Mitigating Land Degradation with Chemical Fertilizer Application in the Asunafo Forest, Ghana

Kenneth Peprah

Department of Environment and Resource Studies,
University for Development Studies, Wa Campus, P.O. Box 520, Wa. Ghana

Abstract: ***Spatial distribution of soil properties of the Asunafo Forest was investigated alongside the effect of chemical fertilizer application to the soils. The aim was to provide baseline soil characteristics and soil responses to chemical fertilization in order to aid farming and land management decision making. With the help of satellite imageries and Global Position System (GPS) soil sample sites were identified. Soil samples were collected from fifteen sites at the depth of 0 – 20 cm and analyzed at the laboratory. Soil pH ranged from 5.76 – 6.88. The study revealed ammonium nitrogen range of (280 – 868 $mgNH_4^+$-Nkg^{-1}), nitrate nitrogen (186 – 448 $mgNO_3$-Nkg), available P (1.45 – 5.15 mg/kg) and available K (3.1 – 12.39 mg/kg). As confirmed by a pot experiment, chemical fertilizer application can raise crop production of degraded lands. Maize yields on degraded soil increased between 8% and 72% under chemical fertilization. Chemical fertilizer treatment to both degraded and non-degraded soil, showed maize yield differences of 2% - 15%. The study supports findings of previous research that chemical fertilization hide or mask land degradation.***

Keywords: Soil, Degraded, Non-degraded, Chemical fertilizers.

1. Introduction

Until recently, land degradation in Ghana used to be spatially restricted to the coastal and northern savanna zones. However, it is now established that parts of the forest zone is experiencing land degradation as a results of unsustainable land productivity extraction through activities such as farming, logging, mining, bushfires, firewood and charcoal production [1].

In the Asunafo forest, the land cover was originally dense forest. However, anthropogenic management has converted much tracts of land to cropland and other opportunistic land uses, commonly associated with land degradation. Invasive species (such as *Chromolaena odorata, Alchornea cordifolia, Euphorbia heterophylla, Mimosa pudica, Spigelia loganiceae, Centrosema pubscens, Pupilia lappacea, Ageratum conyzoides* and *Mucuna poggei* as well as grass - *Pennisetum purpureum, Panicum maximum* and *Rottboellia cochinchinensis*) have rather become dominant land cover. Between 1986 and 2003, the area under grassland cover increased by 107.8% (1,001,507.4 km^2). At the same time human settlements increased spatially by 62.3% while protected areas under forest reserve cover had the quality of the vegetation reduced by 26.5% (417,839.4 km^2) and secondary forest under fallow reduced by 34.6% (624,630.6 km^2). The drastic land cover change is suggestive of biological land degradation [2:496].

The accelerating land degradation in the Asunafo forest is mainly driven by the desire of local people to get rich or make money – (greed - [3], accumulation possibilities of the dominant classes (Blaikie) [4:757]). These driving forces have generated direct pressures on the land such as timber extraction and continuous cropping. The pressures have modified state of the land to severe land degradation. Consequently, impacts such as poverty, food shortages/hunger and low crop yield are prevalent. In response, primary land users mainly farmers are subjecting the degraded land to farm maintenance (which includes the use of chemical fertilizers and other inputs) as well as relying on government and NGOs interventions [5].

2. Literature Survey

As reported by Ukut et al. [6] natural endowment of soils in terms of biological and chemical properties occurs over varying geographical spaces. Hence, spatial distribution of soil properties is influenced by natural differences in the soil forming factors such as parent material, topography, climate, biological conditions and the amount of time. To Maniyunda et al. [7] anthropogenic soil management and crop production place further influence on inherent heterogeneity of soil properties. In view of this different soil types require different soil management under various agricultural land uses [8]. According to Mader et al. [9] agricultural land use management is said to be sustainable when it supports good crop yield without compromising on soil fertility and soil ecological factors. In this regard soil fertility refers to provision of essential soil nutrients, support of soil biodiversity, maintenance of soil structure and improvement in decomposition [9].

In the face of global environmental degradation affecting ecosystem provisioning and support of life on earth [10], there is the growing discourse on continuous reliance on organic or conventional farming. Organic farms in Europe are found to possess nitrogen-phosphorus-potassium (NPK) levels of 34% to 51% higher than conventional farms but also revealed crop yield levels of 20% lower than that of conventional farms [9]. Similar results were reported by Mondelaers et al. [11] that organic farming showed higher levels of soil organic matter, agro-biodiversity and natural biodiversity than conventional farming. However, the small land holdings of organic farms as compared to the large holdings of conventional farms make the global benefits appear negligible. Within the African context, the dynamics of organic and inorganic farming shows peculiar features. Conventional farming in Africa is non-industrial and application of chemical fertilizers is generally falling while commercial organic farming is only possible under privately financed contract farming. In the specific case of Uganda under organic certification, coffee production is associated with net revenue increase of 75% equivalent of 12.5% of mean (total) household revenue [12:1102].

Furthermore, food insecurity in Africa is mainly attributed to low food crop yield as a result of soil infertility in smallholder farms. As solution, Africa requires high doses of both P and N fertilizers. In the case of N, biological fixation can increase food production up to 4tons/ha while chemical fertilizer addition could increase food production to 6tons/ha. Both male and female farmers buy chemical fertilizers but the males buy in small bags and apply same in cash crop farms. When women receive chemical fertilizers for cash crop farms they divert some to their food crops farms. Due to poverty women headed households do not invest in soil amendment practices [13].

In Ghana where annual rainfall is high about 1,800 mm the soils tend to suffer from leaching. This happens especially in the south western part of the country. As a result, there are high deficiencies in the availability of phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). In the south eastern section, however, soil infertility is as result of high nitrogen (N) deficiency [14].

In order to pre-empt soil infertility in the country, farmers usually use four types of chemical fertilizers: nitrogen-phosphorus-potassium NPK 15:15:15, NPK 23:10:5, urea and sulphate of ammonia to grow mainly cash crops such as cotton, cocoa and oil palm. Generally, food crop farms do not benefit from chemical fertilization. However, maize which serves both food and cash purposes is reported to enjoy about 40% chemical fertilizer application. The local farmers understand the benefits of using chemical fertilizers as boost to crop harvest, profitability and as soil management input [15].

According to Adjei-Nsiah et al. [16] the introduction of nitrogen fertilizer increases maize grain yield except when intercrop with cassava that maize grain yield reduces by about 9%. Even weed biomass benefitted from N fertilization and increased between 31% and 40%. However, under zero chemical fertilization smaller maize grain yields were realized. Unfortunately, the yield increase could not adequately compensate for the investment made in chemical fertilizer application probably due to high prices of chemical fertilizers and low prices of maize.

In relation to chemical fertilizer usage, about 15% of households in the coastal savanna and forest zone as well as 30% of households in the northern savanna zone use the input. Only 19% of rural households in Ghana purchase chemical fertilizers [17].

The literature further shows that chemical fertilizer policy in Ghana has gone through different strategies from total government subsidy and supply, subsidy removal and private sector supply to subsidy plus public-private partnership supply [15; 18; 19]. In the 1960s, the government of Ghana through Ministry of Agriculture imported and distributed chemical fertilizers. Government subsidy on fertilizer was introduced in 1968; rose from 49 to 86 percent in the 1970s; there were price hikes during 1985 – 1989; and, fertilizer subsidy was removed in 1990 [18]. There was decrease in chemical fertilizer usage from 21.9 Kg/ha in 1978 to 8 Kg/ha in 2006 resulting in government subsidy re-introduction through the voucher strategy with public-private partnership in 2008 [19]. The inability to maintain 2008 subsidized prices resulted in 70% reduction in chemical fertilizer usage and 20% decline in cereal production in 2009. Also, smallholder farmers in remote locations could not benefit from the 2008 chemical fertilizer policy [19].

Other studies point to the specific functions of NPK in the soil. With reference to [20; 21] ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) are vital for the growth of plants. The presence of NH_4^+-N and NO_3^--N depends on the level of microbial activity in the soil, nitrification and denitrification. Ammonium nitrogen does not leach, unused NH_4^+-N is converted to NO_3^--N (nitrification). However, soils repel NO_3^--N so any excess is leach off the root zone. In soils saturated with flood water and no oxygen, NO_3^--N is denitrified to nitrogen gas.

As stated by Yawson et al. [19] potassium (K) specifically contributes to photosynthesis, crop yield and control of microbial population. Soluble K (1-10 mg/kg) is available to plants while exchangeable K (40-600 mg/kg) is held in soil clay and organic matter. Plant available K recorded in the present study fall within the reported soil solution K for Ghana. Potassium values for Mim series [19] favourably compares with that of the current study. Low levels of K in soils in Ghana are explained by short but intensive cultivation, planting of tuber crops, high rainfall as well as high temperature [19].

Previous studies have indicated that chemical fertilizers are essentially salt. In effect, incorrect chemical fertilizer application results in high concentration of soluble salts in the soil which can be detected by high levels of electrical conductivity (EC). Generally, EC levels at Asunafo were increased from 0.02 – 0.22 mS/cm to 0.04 – 0.64 mS/cm after chemical fertilizer application which still fell within the benchmark range of 0 – 2 mS/cm [22].

3. Materials and Methods

The forest of Asunafo is located in the Asunafo north and south Districts of the Brong Ahafo Region, Ghana. The reason for the occurrence of land degradation is the same as that reported by [1]. The only exception is that there is no mining of gold or other precious minerals currently at Asunafo. Specific details about land degradation in Asunafo could be found in [2; 5].

In order to investigate the effect of chemical fertilizers on different soils, existing studies have used two basic methods: field/plot and pot experiment [23]. The current study used pot experiment. The pots involved in the experiment measured 26 cm height x 29 cm top diameter x 20 cm bottom diameter. Other materials used included improved maize seed (obatanpa), chemical fertilizer – NPK 15:15:15 (330kg/ha) and sulphate of ammonia (150kg/ha). Completely

Randomized Design (CRD) was applied. Soils for the experiment were selected from five land use/cover classes.

- First, forest reserve cover – 1. Bosam Bepo, 2. Bonkoni and 3. Aboniyere;
- Second, cocoa farm cover– 1. Kwapong, 2. Kasapin and 3. Assummura;
- Third, fallow land cover – 1. Bediako, 2. Dantano and 3. Camp No. 1;
- Fourth, grassland cover – 1. Aboum, 2. Goaso and 3. Asanteman; and,
- Fifth, bare surface – 1. Akrodie, 2. Sankore and 3. Mim.

The lucky dip method was used in labeling the land cover classes and the soil sample sites.

Three holes were made at the bottom of each pot to allow excess water to drain. Soil replicates collected at a depth of 0 – 20 cm were air dried, sieved, weighed (8 kg) and placed in each plastic pot. From each soil sample site, six pots were filled with soil (6 x 15 = 90 pots). The lucky dip method was employed to position pots in appropriate rectangles: three rectangles were used for no fertilizer and fertilizer treatments. Distances of 40 cm within rows, 60 cm between rows and 1.5 m between rectangles were adopted. Three seeds of obatanpa per pot were sown on 8th December 2010 and thinned to one plant per pot two weeks after sowing. The plants were watered regularly. Two grams of NPK 15:15:15 were applied per pot/plant at weeks 2 and 4. Two grams of sulphate of ammonia per pot/plant were applied at weeks 8 and 10. Plants tasseled two days before week eight, that was observed on 31st January, 2011. Data generation on growth of maize started at week two and terminated at week eight i.e. 3rd February, 2011. Data collected during weeks 2, 4, 6 and 8 included: leaf area – length and breadth of each leaf multiplied by 0.75 (cm^2) and dry matter – oven dried (g). Weight of seeds (g) was measured after the cobs were oven dried.

Furthermore, samples of the soils used for the pot experiment were tested at an ecological laboratory at the Department of Geography and Resource Development, University of Ghana, Legon-Accra. Chemical properties tested include: phosphorus (P) Blay 1 Method [20 cited Bray and Kurtz], potassium (K) – Flame Photometer [20 cited Moss] as well as nitrogen in the form of ammonium (NH_4^+-N) and nitrate (NO_3^--N) – [24].

The laboratory results of the soil, data on growth of maize plus the GPS points of the fifteen locations of soil sample served as basis for mapping using the ArcGIS software, specifically IDW and proportional circles.

In conducting research on ecology and edaphic characteristics, data is not always collected from all case study sites due to logistic constraints. For this reason the sample size data is spatially predicted for majority of the sites where actual data measurement did not take place [25 citing Burgess and Webster]. According to Miller et al. [26] spatial extrapolation and interpolation have become sine qua non for ecological research and the additions of technologies of remote sensing and geographic information systems have turn out to be very useful for such purpose. Under the spatial analyst tool of ArcGIS – interpolation (Inverse Distance Weighted [IDW]) is used to fill in the unknown data. The IDW operates on the assumption that the variable being mapped decreases in influence with distance from the site where it is measured [27]. Inverse distance weighted is based on the principle of spatial autocorrelation, meaning nearer locations have more similar conditions than further away conditions [28:322].

4. Results and Discussion

Figure 1 shows distribution of soil pH (1:1) which ranges from 5.76 – 6.87 interpreted as strongly acidic (4.6 – 5.5), moderately acidic (5.6 – 6.5) and slightly acidic (6.6 – 6.9) on a scale of 0 – 14 where 0 – 7 indicates acidic levels, 7 represents neutral and 7 – 14 describes basic/alkaline levels [22:33]. Soil pH influences availability of nutrients to crops as well as regulation of microbial population in the soil [22; 29].

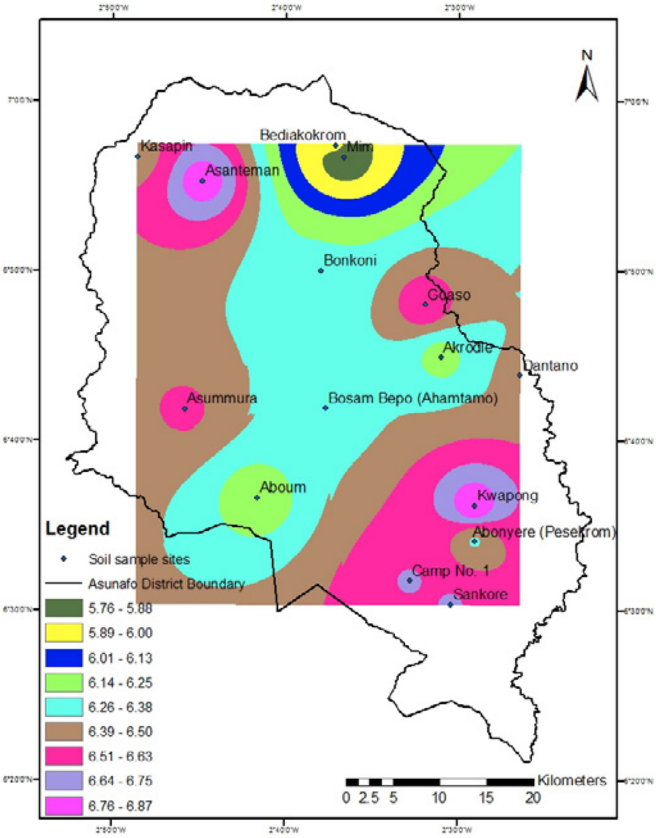

Figure 1: Soil pH distribution at Asunafo

Figure 2 shows the concentrations of ammonium nitrogen (NH_4^+-N). Ammonium nitrogen (NH_4^+-N) has a positive charge which is important because it explains its behavior in soil. Because soil particles have a negative charge, there is an attraction between ammonium and soil particles which prevents ammonium from moving with water flowing through the root zone. In a sense, ammonium "sticks" to soil [21:2].

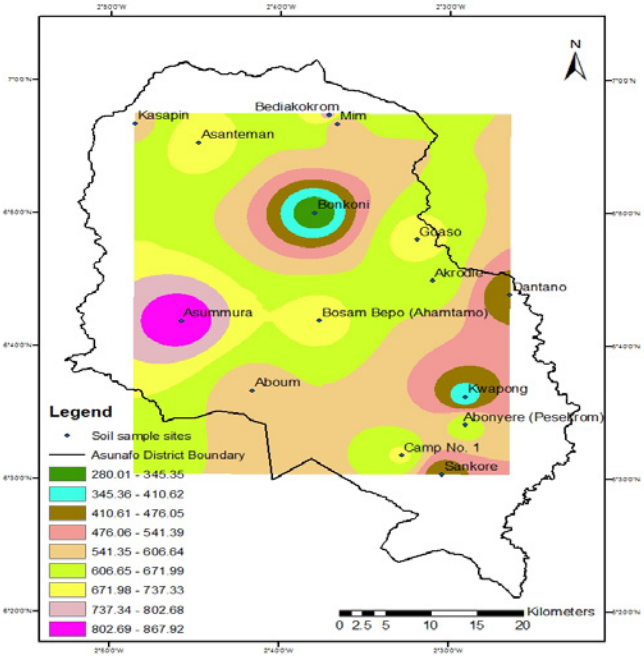

Figure 2: Distribution of NH_4^+-N (ammonium nitrogen) in ($mgNH_4^+$-Nkg^{-1}) at Asunafo

Figure 3 shows the spread of nitrate nitrogen. Asunafo receives copious rainfall in all twelve months of the year. In effect, there is the possibility of a high leaching of nitrate nitrogen.

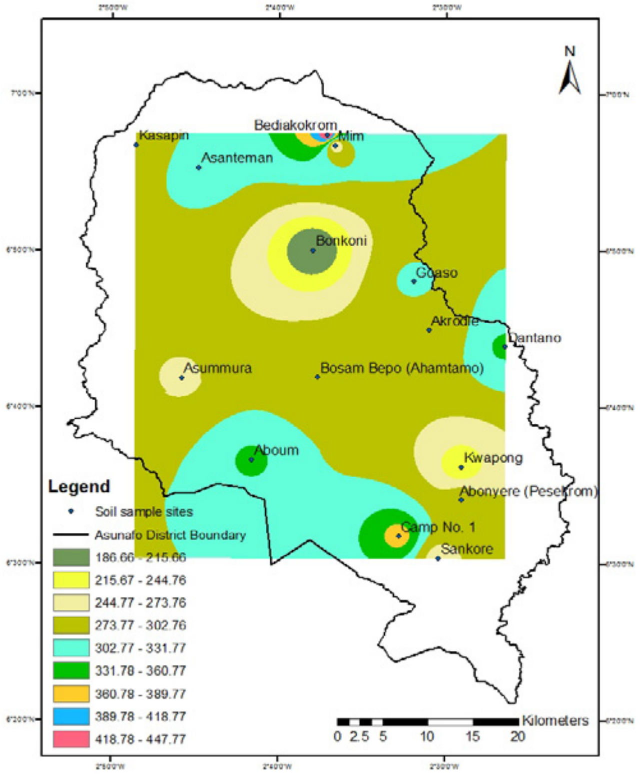

Figure 3: Distribution of NO_3^--N (nitrate-nitrogen) in ($mgNO_3^-$-Nkg^{-1}) at Asunafo

Figure 4 displays available phosphorus (P) distribution. The high rainfall may lead to leaching of P.

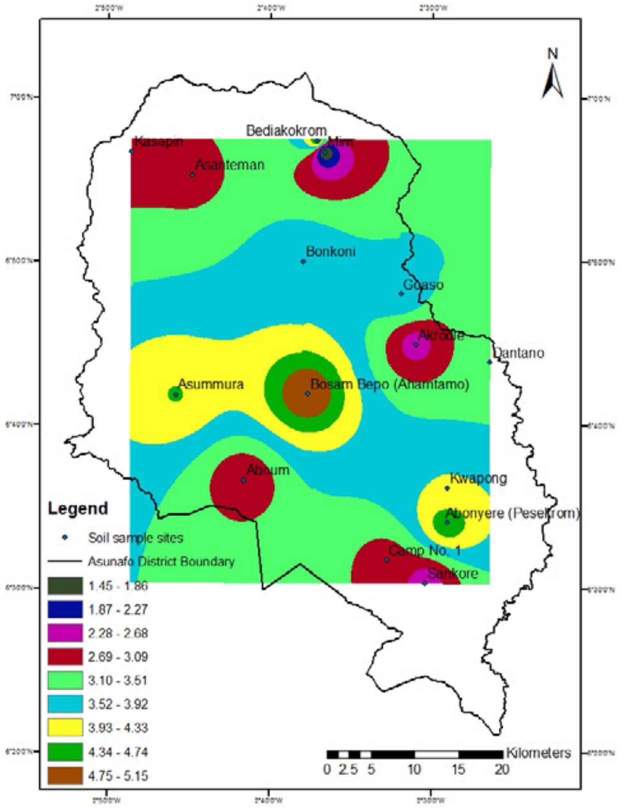

Figure 4: Available P (phosphorus) concentrations at Asunafo

Figure 5 shows plant-available potassium (K) concentration. Besides rainfall, root tubers of cassava, cocoyam and yam may also drain the soil of K.

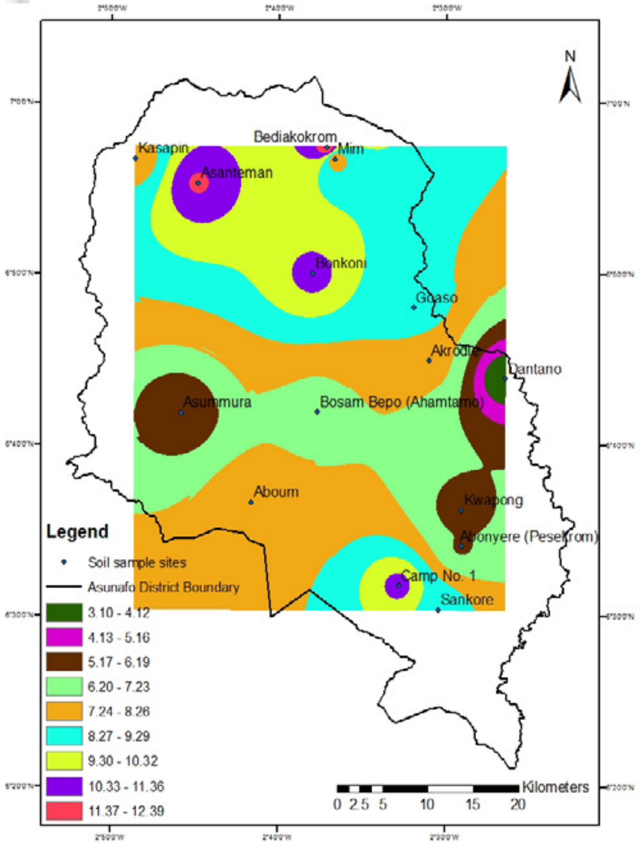

Figure 5: Plant-available potassium (K) levels at Asunafo

Figure 6 shows detailed output of leaf size. At Akrodie for instance, soil of the burrowed pit (degraded) produced 89% under chemical fertilization and 11% under zero chemical fertilization. Also, at Bediako, soil of the fallow (non-degraded) produced 68% under chemical fertilization and 32% under zero chemical fertilization. The non-degraded soil showed 36% difference between chemical and zero chemical fertilization. However, there was a higher difference of 78% in the case of the degraded.

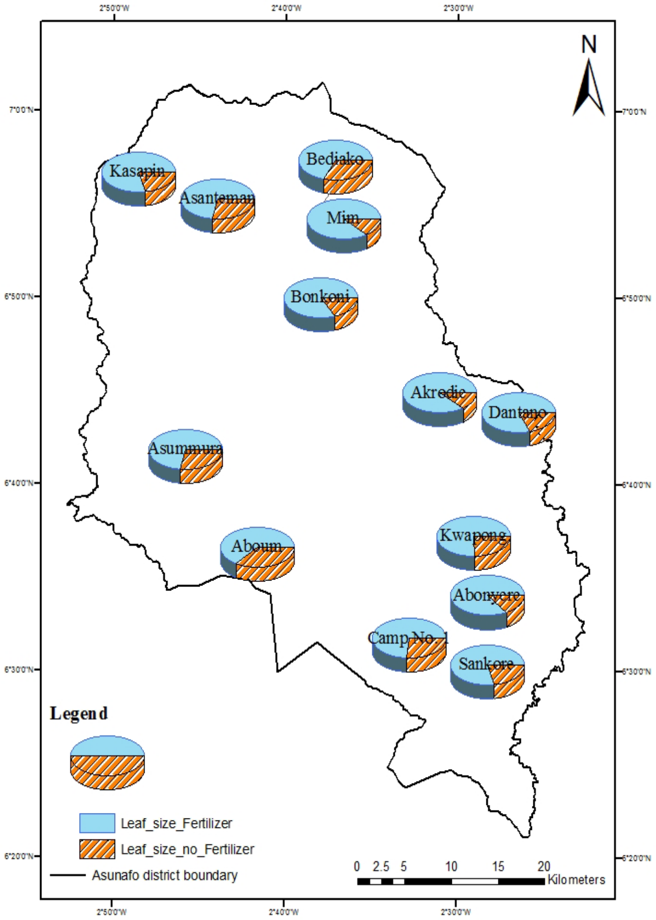

Figure 6: Proportion of maize leaf developed under chemical fertilizers (Blue) and the fraction developed under zero chemical fertilization (Brown Strips)

Figure 7 shows dry matter yield under chemical fertilization and zero chemical fertilization. At Akrodie for example, soil of burrowed pit (degraded) produced 81% dry matter with the help of chemical fertilizers and 19% without chemical fertilizers. The non-degraded soils of Aboniyere Forest Reserve produced 67% of dry matter with the support of chemical fertilization and 33% under zero chemical fertilization. There were 62% and 34% differences for degraded and non-degraded soils respectively.

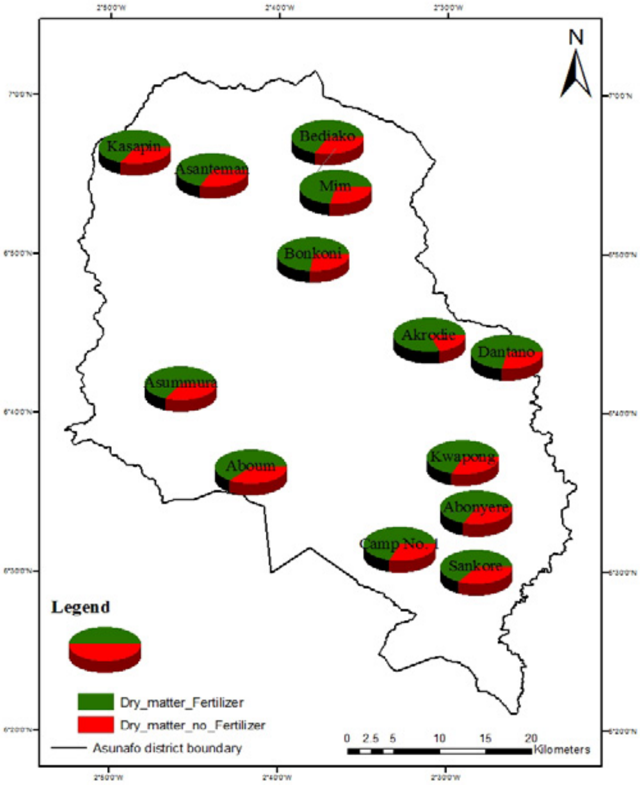

Figure 7: Proportion of dry matter developed under chemical fertilizers (Fir Green) and the fraction developed under zero chemical fertilization (Mars Red)

Figure 8 shows maize grain yield on degraded and non-degraded under application of chemical fertilizer and zero chemical fertilization. On the degraded soil (burrowed pit) at Akrodie, chemical fertilization helped in the production of 86% grains and zero chemical fertilization 14% (a difference of 72%). On the non-degraded soil (Aboniyere Forest Reserve), chemical fertilization produced 54% and zero chemical fertilization 46% (a difference of 8%).

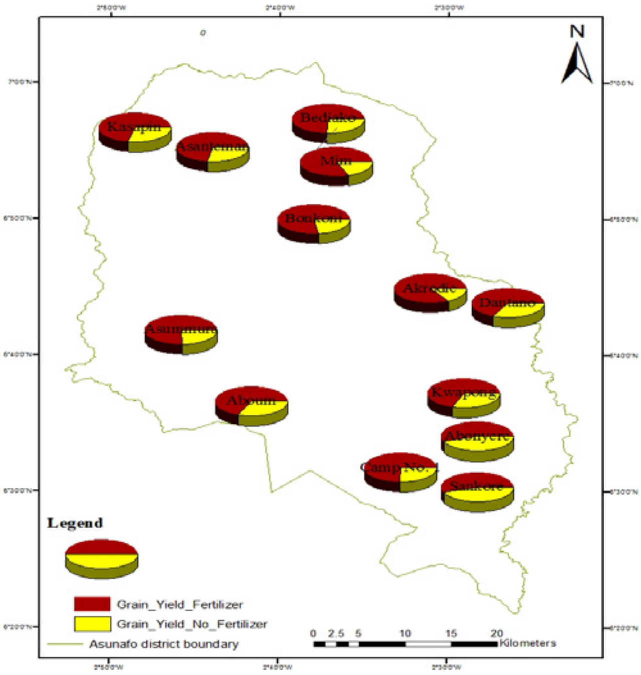

Figure 8: Proportion of maize grains produced under chemical fertilization (Tuscan Red) and the fraction produced under zero chemical fertilization (Solar Yellow)

Figure 9 shows percentage difference between non-degraded soil (forest reserve) and degraded soil (bare ground) when NPK 15:15:15 and sulphate of ammonium are applied to the two contrasting lands.

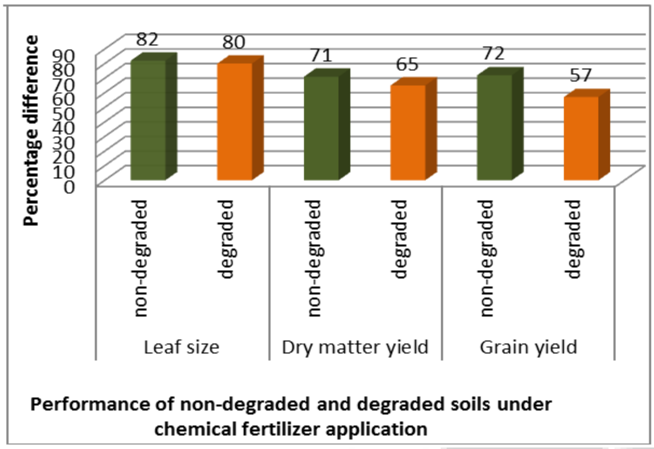

Figure 9: Percentage of maize leaf, dry matter and grains produced by non-degraded and degraded lands under chemical fertilizer application

In summary, the study reveals that soil pH (1:1) levels fell within the acidic range from slight through moderate to strong. Ammonium nitrogen, nitrate nitrogen, available P and K levels support the findings of earlier studies [19; 29]. Leaf size, dry matter and grain yield were disproportionately larger under the chemical fertilizer treatment than zero chemical fertilization. Chemical fertilizer treatment for both non-degraded and degraded soil revealed slight to moderate differences. The difference in leaf size was 2%; dry matter was 6% and grain yield 15%. In consonance with [30; 31], chemical fertilizer hides land degradation in the degraded soil.

Chemical fertilizer application enhanced production levels of all the soils under the five cover types. The bare surface soil showed the highest increase in maize production of about 24.6%. It was followed by soil under forest reserve cover 18.2%, grassland cover 12.4%, fallow land cover 10.5% and cocoa farm cover with 5.2%. Cocoa farms enjoy chemical fertilizer application frequently which may explain the lowest difference between chemical fertilizer and zero chemical fertilizer treatments.

With regard to dry matter yield, the difference between chemical fertilizer and zero chemical fertilizer soil replicates were large. For instance, forest reserve cover recorded 97.3% for zero chemical fertilization and 156.9% for chemical fertilization while fallow land cover followed with 73.8% and 152.5% respectively. Cocoa farm cover showed 71.7% for zero chemical fertilization and 110.5% for chemical fertilizer treatment while grassland cover and bare surface soil followed with corresponding values of 41.1% : 93.8% and 37.1% : 93.0%.

The observed values of crop growth particularly grain yield was lower than reported values from the literature. For example, the grain yield of 0.0024-0.0117 t/ha reported by the present study was lower than 3.53-4.0 t/ha found by Akande and Lamidi [32]. The present study adds to the findings of Donkor and Awuni [33] that chemical fertilizer application produces significant crop yield in rice farms in northern Ghana.

5. Conclusion and Recommendations

Dry matter gives better indication of chemical fertilizer support than grain yield notwithstanding the fact that grain yield is the most important output required by all farmers. Chemical fertilizer application appears to be a promising pathway to dealing with land degradation in the forest ecosystem. The major strength of chemical fertilizer as an adaptive strategy is its ability to increase crop yield; the biggest weakness is that farmers find it expensive; the strongest opportunity is its availability at district agricultural offices and retailed shops; while, its greatest threat is the rising prices.

It is recommended to the government of Ghana to revise the 2008 chemical fertilizer policy and keep prices within farmer acceptable and affordable range and address chemical fertilizer accessibility issues for smallholder and remotely placed farmers. Since previous attempts at crediting chemical fertilizers to farmers and redeeming payment during sale of cocoa failed; farmers may be ask to pre-pay for chemical fertilizers during the sale of cocoa beans. Pre-payment could work because in the past cocoa farmers used the pre-payment system to finance self-help projects. A few kilos of cocoa beans were deducted at point of sale. It is strongly recommended that farmer associations manage the pre-payment.

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Author Profile

Kenneth Peprah is a lecturer at the Department of Environment and Resource Studies, Wa Campus of the University for Development Studies, Tamale since 2004. He is currently awaiting result of PhD thesis submitted to University of Ghana, Legon-Accra.