method for NH_3, colorimetric method for NO_3^- and NO_2^-, orthophosphate method for P and $PO_4^{3-}$and tetraphenylbrorate method for K. Data was analyzed using Genstat Teaching Edition 2009 and Microsoft Excel 2007 in the computation of the nutrient loads and ANOVA was performed at 5 % significance level to ascertain the level and seasonal variation of the nutrients load.

RESULTS AND DISCUSSION

Intra-Seasonal Concentration of Nitrogen Compounds in Water: NH_3 in the irrigation dam water recorded mean concentration values of 1.267 mg/l before crop planting, 1.460 mg/l at initial crop development stage, 0.543 mg/l at mid-crop growth stage and 0.240 mg/l after crop harvest as presented in Figure 2. ANOVA at 5 % significance showed an F-probability (f-pr) value of < 0.001 which means the concentration variation is statistically significant. The high concentration value at initial development stage could be attributed to the fact that farmers who cultivated their crops such as *Oryza sativa* in the irrigation dam catchment area typically applied fertilizers with high NH_3 levels. However, the decrease of NH_3 concentration in the irrigation dam water from mid-plant growth stage could be due to its volatilization property and also an increase in the volume of the irrigation dam water resulting from increase in the rainfall events and amounts thus resulting in dilution. In the pond water, NH_3 mean concentration before crop planting was 2.270 mg/l, 0.850 mg/l at initial crop development stage, 0.533 mg/l at the mid-crop growth stage and 1.520 mg/l after crop harvest as shown in Figure 3. ANOVA at 5 % significance showed that, NH_3 concentration in the pond water recorded f-pr value of 0.003 which is statistically significant. The clear-cut variation within the seasons with respect to decline from before crop planting to mid-crop growth stage means as the water level of the pond increases ammonia concentration decreases as a result of dilution.

In 2016, fertilizer consumption for Ghana was 20.9 kilograms per hectare. Though Ghana fertilizer consumption fluctuated substantially in recent years, it tended to increase through 2002 - 2016 period ending at 20.9 kilograms per hectare in 2016 (Knoema, 2020). MoFA (2003) reported that compound fertilizers accounted for 48 % of the total amount of fertilizers consumed from 1995 to 1999 whilst Nitrogenous fertilizers (urea and ammonium sulphate) accounted for 30 % of the total fertilizers consumed. Excessive fertilizer use, beyond the requirement of a specific crop yield, is the main cause of N loss. On fertile soils fertilizer use can be reduced to the level of nutrient export by crop produce and thereby N loss can be decreased. The high concentration of NH_3 was noted to have led to high level of eutrophication (Figure 4) in the two water bodies and with eutrophication having a potential effect of reducing the quantity of water in these water retention structures.

According to Walna, Kurzyca and Siepak (2004), the main anthropogenic sources of nitrates in the environment are municipal and industrial wastes and artificial fertilizers. In Figure 2, NO_3^- mean concentration in the irrigation dam water was 0.003 mg/l before crop planting, 0.070 mg/l at initial crop development stage, 0.700 mg/l at mid-crop growth stage and 0.367 mg/l after crop harvest. NO_3^- concentration as presented in Figure 3 for the pond water was 0.0 mg/l before crop planting, 0.133 mg/l at initial crop development stage, 0.0 mg/l at mid-crop growth stage and 0.0 mg/l after crop harvest. NO_3^- is noted to biochemically reduce to NO_2^- by denitrification processes, usually under anaerobic conditions. NO_2^- ion is rapidly oxidized to NO_3^-. Natural sources of NO_3^- to surface water include animal

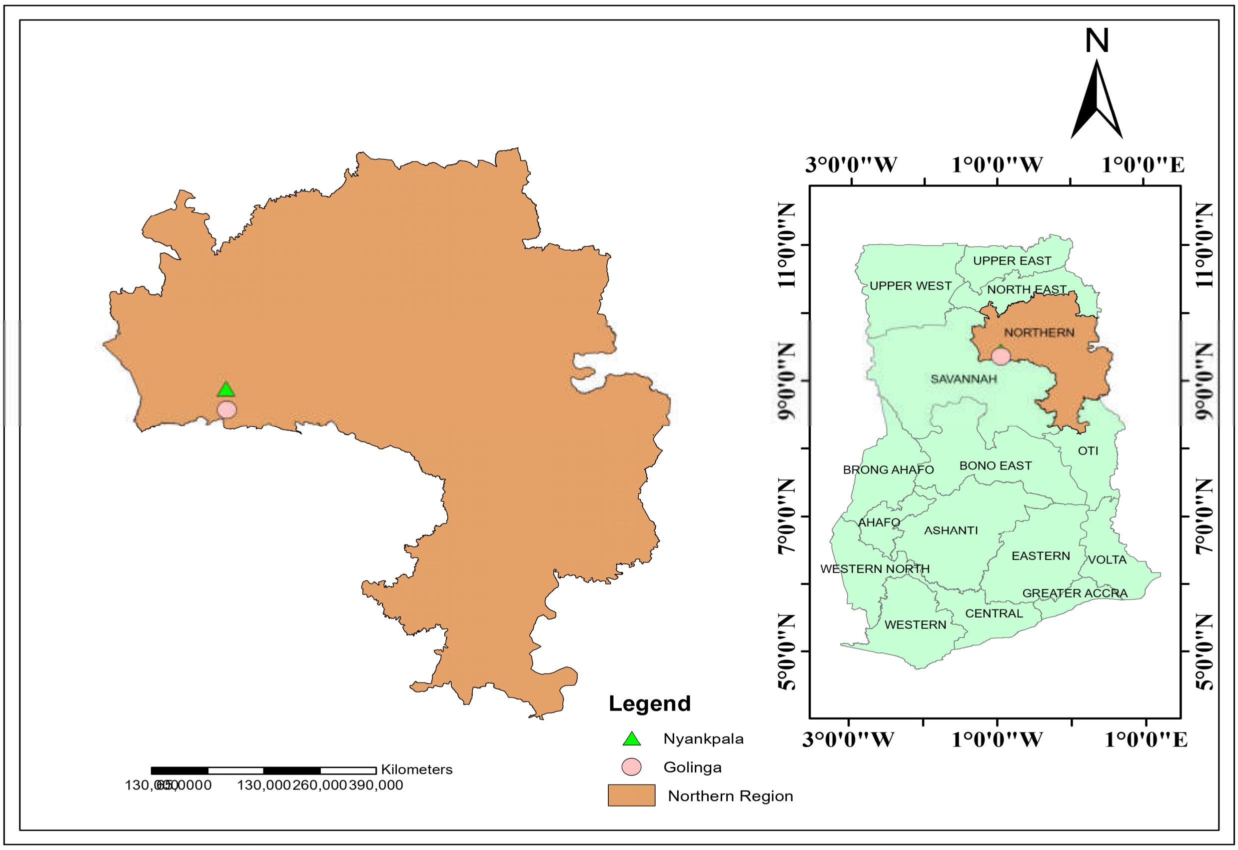

Figure 1: Map of Ghana Showing Water Sampling Points

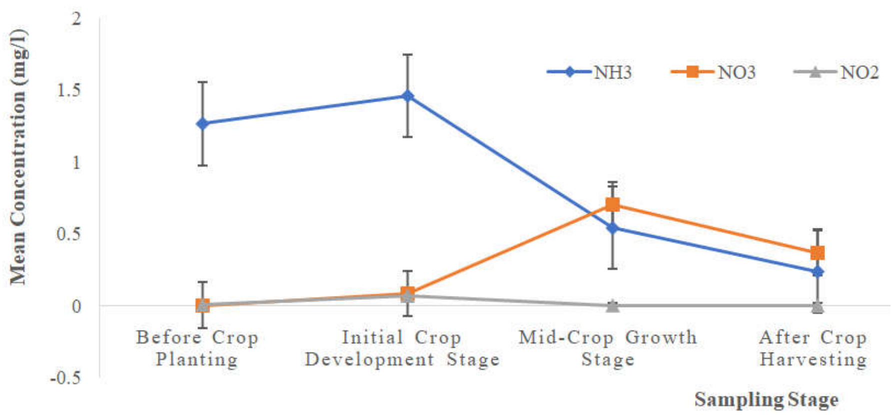

Figure 1. Seasonal Concentration of Nitrogen Compounds in Irrigation Dam Water

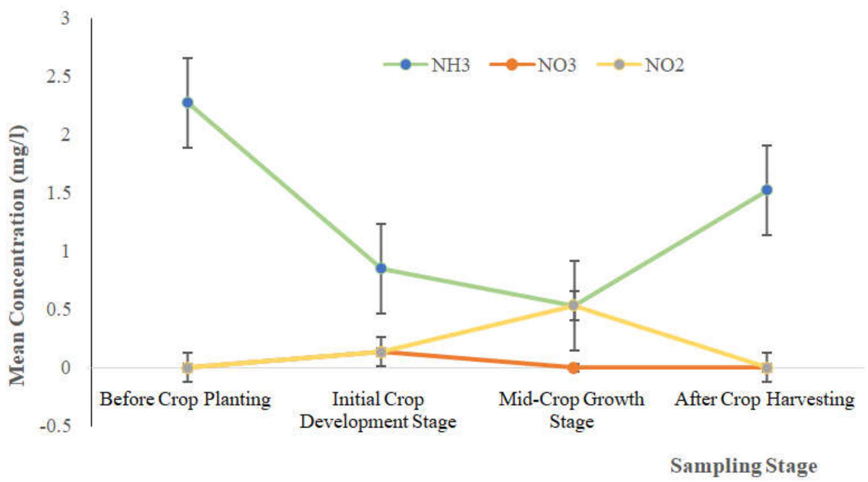

Figure 2. Seasonal Concentration of Nitrogen Compounds in Pond Water

a. Eutrophication in Pond

b. Eutrophication in Irrigation Dam

Figure 3: Eutrophication in Ponds and Irrigation Dam Water

Table 1. Mean Concentrations of Plant Nutrients

Nutrient	Irrigation Dam (mg/l)	Pond (mg/l)	GSB (1998) Standard (mg/l)	EPA (2003) Standard (mg/l)
NH_3	0.88	1.29	1.5	1.0
NO_3^-	0.29	0.17	50.0	50.0
NO_2^-	0.02	0.02	3.0	-
PO_4^{3-}	0.30	0.28	-	-
P	0.11	0.09	2.0	2.0
K	4.76	4.77	13.0	-

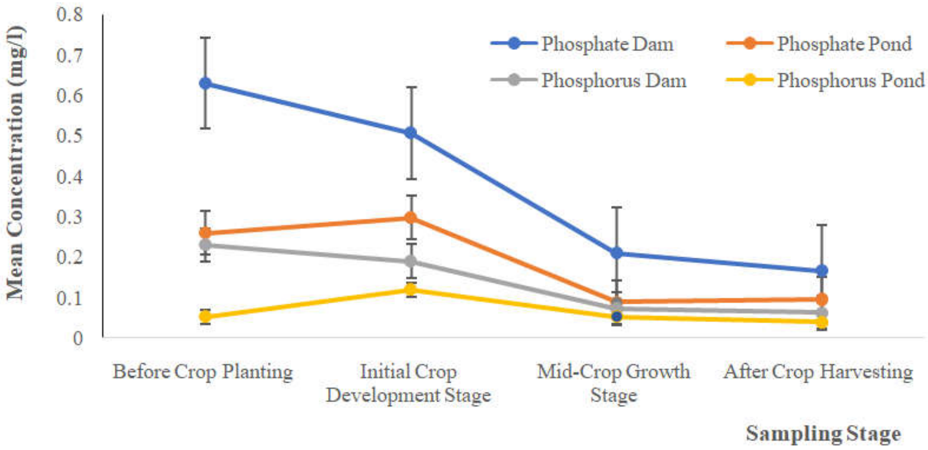

Figure 4. Seasonal concentrations of Phosphate and Phosphorus in Irrigation Dam and Pond Water

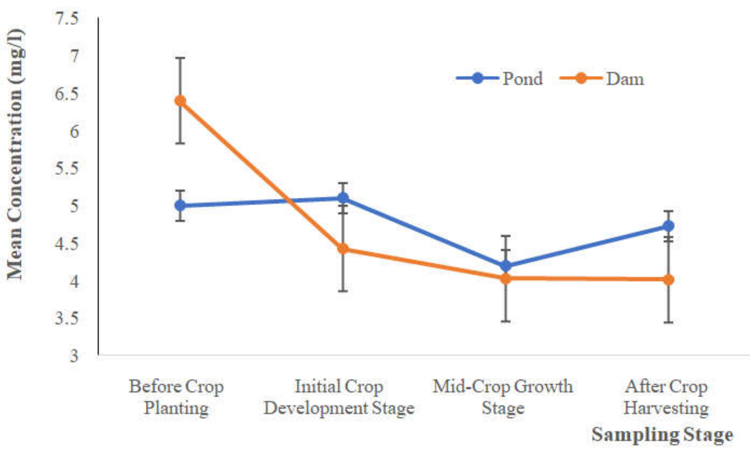

Figure 5. Seasonal Concentration of Potassium in Irrigation Dam and Pond Water

excreta, debris, land drainage, etc (Deborah, 1996). In the irrigation dam water, NO_2^- concentrations were 0.007 mg/l before crop planting, 0.070 mg/l at initial crop development stage, 0.003 mg/l at mid-crop growth stage and 0.001 mg/l after crop harvest (Figure 2). The concentration difference between nitrate 0.700 mg/l and nitrite 0.003 mg/l in the mid-crop growth stage could be due to a biochemical change in the reservoir water. NO_2^- concentration in the pond water recorded the concentration at crop development stage with mean value of 0.0 mg/l, 0.133 mg/l before crop planting, 0.533 mg/l at mid-crop growth stage and 0.0 mg/l after crop harvest (Figure 3). Nitrite has been reported to typically occur in water from fertilizers and is found in sewage and wastes from humans and farm animals (US EPA, 1994). ANOVA of the results at 5 % significance showed that there is statistically significant difference between NO_3^- and NO_2^- concentration in the pond water and irrigation dam water with f-pr values of 0.004 and < 0.001 respectively. Nitrogen compounds primarily as ammonia or nitrogen gas can be lost to the air and eventually return to the soil, streams and lakes through rainfall events.

The biological transformations consist of assimilation of inorganic forms (ammonia and nitrate) by plants and micro-organisms to form organic nitrogen e.g. amino acids, reduction of nitrogen gas to NH_3 and organic nitrogen by micro-organisms, complex heterotrophic conversions from one organism to another, oxidation of NH_3 to NO_3^- and NO_2^- (nitrification), ammonification of organic nitrogen to produce NH_3 during the decomposition of organic matter, and bacterial reduction of NO_3^- to nitrous oxide (N_2O) and molecular nitrogen (N_2) under anoxic conditions (denitrification) (EPA, 2003). In a study by McCarthy *et al.,* 2007) in Taihu (lake Tai), it was noted that N may be the limiting nutrient, and not phosphorus. This is of considerable consequence to agriculture given the very large amount of urea fertilizer used by farmers. Irrespective of whether N or P is the limiting nutrient in Chinese lakes, Chinese scientists consider agriculture to be a significant contributor to the poor quality of lake water. They have noted that agriculture is becoming a major contributor to surface water pollution, especially from runoff of N and P from excessive use of fertilizer.

Phosphate, Phosphorus and Potassium Concentrations: Phosphorus moves into surface waters mainly during surface runoff and soil erosion and it's the main cause of eutrophication in lakes and rivers. In paddy soils in Jiangsu province where phosphate fertilizers are applied, mobile and total P have significantly increased Xie *et al.* (2007). Phosphorus has been noted to concentrate in the top few inches of most soils and is carried away with soil particles during soil erosion. Freshwater ecosystems develop under very low phosphorus conditions, but large additions of phosphorus increase its concentration in water, which leads to eutrophication and stimulates the production of algae blooms that can produce algal toxins that are dangerous to animals and people. In this study, PO_4^{3-} (Figure 5) recorded a mean concentration of 0.630 mg/l before crop planting, 0.507 mg/l at initial crop development stage, 0.210 mg/l at mid-crop growth stage and 0.167 mg/l after crop harvest. Similarly in the irrigation water, P also recorded concentration of 0.230 mg/l before crop planting, 0.190 mg/l at initial crop development, 0.073 mg/l at mid-crop growth and 0.063 mg/l after crop harvest as shown in Figure 5. ANOVA at 5 % significance level showed that the mean concentration of $PO_4^{3-}$and P in the irrigation dam water were statistically insignificant but showed a difference with f-pr value of 0.498 and 0.582 respectively. In the pond water, PO_4^{3-}recorded concentration of 0.260 mg/l before crop planting, 0.297 mg/l at initial plant development stage, 0.090 mg/l at the mid-crop growth stage and 0.097 mg/l after crop harvest (Figure 5). Also, P recorded concentration of 0.053 mg/l before crop planting, 0.120 mg/l initial crop development stage, 0.040 mg/l at mid-crop growth stage and 0.040 mg/l after crop harvest (Figure 5). ANOVA at 5 % significance level showed that, $PO_4^{3-}$and P mean concentration in the pond water were statistically insignificant, but showed a difference with F-pr value of 0.078 and 0.068 respectively. Declining concentration in both parameters was observed along the seasons. For potassium in the irrigation dam water, the mean concentration recorded was 6.50 mg/l before crop planting, 4.03 mg/l at initial crop development stage, 4.03 mg/l at mid-crop growth stage and 4.02 mg/l after crop harvest (Figure 6). ANOVA at 5 % significance showed that, mean concentration of K in the irrigation dam water is statistically significant with recorded f-pr value of 0.008. K in the pond water recorded mean concentration of 5.0 mg/l before crop planting, 5.10 mg/l at initial crop development stage, 4.20 mg/l at mid-crop growth stage and 4.730 mg/l after crop harvest as presented in Figure 6. ANOVA at 5 % significance showed that, K mean concentration value in the pond water was significant statistically with f-pr value of < 0.001. The mean concentration levels revealed a decreasing rate of the parameters in the pond water along the seasons. Enrichment of surface water can be classified into various levels of eutrophication. Jin (2002) found that of 50 Chinese lakes across the country, 44 % were eutrophic and 22 % were hypereutrophic with a rapidly increasing rate of change towards eutrophy and hypereutrophy. Algae growth requires, in particular, the nutrients N and P for optimum growth. In northern temperate lakes and reservoirs, the controlling/limiting nutrient is usually phosphorus (P). Consequently, nutrient control policies in many Western countries focus on phosphorus control strategies both for wastewater and agriculture (FAO, 2013).

Plant Nutrient Concentration in Water: Nutrient loads at the two study sites showed varied mean values, concentrations in the irrigation dam water were generally higher than the pond, except in NH_3 which recorded high levels for the pond as in Table 1. The study revealed runoff as a main contributor of the plant nutrients which are washed off after application in farmlands. According to Nikolaidis (1998) plant nutrients in water bodies are normally associated with agricultural, silvicultural and human activities within a particular catchment area. John and Steve (2006) stated that, runoff soon after manure and other fertilizer applications carry high concentrations of dissolved nutrients. All the plant nutrient concentration in the irrigation dam and pond water were below the critical levels of Ghana Standard Board and the Environmental Protection Agency (EPA) of Ghana set levels. NH_3 in the pond was however slightly higher than the EPA defined levels. Algae is a symptom of eutrophication, which is the technical term that describes the enrichment of river, lake and reservoir water by nutrients, especially nitrogen (N) and phosphorus (P) that, together with potassium (K), are the main components of agricultural fertilizer (FAO, 2013).

Nutrients, primarily nitrogen and phosphorus when in excess amounts have a high level of potential in promoting aquatic weed and algae growth. This may lead to high level of consumption of dissolved oxygen thus resulting in oxygen depletion which may lead to death of fish and other aquatic animals. Agricultural use of fertilizer is a major source of nutrients in rivers, lakes and reservoirs (US EPA, 2009). In 2004 Zhang *et al.* (2010), found that 54 % of total N volatilization from agriculture was from mineral fertilizer, and 47 % from animals (directly, or indirectly from manure). Nitrogen and Phosphorus fertilizer application can be several times higher than the vegetable requirement (Wang, Zong and Li, 2002) and up to 1 000 kg N/ha/yr have been reported.

Conclusion

Except NO_3^-, NO_2^- which recorded low levels of concentration at the time of crop planting, NH_3 PO_4^{3-}, P, and K recorded high levels of plant nutrient concentration. This is as a result of the reduction in the amount of water contained in these water retention structures at the onset of the rains which marks the end of the dry season. As a result of the application of fertilizer at the initial crop development stage as well as at mid-crop growth stage, the concentration of all the studied plant nutrients was appreciably high even though the dilution factor of transported plant nutrients from rainwater cannot be discounted. Due to the high concentration of these nutrients, eutrophication was noted to be high with the pond totally covered with water weeds due to the oligotrophic nature of the concentrations. When one or more of these nutrients are in higher levels, pollution of water bodies will occur and may result in eutrophication and its attendant effect on aquatic life.

Conflict of Interest

"The authors have not declared any conflict of interest regarding the conduct of the study and the publication of this manuscript”

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