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Review

Values of organic materials as fertilizers to northern Nigerian crop production systems

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Organic materials, the combined products of different animal and plant sources, play vital roles in agricultural crop production systems. They are more environmental friendly than inorganic fertilizers and added many values to soil and crop production, economically. They sustain and restore soil inherent properties, enhance soil biological activities and potentially increase crop yields, which are safe for human consumption (that is, free from chemicals). This paper aims to discuss the values of organic materials as fertilizers in crop production systems of northern Nigeria. This is hoping to provide awareness for the possibility of the implementation of bioorganic fertilizers industries in northern Nigeria for permanent and economic sustainable crop production.

Key words: Organic materials, bioorganic fertilizers, crop production, Northern Nigeria.

INTRODUCTION

Agricultural soils in northern Nigeria are important areas for the production of diverse crops: Cereals (e.g. millet, sorghum, maize, rice and wheat), legumes (e.g. cowpea, ground nut and soybean), vegetables (e.g. tomato, onion), root and tubers (e.g. cassava, yam and sweet potatoes) and many others (Usman, 2007). Farmers in northern Nigeria are becoming increasingly complained about the poor soil quality, soil fertility and low crop yields due to lack of affordable and sustainable fertilizers in the region. The sprit behind healthy and high economic crop yield in farm management systems lies within the heart of organic manures applied to soils for many years in the region. However, the intensification of inorganic fertilizers in this part of Nigeria diminishes the values and economic benefits of organic materials for the last 35 years or more. This has resulted in increase soil acidity, decline soil quality, and unsustainable soil fertility managements in dryland and fadama areas of many states in the region (Bationo et al., 2003). The revitalization and/renewability of crop production under this circumstances, must readapt the traditionally old system of using only organic manures and organic materials in Nigerian cropping systems. This could help to transform our agricultural production systems into more of sustainability for significant economic developments (Wickama and Mowo, 2001; Uzoma et al., 2011; Usman, 2013).

The values and benefits of using organic materials in crop production are many. They improve and maintain soil quality, soil fertility and soil health, enhance soil water and air qualities, and potentially restore essential soil and plant nutrients (FAO, 2005; Usman, 2013). They also protect soil against erosion, runoff and mass movements,

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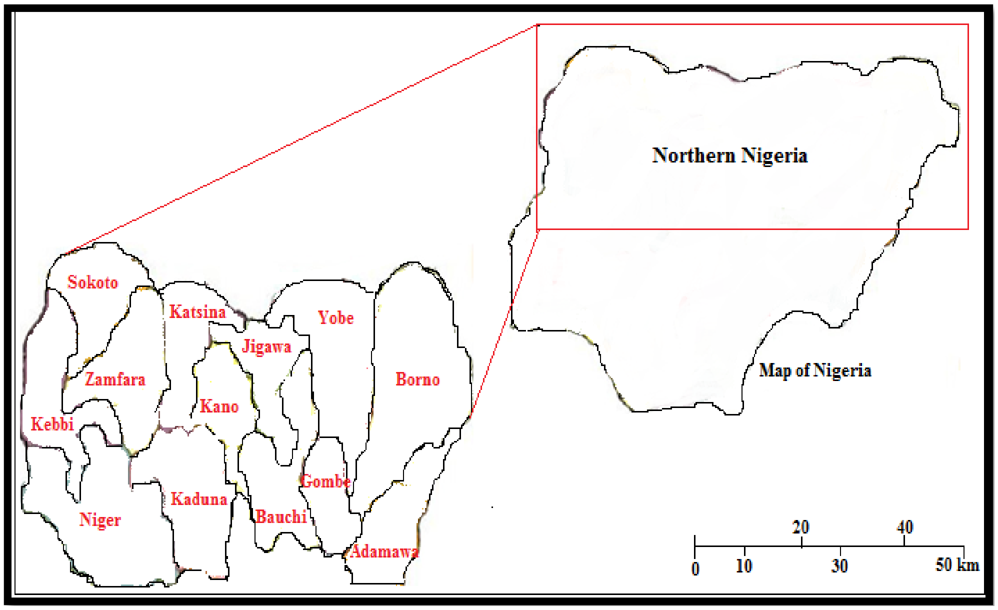

Figure 1. Geographical map of northern Nigeria.

and sustain the genetic and morphological soil properties for divers' cropping benefits (FAO, 2005; Masri and Ryan, 2006). As form of organic matter, plant and animal materials added to the soil maintains and improves soil physical quality and as such considered the most important indicator of agronomic sustainability (Reeves, 1997; Johnston, 2011). Besides, the adaptation of application of pure organic materials to soils in northern Nigeria crop production would undoubtedly leads to the development of bioorganic fertilizers industries in the region. This paper aimed to explain the values and economic benefits of organic materials as fertilizers with the possibility of the implementation of bioorganic fertilizers industries in northern Nigeria for permanent sustainable crop production.

NORTHERN NIGERIA IN A GEOGRAPHICAL CONTEXT

Northern Nigeria is a viably economic region believed to cover 75.9% of Nigeria landmass, and about 57% of this land is also believed to be under crop production or pasture (FMEN, 2001). The region lies within latitude 11° N and 14° N covering the states of Adamawa, Bauch, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe and Zamfara (Figure 1). The two important agricultural lands recognised in these states are: dryland and fadama. The dryland area covered approximately 170,000 km^2 characterised by high sand particles, which are very low in organic matter and easily moved away by high rainfall intensity (Mortmore, 1989). On contrary, the fadama land is dominated by alluvial clay particles, which are characterised by high water holding capacity and clayed in nature (Kparmwang and Esu, 1990). The cropping systems remained the most important permanent and reliable source of income to million people living in the rural areas. The most common systems particularly in the rural areas are (Bationo et al., 2003): Millet/groundnut, millet/cowpea/sorghum, millet/cowpea and millet/sorghum. This traditional system of crop production was noted to cover 75% of the cultivated land in the tropical area of semi-arid region of Nigeria (Norman, 1974).

AVAILABLE ORGANIC MATERIALS IN NORTHERN NIGERIA

There are abundant of organic materials, which could be used for the revitalization of soils for sustainable crop production in the focus region. These organic materials are considered the most important component of crop production, and their transformation as fertilizers and compost manures remained the most vital technology in agriculture (Parr and Colacicco, 1987; Díaz et al., 2007). This technology would grants many possible ways of enhancing and maintaining agricultural soils in dryland and fadama areas of Nigeria. The organic materials consist of different source of plants, animals and varieties of dead and unwanted materials that can be easily decompose and transform into organic matter or humus (FAO, 2005). The transformation of organic matter into humus undergoes two processes, namely, mineralization and humification. Mineralization is the biochemical breakdown of dead organic materials (by soil biota) into

Table 1. Summary of the available organic materials used in northern Nigerian crop production.

Organic materials	Local name (Hausa)	Research example(s)
Animal materials: Cow dung Goat and sheep dung Donkey dung Camel dung Horse dung	Takin Dabbobi Kashin Shanu Kashin Awaki Kashin Jaki Kashin Rakumi Kashin Doki	Usman and Burt (2013): Authors tested 12 different organic materials used by farmers in northern Nigeria. Uzoma et al. (2011): Authors tested effect of cow manure on maize productivity under sandy soil condition.
Plant materials: *Acacia albida* *Acacia nilotica* *Azadirachta indica*	Takin Ganye Ganye Gawo Ganye Bagaruwa Ganyen Darbejiya	Wickama and Mowo (2001): Authors tested 8 different plant materials used by farmers in Tanzania.
Crop materials: Rice husk Millet husk Crop residues	Ganyen anfanin gona Soshiyar shinkafa Soshiyar gero Takin anfanin gona	Spaccini et al. (2002): Authors studied the influence of organic residues of some highland soils in Ethiopia.
Wood materials Wood husk Wood ash	Katako Soshiyar katako Habdi	FAO (2005): Author provided detail review of the importance of organic materials as organic matter.
Manure forms materials: Poultry manure Farmyard manure Compost manure	Takin gargajiya Takin kaji Takin gona Hadadden taki gargajiya	Parr and Colacicco (1987): Authors provided a detail review of organic materials as an alternative nutrient source of crop production in the United State.
Other materials: House refuse	Sauransu: Sharar-gida or Bolar-shara	Usman (2007): Author provided diverse ways of soil management using some organic materials in northern Nigeria.

soluble organic substances whereas humification is the change of these soluble substances into larger form (FAO, 2005). The organic matter obtained from these processes could be transform as composting, vermicomposting, bioslurry or bioorganic fertilizers. Misra et al. (2003) have provided an improved scientific on-farm composting methods, which are quite useful in the transformation of organic materials to either compost manure or bioorganic fertilizers in northern Nigeria. The most available and widely accepted organic materials in the region and their common physical properties are summarised in Tables 1 and 2, accordingly.

VALUES OF ORGANIC MATERIALS AS FERTILIZERS TO NORTHERN NIGERIA

Today, the values of organic materials as fertilizers in crop production received less concern in Nigerian crop production systems. Similarly, the appropriate use of organic matter for the management of soil quality and soil fertility was abandoned and forgotten by many households' farmers. Even with the abundant of organic materials around, there is little concern on the development of bioorganic fertilizer industry in the region. Evidences show that organic matter contains important soil nutrients (micro- and macro elements) that are more sustainable in crop production than inorganic fertilizers (FAO, 2005; Uzoma et al., 2011). In addition to macronutrients including Nitrogen (P), Phosphorus (P) and Potassium (K) which can contribute significantly to higher crop yields, there are other essential nutrients (secondary elements: Sulphur (S), Iron (Fe) and Magnesium (Mg); and micronutrients: Cupper (Cu), Boron (B), Zink (Zn), Manganese (Mn) and Molybdenum (Mo), which are presence in many organic materials (FAO, 2005). If these constituents can be substitute for essential production inputs, the values of organic materials would increase significantly in crop production (Parr and Colacicco, 1987). The development of modern bioorganic fertilizer industries could provide a permanent sustainable means of revitalizing and rehabilitating agricultural soils for healthy and high crop yield in Nigeria. There are many benefits of this including soil value, crop production value, biological value, environmental value, economic value, human health

Table 2. Common physical properties of some available organic materials in northern Nigeria (after Usman and Burt, 2013)**.**

Organic material	Colour	Consistency	Structure	Texture
Cow dung	Black	Soft-hard	Blocky (plate)	Cemetery
Sheep dung	Black	Slight-hard	Sub-angular	Gravely
Goat dung	Dark	Slight-hard	Sub-angular	Gravely
Donkey dung	Black	Soft	Blocky (round)	Cemented
Rice husk	Dark brown	Loose	Single-grain	Fine-husk
Millet husk	Light	Loose	Granular	Coarser
Acacia albida	Light brown	Loose	Massive-leafy	Fine-leafy
Acacia nilotica	Green	Loose	Massive-leafy	Fine-leafy
Wood ash	Light grey	Flowery	Massive	Ashy
Wood husk	Dark pink	Loose	Granular	Woody
House-refuse	Black-dark	Clotted	Decomposed	Clay-loam (like)

value and many others.

Soil value

Soil is the most important component of crop production and human economic interactions that we have (Brady and Weil, 2007; Usman, 2013). However, soil erosion, soil desertification and decline in soil quality and soil fertility affect most of the agricultural soils in northern Nigeria (FMEN, 2001). These soil problems, have been since recognised as serious environmental degradation that caused decline soil quality, soil fertility and crop yield in great part of sub-Saharan Africa, Asia, Europe and US (Hudson, 1981; Eswaran et al*.,* 2001; Lal et al*.,* 2003). As such, were given a special attention in 1993 at the United Nations Conference on Environment and Development (ICLDD, 2001). Conversely, the values of organic materials as organic matter were acknowledge to improved soil quality and soil fertility, suppressed soil erosion and subsequently increase crop yields in many African regions (Mango, 1999; Ramaru et al*.,* 2000; Wickama and Mowo, 2001; Gachimbi et al*.,* 2002; Usman, 2013). Besides, they were noted to increase nutrient availability of the soils, soil organic matter and soil organic carbon (Reeves, 1997; Nagaya and Lal, 2008). Application of organic matter to the soil could also improve aggregate stability and resistance to soil compaction, enhanced fertility and reduced nutrient leaching, increased biological activity, enhance water retention capacity and reduction of greenhouse gases by soil carbon sequestration (Spaccin et al*.,* 2002; Laura and DeJong-Huges, 2010). Therefore, revitalization of degraded soils for high crop yield could be cheaply minimised with the use of available organic matter in the region. This might help to restore and sustain great part of dryland and fadama soils for permanent sustainable and economic crop productions in the states of Adamawa, Bauch, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe and Zamfara. Above and beyond, the increasing human population in these states would undoubtedly benefit much from their agricultural soils with little cost.

Crop production value

The agronomic value of organic matter applied to the soil is a subject that could be related to the increased crop yield and reduce hunger and malnutrition in Nigeria. Application of organic matter to soils would help to improve the growth and development of plant as well as yield performances (FAO, 2005). However, the crop yield response to additions of organic materials was considered to be highly variable and is dependent upon the crop type, soil type, climatic conditions, management system, and the organic materials used (Parr and Colacicco, 1987). This could mean that the crop yield performance depends greatly on these factors, and that revitalization of crop production through application of organic materials most takes note of them. Thus, reliable estimates of the economic value of organic materials in crop production depend upon the correct evaluation of agronomic information describing the crop yield response to the application of a particular organic material (Parr and Colacicco, 1987). Understanding the relationship of both single and combine organic materials with respect to their application to soil for higher crop yield performances in northern Nigeria, is highly needed (Usman and Burt, 2013). This is to ensure a permanent sustainable crop production and economic revitalization of dryland and fadama soils in the region.

Biological value

Organic materials added to the soil help to increase the activities and biodiversity of living organisms in soil and also serve as an essential source of food to million organisms in soil (FAO, 2005). During the process of decomposition of organic materials in soil, the interaction of soil organisms with the system derives many functional services for the great biodiversity (Coleman, 2001). The decomposed organic materials on the surface soil generally results in a great biodiversity in soil environment which in turn provides protection to soil against erosion, energy source for soil biota, an effective uptake of nutrients by diverse plant roots, good rooting condition, sufficient soil moisture and perfect physical and hydric condition for plant growth (Mollison and Slay, 1991). This great biodiversity also contributes significantly to the revitalization of crop production, soil formation and soil quality rehabilitation (Jenny, 2009). The biological environment created as a result of organic materials in soil was considered to improve soil structural quality, increase aggregate stability, maintains soil moisture and improves the microbial number of soil organisms (FAO, 2005). These could help to restore and sustain great part of dryland soils, which are low in fertility and received poor management systems in northern Nigeria.

Economic value

The economic value of an organic materials added to the soil is solely related to increase crop yield (Parr and Colacicco, 1987), and absolutely related to soil fertility and soil quality management. Therefore, long term effect of organic amendment has many economic values to rural farmers (Diacono and Montemurro, 2010). This may means that the use of organic amendment in crop production by farmers could help to minimise reliance on inorganic fertilizers and hence reduce the cost of the production, increase profit and sustain better livelihood of the rural farmers in northern Nigeria. Critically, the cost implications for the use of inorganic fertilizers by farmers in many states of northern Nigeria have yielded decrease in crop production. On contrary, the application of organic materials is cheap and economically might increase the average number of farmers for the production of many vital crops in northern Nigeria. Hence, an increase in the crop productions would result in reduces hunger, malnutrition, poverty and other social crises in the whole of northern Nigeria.

Other general values

Generally, there are many other benefits of organic materials and/ bioorganic fertilizers to northern region. Some of these benefits are listed below (Usman, 2011):

1. Reduce dependence on inorganic chemical fertilizers: Available bioorganic fertilizer products in the market may reduce reliance on inorganic chemical fertilizers in northern Nigeria. Although there is need for further enlightening and awareness of the potential benefits of the products to rural farmers in the region, it is optimistic that the products would gain more acceptances as soon as the productions become fully implemented.
2. Increase yield performance: It is undoubtedly that application of organic materials and/bioorganic fertilizers to the soils would sustain soil-crop productivity and results in high crop yields in dryland and fadama areas of northern Nigeria. Although this may be affected with time by diminishing factor (Parr and Colacicco, 1987), it is believed that the shelf life of bioorganic fertilizers in soil is far higher than that of inorganic fertilizers. Bioorganic fertilizers or composting applied to the soils may last longer than inorganic fertilizers in soil.
2. Sustain and restore the inherent soil fertility of agricultural soils: The nutrients contain in the bulk of organic materials as fertilizers in soil increase the fertility of the soils. The micro and macro elements as well as aggregate stability are soil properties, which affect crop production in many ways. Application of bioorganic fertilizers in soil would enhance these properties and increase their potentialities in crop production.
3. Soil resilience against impact of raindrops: The impact of raindrops on surface soils affects soil productivity in many ways. However, presence of organic materials as litter or cover prevent surface soil against runoff, splash erosion and leaching of essential soil nutrients.
4. Seed free from chemical impact: Inorganic fertilizers, herbicides and insecticides contain chemicals, which are not good for health whereas composting and/ organic matter are free from such chemicals. Hence, the use of organic materials in crop production would yield a potential healthy seeds for human use.
5. Contribute to proper waste disposal: Physically there is urgent need of proper way of recycling and disposing unwanted dead materials in northern Nigeria. Implementation of bioorganic fertilizers and their production might help to reduce dumping of house refuse and many other unwanted organic materials on the streets. Hence, this may sanitise our environment and potentially minimise the population and impact of mosquitoes in the region.
6. Contribute to greater biodiversity: Organic materials in soil provide room for the survival of many living organisms. Addition of organic materials may increases the number of these organisms and their formation in soil.
7. Lessen environmental pollution: If organic materials are fully decompose in soil, they would help in maintaining soil health and hence minimise the soil contamination and soil hazards.
8. Environmental friendly: Organic materials are safer to environment than inorganic chemical fertilizers. They control soil contamination and soil pollution.
9. Enhance nutrient availability: Organic matter increase nutrient availability in soils and supply then to crop.
10. Preserve and sustain natural habitat: Decomposed organic materials as humus in soil preserved soil fauna

Figure 2. Example of the industrial production of bio-organic fertilizers using animal materials.

and flora, micro- and microorganism in soil.

11. Correct and maintain proper level of acidity and alkalinity in soil: Degree of acidity and alkalinity (pH) in soil may be control by addition organic materials.

IMPLEMENTATION OF BIO-ORGANIC FERTILIZERS INDUSTRIES IN NORTHERN NIGERIA

It is very clear that, the permanent sustainable soil management of agricultural soils in northern states of Nigeria is highly needed for an improvement of agricultural activities and economic developments of low input farmers, government sector and small scale holders in the region (Bationo et al*.,* 2007). Millions of people live in the rural areas of northern Nigeria and many of them depended greatly on agriculture for their daily livelihood (FMEN, 2001). One of the important economic projects that might help to improve the sustainable livelihood of these rural people is the implementation of the production of bio-organic fertilizers and compost technology (Díaz et al*.,* 2007). However, the development of bioorganic fertilizer industries in the region depends largely on the effort of the State governments to implement the projects related to the successful production of the products. It is important to mention that, northern Nigeria is one of the sub-Saharan African regions, which have considerable amount of organic materials that could be transformed into fertilizers for permanent sustainable crop production (Table 1). Thus, as one of the key goals of sound soil management to create a healthy soil environment which may retain balance nutrient status such that its fertility and high crop yield are maintained over time (Omotayo and Chukwuka, 2009), the northern states of Nigeria have the role to play in the implementation of the production of bio-organic fertilizers. These are manufactured with utmost care to ensure that they are free from all chemicals and convey longer shelf life to the rural farmers along with making crop yields safe for human consumption (Usman, 2011). The typical examples of the production industries are depicted in Figure 2 and 3 as modified after Ref 1 and Ref 2.

It is well known that the agricultural lands in the whole of northern states of Nigeria are important areas for the production of crops such as cereals (e.g. millet, sorghum, maize) and irrigated crops (e.g. rice, wheat and verities of vegetable crops such as tomato, onion etc). These agricultural lands have provided many economic opportunities to numerous people in the rural areas of Adamawa, Bauch, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe and Zamfara states. The future agricultural economic development for healthy, high and fiscal yield performances of the agricultural lands in the region depends much on sustainable soil functions and soil quality rehabilitations through organic farming (Usman, 2007). Therefore, to ensure permanent and sustainable soil fertility functions of the agricultural lands in northern Nigeria, it is quite an important to follows example of countries such as China and India who have used the scientific knowledge and skills acquired by some of their successful researchers in the field of soil and agronomy, to transform our agricultural lands to a standard level for high crop yield and sustainable economic development in the whole of northern region. This would not only advance the standard living of millions of the rural peoples, but also

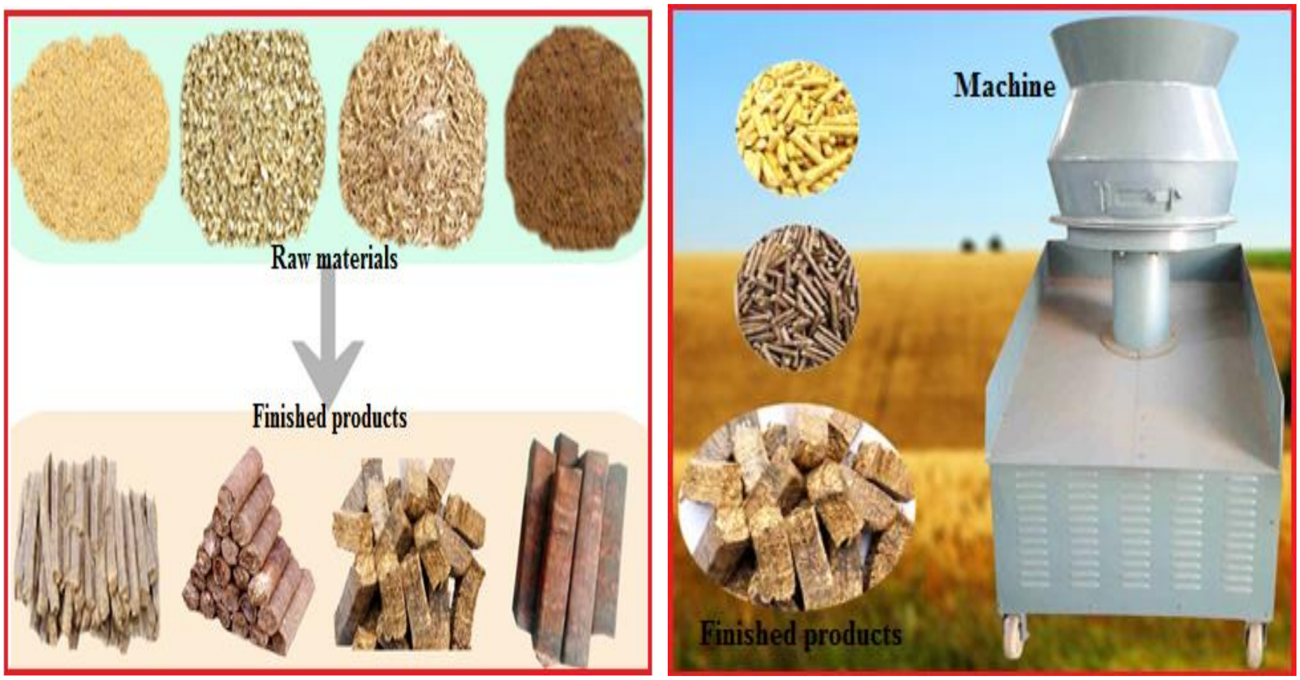

Figure 3. Example of the industrial production of bio-organic fertilizers using plant materials.

provides an opportunity for the State governments to create a self-reliance financial sector in the region and Nigeria in general.

As noted in many scientific research journals and textbooks, organic materials from plants and animals are more environmental friendly than inorganic chemical fertilizers used by farmers in the region. Consequently, the implementation of the production of bioorganic fertilizers would certainly plays an important role for the sustaining and improving soil structure, soil quality, soil function, soil health, soil fertility and overall crop yield performances in northern Nigeria. Other benefits to the entire people of the region include:

1. Government would create a permanent and sustainable economic way of self-reliance among the people of northern Nigeria
2. Government would provides job to thousands of people without any future cost (i.e. no provision of monthly salaries, pension and/ or gratitude)
3. Substantial benefits to rural people who depend fully on agriculture for their livelihood
4. Cheap fertilizer products as compared to chemical fertilizer currently marketing in the region (government could save up to 40 to 50% e.g. chemical fertilizer = N5000/bag while the organic fertilizer = N2500/bag or even less)
5. High content of NPK in organic form will reduces reliance on chemical-fertilizers
6. Increase organic carbon content of the soil to approximately 15%.
7. Improves the fertility and the productivity of the soil 100% organic without chemicals
8. Maintains a proper balance of secondary nutrients (Ca, Mg, and S) and micronutrients (Zn, Fe, Cu, Mn, B and Mo) for better plant growth
9. Helps in maintaining the soil pH and increases the plant root growth
10. Increases the microbial number and their activities/ biodiversity in soil.

CONCLUSION

The values of organic materials as fertilizers could be essential to the sustained soil-crop productivity in northern Nigeria. The revitalization of crop production in the region would be expected to yield significant results when organic materials and bioorganic fertilizers are consider the most imperative component of agricultural systems. It is optimistic that the successful implementation of bioorganic fertilizers industries in the region would certainly plays an economic role for the sustaining and improving soil structure, soil quality, soil function, soil health, soil fertility and overall crop yield performances in northern Nigeria. The relatively available organic materials in the region are resources, which may well provide many economic opportunities to the growing population in Nigeria. Management of these diverse organic resources should be consider as part of job creation, poverty reduction, environmental health administration and social youth networks under Nonadministration and social youth networks under Non-Governmental Organizations (NGOs).

Conflict of interests

The authors have not declared any conflict of interest.

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Impact of deforestation and subsequent cultivation on soil fertility in Komto, Western Ethiopia

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The study examined the impact of deforestation and subsequent cultivation on soil fertility and acidity conditions under varying soil depths. Soil profiles were opened in two adjacent land units, namely forestland and arable land and samples were collected from genetic horizons. Deterioration of soil fertility was observed after deforestation and traditional cultivation. The main aim of deforestation was agricultural expansion. Soil pH consistently decreased with depth in both land units and it was relatively lowest in arable land perhaps due to depletion of organic matter (OM) and decrease in buffering capacity of the soil. The OM and total nitrogen (N) ranged from 0.78 and 0.06% in the 75 to160 cm layer of arable land to 15 and 0.61% in the 0 to10 cm layer of forestland, respectively. Total N was strongly and positively correlated with soil OM (r = 0.99). Exchangeable Al was poorly and negatively correlated with available phosphorous (r = -0.41). Conversion of forestland to arable land reduced the mean available phosphorus (P) from 4.04 ppm to 1.95 ppm most probably due to decline in OM, soil acidification and erosion. Deforestation and subsequent continuous cultivation over the past 25 years apparently amplified the mean exchangeable acids from 0.83 cmol (+) kg^{-1} to 5.96 cmol (+) kg^{-1}. Soil acidification and related problems were the major challenges of continuous cultivation in the study area. The study indicated that land use change and management practices have had a considerable negative effect on soil physical and chemical properties.

Key words: Deforestation, continuous cultivation, land use change, soil properties, soil fertility, soil acidity, Western Ethiopia.

INTRODUCTION

One of the most important driving forces of land use change induced soil degradation is human activities such as deforestation and poor agricultural practices. Owing to deforestation, the area of native forest in Ethiopia was declined from 40% land cover during the 1950 according to Pohjonen and Pukkala (1990) to about 2.2% in 2002

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(Berry, 2003).

Increase in population and a continuous decline in the amount of agricultural land have led to relentless and an indiscriminate exploitation of natural forests and fragile lands for agriculture (Mahtab and Karim, 1992). Intensive farming and mismanagement of the deforested areas brought environmental problems and soil impacts such as soil erosion, acidification, soil compaction and pollution (Salehi et al., 2008). These problems have many interlink effects that can appear through the reduction of chemical and physical qualities of the soil resources (Seeger and Ries, 2008). Studies by Mulugeta et al. (2005) and Nega and Heluf (2009) indicated increment of bulk density, organic matter deterioration and reduction in cation exchange capacity (CEC) following deforestation and continuous cultivation in Ethiopia. Another study in Ethiopia showed that soil organic carbon (SOC) and total N of the top 0 to 10 cm soil layer declined significantly and exponentially with increasing years under cultivation following deforestation (Lemenih et al., 2005).

In addition to natural factors such as excessive leaching of basic cations and nature of the parent materials, agricultural practices and processes such as intensive cultivation of leguminous crops and continuous use of ammonium containing fertilizers in N limited cultivated soil, soil erosion and tillage triggered OM oxidation were the main causes of soil acidification in the study area. Because of limitation of N in the arable soils, farmers usually used to apply ammonium nitrate and commonly grow legumes. Agriculturally, acidic soils have limiting characteristics like weak buffering capacity; low P bioavailability due to high P fixation capacity; toxicities of Al, occasionally H; deficiencies of Ca, Mg, K; and low CEC (Clark et al., 1988).

Soils unconditionally respond to human as well as natural disturbances. The reaction of soils to human influence can be measured from changes in soil properties following the interference. Cognizant of this issue, the study was conducted in soils of adjacent land units; namely forestland and arable land (historic forestland) mainly to examine the impact of major land use shift from forestland to arable land on soil fertility and acidification. Although soil deterioration following forest clearing and continuous cultivation is well known, the degree of changes in soil physical and chemical properties for the study area was not depicted. The study is in line with the current Ethiopia's Agricultural Transformation Plan aimed to strengthen the Ethiopian Soil Information System (Ethio-SIS) by creating soil information at large scale map.

The results of the study can help the farming community to recognize the negative effects of deforestation and adopt recommendations of sustainable land use and management practices. It also assists policy makers and land administrators to pose strong policy ground on protection of natural forests and devise options to practice precision agriculture.

MATERIALS AND METHODS

Description of study area

The study site is situated between 9.084768 and 9.111881N and 36.609009 and 36.630832E in Komto village of Wayu Tuka district, western Ethiopia (Figure 1).

The area is characterized by a unimodal rainfall pattern receiving mean annual rainfall of 2140 mm. The mean annual temperature is 18.7°C. The entire village was once covered with Afromontane moist ever green forest known as Komto forest. Population growth over the past 25 years had led to destruction of portion of the native forest and expansion of arable land. Western Ethiopia in general and the study area in particular are dominated by highly weathered soils like Alfisols, Ultisols, and Nitisols (Mesfin, 1988).

The dominant agriculture in the district is mixed farming system where livestock and subsistence crop production supports the livelihoods of the community. Portion of the forestland converted to arable land was under cultivation for the last 25 years. The most widely cultivated crops include cereals such as Teff (*Eragrostistef*), millet (*Panicummiliaceum*), wheat (*Triticumaestivum*), maize (*Zea mays*), barley (*Hordeumvulgare*) and legumes such as horse bean (V*iciafaba*), ground nut (*Arachishypogaea*) and oats (*Avena sativa*). Crop residues were partly subjected to uncontrolled grazing and partly collected for fuel wood usually leaving bare soil surface.

Soil sampling, preparation and analysis

Small scaled study by Mesfin (1988) indicated that arable land was dominated with Nitisol while forestland was dominated with Alfisols. Due to similarity of soil types across specific land units in the site, one representative pedon with 1.5 m x 2 m x 2 m was opened in each land unit, namely forestland and arable land. Soil samples were collected from genetic horizons−layers designated based on differences in color and other morphological properties. Horizons can be designated either simply by assigning evenly distributed random depths or depths based on genetic/ nature of the soil layers. Horizon classification for this study was, thus, based on depths equivalent to genetic layers that vary with the type of soil. Following sampling, soil samples were labeled, air dried, cleaned from contaminants and plant debris, ground by mortar and pestle and finally sieved with a 2 mm sieve. Based on standard laboratory procedures, soil particle size distribution was determined by the Bouyoucous hydrometer method while particle density was determined using pcynometer method. Dry bulk density was determined by core method. Soil pH was measured potentiometrically in 1:1.25 soil water suspensions. Exchangeable acidity was determined by titration with NaOH. Organic C was determined by Walkley–Black oxidation method. Total N was determined by Kjeldhal method and available P was determined following Bray II method. The CEC was determined by using ammonium acetate method. Among exchangeable bases, Ca^{2+} and Mg^{2+} in the original ammonium acetate leachate were measured by atomic absorption spectrophotometer; whereas exchangeable K^+ and Na^+ were determined by using flame photometer.

Statistical analysis

Measured and weighted average values for variables were

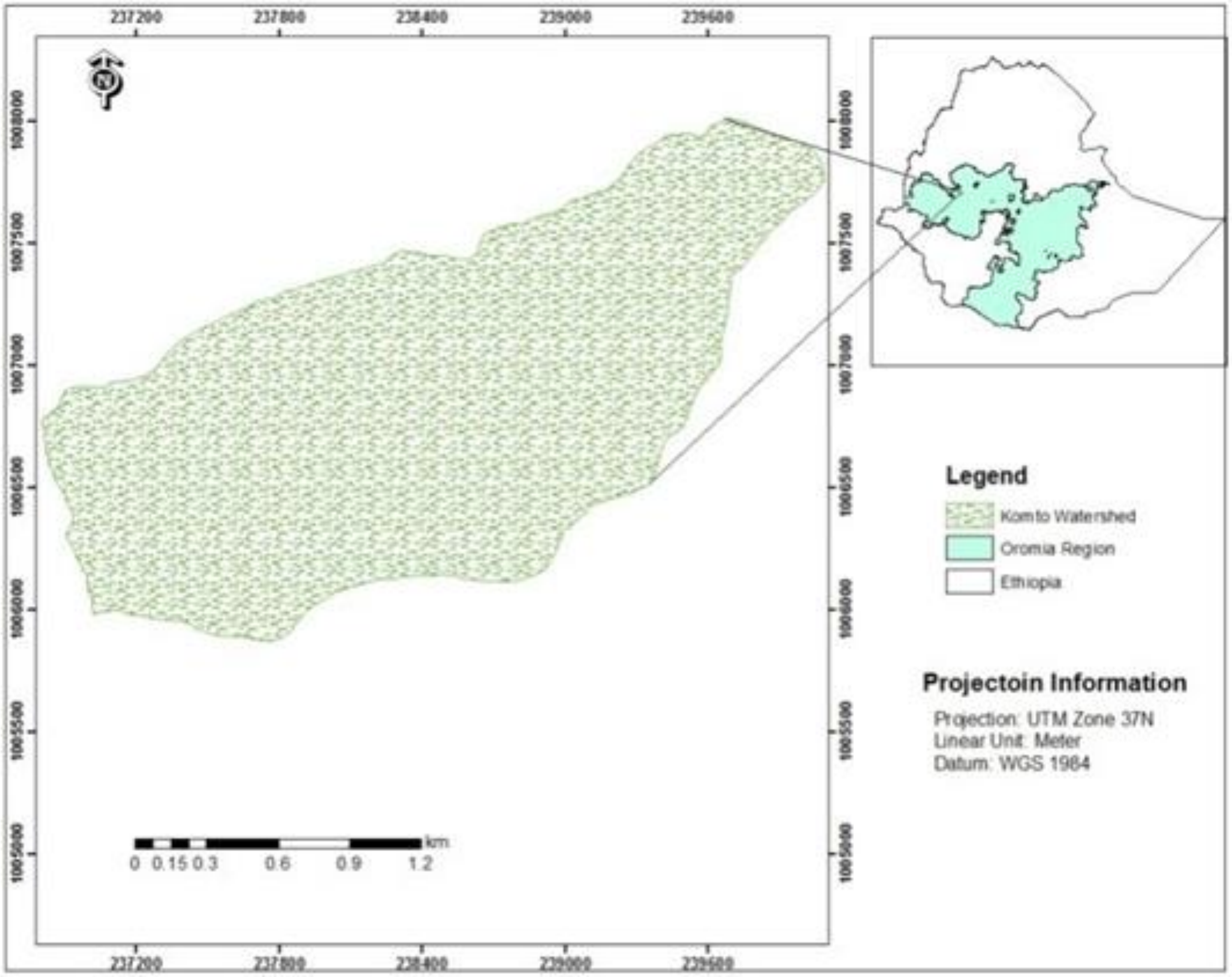

Figure 1. Location map of the study site.

compared with critical value and interpreted. Pearson correlation coefficient was used to evaluate the relationship between variables at $p < 0.05$ and 0.01. Descriptive statistics was used to illustrate mean of the measured variables. The least significant difference (LSD) was employed to compare means of parameters of the land uses at 0.05 and 0.1 significance levels.

RESULTS AND DISCUSSION

Response of soil physical properties to deforestation and subsequent cultivation

Particle size distribution

Variations in particle size distribution within a pedon with soil depth and between pedons due to land use change was observed in the study site (Table 1). Whilst sand and silt fractions showed consistent trend with depth in soils of arable land, clay and silt fractions did in soils of forestland. Clay content was relatively higher at subsoil than the topsoil which might be the result of pedoturbation following intensive weathering accelerated by continuous tillage. The mean clay content was higher for arable land than forestland whereas the mean sand and silt contents were lower for arable land.

This was attributed to the fact that forest destruction and shift to arable land facilitates soil particle breakdown during plowing. Chikezie (2009) revealed that higher mean clay fraction recorded in the arable land attributed to the impacts of deforestation and farming practices. Study by Amir et al. (2010) also suggested that increase in clay content after land use shift from forestland to arable land is a result of intensified chemical soil

Table 1. Comparison of particle size distribution, bulk density, particle density and total porosity in soils of forestland and arable land.

Land unit	Horizon	Depth (cm)	Particle size distribution (%)			STC	Densities (g cm^{-3})		TP (%)
			Sand	Silt	Clay		Bulk	Particle	
Forestland	O_e	0-10	42.00	30.00	28.00	CL	0.99	2.10	52.86
	A_h	10-60	47.00	22.00	31.00	SCL	1.12	2.20	49.09
	EB	60-115	38.00	20.00	42.00	C	1.25	2.43	48.56
	B	115-200	36.00	14.00	50.00	C	1.29	2.56	49.61
	-	Mean	41.75	21.50	37.75	-	1.16	2.32	50.03
Arable land	A_p	0-30	37.00	30.00	33.00	CL	1.28	2.49	46.44
	B_t	30-75	38.00	10.00	52.00	C	1.26	2.54	50.39
	BC	75-160	46.00	6.00	48.00	SC	1.40	2.61	46.36
	-	Mean	40.33	15.33	44.33	-	1.31	2.55	47.73

STC= soil textural class, CL=clay loam, SC=sandy clay, SL=sandy loam, SCL= sandy clay loam, L=loam, C= clay, TP = total porosity.

Table 2. Comparison of soil pH, organic matter, total nitrogen, available phosphorus and C:N ratio in soils of forestland and arable land.

Land unit	Depth (cm)	pH (H_2O)	OM (%)	Total N (%)	Av. P (ppm) Olsen	C:N ratio
Forestland	0-10	6.36	15.40	0.61	9.75	14.64
	10-60	5.92	10.05	0.42	4.09	13.88
	60-115	5.62	4.72	0.27	1.42	10.15
	115-200	5.36	0.97	0.08	0.90	7.00
Arable land	0-30	5.02	4.17	0.22	3.12	11.00
	30-75	5.00	2.05	0.15	1.06	7.93
	75-160	4.38	0.78	0.06	1.67	7.50
Forestland mean values		5.82^a	7.79^a	0.35^a	4.04^a	11.42^a
Arable land mean values		4.80^b	2.33^b	0.16^b	1.95^a	8.02^b

Means within column followed by different letters are significantly different at ($p < 0.1$).

degradation. Mean silt content of forestland was higher than arable land. Significant alteration of particle size distribution due to management practices like intensive tillage over a long period of time could result in soil textural change.

Soil densities and total porosity

Bulk density regularly increased with depth in soils of forestland (Table 1). This might be attributed to consistent decrease in OM content (Table 2) and subsequent increase in dry weight per unit volume of the soil with depth. Sandy soils usually have higher bulk density than clay soils provided that other factors including soil OM content are not significantly different.

Comparatively, the highest bulk density (1.40 gcm^{-3}) was recorded in arable soil at a layer containing significant proportion of sand fraction (46%) but very low OM (0.78%) whereas the lowest bulk density (0.99 g cm^{-3}) was recorded in forest soil at the OM rich topsoil (0 to 10 cm). The mean bulk density was increased during course of deforestation and subsequent cultivation from 1.16 g cm^{-3} for soils of forest ecosystem to 1.31 g cm^{-3} for soils of arable land. This could be mainly caused by soil compaction during tillage practices and reduction of soil OM, similar to the reports of Amir et al. (2010). Based on rating the effect of bulk density on soil condition given by

Table 3. Comparison of exchangeable cations, cation exchange capacity, total exchangeable bases and total exchangeable acids in soils of forestland and arable land.

Land unit	Depth (cm)	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	Ex. Al	Ex. H	CEC	EB	EA
		------------ (cmol(+) kg $^{-1}$) --------------								
Forestland	0-10	19.88	3.67	2.71	1.10	T	0.78	54.83	27.36	0.78
	10-60	9.94	2.04	0.92	0.65	T	0.71	40.74	13.55	0.71
	60-115	8.19	2.53	0.59	0.61	T	0.86	42.81	11.92	0.86
	115-200	4.28	2.15	0.43	0.51	0.32	0.65	28.16	7.37	0.97
Arable land	0-30	3.68	1.36	0.53	0.47	2.60	2.17	25.59	6.04	4.77
	30-75	2.18	1.02	0.32	0.21	4.87	1.41	22.85	3.73	6.28
	75-160	1.16	0.99	0.23	0.26	5.87	0.96	15.03	2.64	6.83
Forestland mean values		10.57^{a}	2.60^{a}	1.16^{a}	0.72^{a}	0.08^{a}	0.75^{a}	41.64^{a}	15.05^{a}	0.83^{a}
Arable land mean values		2.34^{b}	1.12^{b}	0.36^{a}	0.31^{b}	4.45^{b}	1.51^{b}	21.16^{b}	4.14^{b}	5.96^{b}

Means within column followed by different letters are significantly different at ($p < 0.05$); CEC: cation exchange capacity; EB: exchangeable bases; EA: exchangeable acids; T: trace.

(Hunt and Gilkes, 1992), soils containing bulk density >1.8 g cm^{-3} for sandy soils, >1.6 g cm^{-3} for loam soils, and >1.4 g cm^{-3} for clay soils were considered very compacted and restrict root penetration. Accordingly, the 75 to 160 cm layer of arable land was very compacted and affects soil property and root penetration.

The value of particle density consistently increased with depth in all land units. Forest soils have lower particle density than arable soils since the former have better OM. Heavy soils or soils containing high clay fraction including the 30 to 160 cm layer of arable soils and the 60 to 200 cm layer of forest soils tends to have larger particle density (Table 1). Total porosity was highest (52.86%) for the top organic layer of native forest as compared to arable land. The study result suggested that deforestation and consecutive cultivation had posed more effect on the total porosity of the topsoil than subsoil. Handayani (2004) revealed that porosity decreased by 10.50% following deforestation and continuous cultivation.

Similarly, previous authors reported that macro-pore volume decreased as a result of soil compaction due to tillage and trampling by humans coupled with depletion of SOC content in the upper soil horizon (Yimer et al., 2008). A reduction of the volume of soil pores has a direct negative effect on infiltration capacity and moisture content encouraging soil erosion.

Response of soil chemical properties to deforestation and subsequent cultivation

Soil pH, organic matter, total nitrogen and C:N ratio

Soil pH consistently decreased with depth in soils of both land units indicating subsurface soils are more acidic than surface soil (Table 3). This might be due to leaching of exchangeable aluminum (Ex. Al) from the surface to subsurface horizon facilitated by tillage practices and subsequent hydrolysis reaction that releases hydrogen (H) ions into the soil solution. According to Donald (2012) soil pH classification, arable soils of the study area were more acidic than forest soils. Destruction of native forest and subsequent cultivation had decreased OM content and finally reduced the buffering capacity of soils. This factor coupled with continuous use of ammonium containing fertilizers, soil erosion, OM oxidation facilitated by tillage, complete removal of crop residues and elevated Ex. Al might have made soils of arable land to be more acidic.

Study by Amir et al. (2010) indicated that oxidation of nitrogen could result in an intensified decomposition of soil OM under cultivated land and subsequent reduction in the soil pH. In contrast, forest soils contain high OM and are less subjected to pH changes, for such soils have high buffering capacity. Besides, chelating of H ions with organo-complexes of the forest soils might have reduced the likely release of free H into the soil solution. Had the farmers practiced conservation tillage, the difference in soil reaction between arable land and its counterpart would have been narrow. Due to consistent decrease in soil OM and total N, the C:N ratio regularly decreased with depth for both land units. Soil OM content was smaller for soils of arable land than forestland (Table 2).

The relatively low OM content in soils of arable land as compared to native forest ecosystem could be attributed to intensive cultivation which aggravated oxidation of OM (Alemayehu et al., 2011) and prolonged cultivation coupled with frequent burning of crop residues that accelerated the rapid turnover rates of OM (Yacob, 2015). Farmers usually collect and store crop residues for livestock feed, fuel wood, and sell to the market to generate income. A portion of residues remaining in the field was purposely burned thinking it enhances soil fertility. Poverty and lack of knowledge were, therefore, the major driving factors for complete removal of crop residue prohibiting it from enriching the soil OM.

Additionally, increased soil erosion due to complete removal of crop residues in the arable land could have resulted in low soil OM. This indicates a reduction in the nutrient supply, water holding capacity, structural stability and cation exchange capacity of the soils (Amir et al., 2010). Conversely, the virgin soils of forestland produced high mean value of OM which could be due to the continuous accumulation of decomposed plant and animal residues in the absence of disturbance of soil environment over a long time period.

As 95% of total N is found in organic form, it followed similar pattern as the OM change with land unit and soil depth. In this view, OM could have contributed to higher level of total N in soils of forestland. Although rating of soil parameters slightly differ among authors, Bruce and Rayment (1982) adopted that total N (%) < 0.05 is very low, 0.05 to 0.15 low, 0.15 to 0.25 medium, 0.25 to 0.5 high, and >0.5 is very high. In relation to this rating, the total N in soils of forestland ranged from low (0.08%) for the 115 to 200 cm layer to very high (0.61%) for the top 0 to10 cm layer whereas that of arable land ranged from low (0.06%) for 75 to160 cm genetic depth to medium for the top plow layer (0 to 30 cm).

Continuous cultivation and lower activity of N fixing bacteria due to strong acidity (pH < 5.5) might have resulted in the reduction of total N in soils of arable land as compared to forestland. A report of Wakene and Heluf (2004) revealed that intensive and continuous cultivation forced oxidation of SOC and thus resulted in reduction of total N. The present study result indicate that total N was strongly correlated with soil OM (r^2 = 0.99 for forestland and r^2 = 0.98 for arable land) and it was consistent with the conclusion of Jobbagy and Jackson (2000). The C:N ratio, a measure of balance between SOC and total N, is an important indicator for well-functioning of soil micro-organisms and adequate supply of N to plants. The mean C:N ratio was higher for forestland than arable land. The reason could be obviously the significantly higher OM content in soils of forestland (Teshome et al., 2013).

Based on Gavlak et al. (1994) rating, soil C:N ratio of < 10 is medium, 10−14 is good, and >14 is poor. Accordingly, the mean C:N ratio for forest soils (11.42) was classified as good. This was because the proportion of SOC and total N was at par for normal functioning of soil micro-organisms. In contrast, arable soils had mean C:N ratio of <10, which means too low OC.

Available phosphorus

Though not consistent in soils of arable land, available P was decreased with depth in both land units. Reduction in available P value with depth could be attributed to P fixation caused by increased Ex. Al with depth. Numerically, the mean available P value for forest soils was higher than arable soils. Since there exists positive correlation between available P and SOC (r^2 = 0.78 for arable soils and r^2 = 0.95 for forest soils). Decline in OM content, soil acidification and erosion could be the main causes for the depletion of available P from arable land.

Due to current management practices, deforestation and continuous cultivation and crop residue removal, the existence of available P in the soil is endangered for the near future (Alfred and Tom, 2008).

Exchangeable cations, percent base saturation and acid saturation

Exchangeable calcium (Ex. Ca) and potassium (Ex. K) regularly decreased with depth in soils of both land units (Table 3). The concentration of basic cations on exchange site of arable and forest soils in the study area decreased in order of Ca >Mg >K >Na. According to Eckert (1987) rating of Ca/Mg ratio, arable soils have extremely low Ca relative to Mg and leads to Ca deficiency in plants. The data presented in Table 3 indicate that exchangeable bases were better in soils of forestland than arable land. Though leaching of exchangeable bases is common in soils of humid tropics including the study site, absence of better OM for ionic retention might have contributed for the significant depletion of exchangeable bases from the arable soils.

Except exchangeable K, exchangeable cations of different land units are significantly different at $p < 0.05$. The OM rich 0 to 10 cm layer of forest soils contained comparatively the highest exchangeable bases (27.36 cmol(+) kg^{-1}). This manifests that the colloidal site of soil OM might have retained better quantity of exchangeable bases. In contrast, continuous tillage practices considerably disturb natural soil structure; facilitate soil OM decomposition and leads to depletion of exchangeable bases from the arable land. Study by Achalu et al. (2012) found that exchangeable bases decreased when natural forest was changed to cultivated land. The mean exchangeable base for forest soils was about 3.6 times higher than arable soils. This shows that 25 years after conversion of forestland to arable land, the mean exchangeable bases was averagely reduced by 72.5%. Percent base saturation was reduced following deforestation and intensive cultivation (Figure 2). As per the rating of Metson (1961), percent base saturation of the study area ranged from very low (0 to 20%) for arable soils to moderate (40 to 60%) for forest soils.

Ex. Al increased with depth for both land units which could be caused by eluviations of Al oxides from surface to subsurface horizons. In line with the finding of Taye (2008), the present study revealed that large proportion of exchangeable acids in arable soils of western Ethiopia

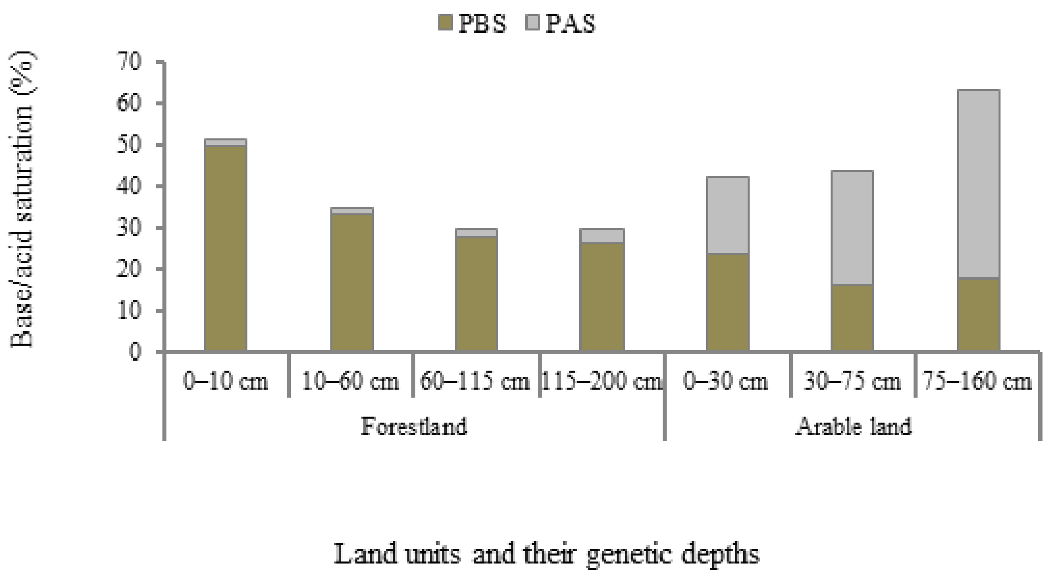

Figure 2. Percent base saturation (PBS) and percent acid saturation (PAS) in soils of forestland and arable land. The graph shows decrease in PBS and subsequent increase in PAS following deforestation and continuous cultivation.

was occupied by Ex. Al. In contrast, the relatively low level of Ex. Al in forest soils could be due to complexation of Ex. Al with OM. These organo-complexes reduce the flux of exchangeable acids between soil colloidal site and the soil solution and hence, resist major pH changes. The exchangeable acids (Ex. Al and Ex. H) in soils of arable land were by far higher than the forestland. Conversion of native vegetation to arable land over the past 25 years had amplified the mean exchangeable acids from 0.83 cmol(+) kg^{-1} to 5.96 cmol(+) kg^{-1}. During this course, the mean exchangeable acids remarkably increased by nearly 7 folds. Percent acid saturation was considerably higher for soils of the arable land mainly due to appreciable amount of exchangeable acids present in the soil (Figure 2). Unless proper management measures are taken, this leads to soil deterioration (Faykah, 2014).

Cation exchange capacity

From the investigated soils, the highest CEC (54.83 cmol(+) kg^{-1}) was recorded for 0 to10 cm layer of forest soils and the lowest CEC (15.03 cmol(+) kg^{-1}) was recorded for 75 to 160 cm layer of arable soils (Table 3). The mean values of CEC were 41.64 cmol(+) kg^{-1} and 21.16 cmol(+) $kg^{-1}$for soils of forestland and arable land, respectively. The higher CEC value in soils of forestland might be attributed to the relatively higher OM colloid in the soil. This concurs with the finding of Sanchez et al. (2002) that changing land use from native forest to cultivated land reduced CEC. The study result showed that large proportion of CEC in the topsoil of arable land was dominated by exchangeable bases whereas the subsoil was dominated by exchangeable acids.

Conversely, soils of forestland were generally dominated by exchangeable bases. The mean proportion of exchangeable cations decrease in order: Al > Ca > H > Mg > K > Na in soils of arable land and Ca > Mg > K > H > Na > Al in soils of forestland. This clearly indicates that land use change and management practices had a considerable influence in modifying soil properties. The proportion of CEC of different cations or simply cation saturation percentage varies for different land uses. Soils of forestland were saturated with Ex. Ca while soils of arable land were saturated with Ex. Al. Comparing with desirable proportions of Ex. Al in the soil for plants adopted by Abbott (1989) as Al < 5%, the study result showed that Ex. Al was above the critical for arable land (10.16 to 39.06%) and in the optimum range for forestland (0 to 1.14%). Continuous cultivation significantly increased Ex. Al concentration in the soil and aggravated soil acidification.

Soil pH has strong and positive correlation with CEC (r = 0.97) (Table 4). Soil pH is negatively correlated with exchangeable acidity indicating increase in exchangeable acidity reduces soil pH. Exchangeable Al is strongly and positively correlated with exchangeable acidity (r = 0.98) at $p < 0.01$ but poorly and negatively correlated with available phosphorus. This implies that increase in Al toxicity in the soil reduces P availability through strong

Table 4. Correlation matrix among measured soil chemical properties.

Variable	pH	Ex. Al	EB	EA	CEC	OM	TN	Av. P
pH	1.00	-0.87*	0.92**	-0.87*	0.97**	0.87*	0.89**	0.72
Ex. Al	-	1.00	-0.69	0.98**	-0.83*	-0.59	-0.62	-0.41
EB	-	-	1.00	-0.71	0.95**	0.94**	0.94**	0.90**
EA	-	-	-	1.00	-0.83*	-0.58	-0.60	-0.40
CEC	-	-	-	-	1.00	0.88**	0.91**	0.75
OM	-	-	-	-	-	1.00	0.99**	0.94**
TN	-	-	-	-	-	-	1.00	0.91**
Av. P	-	-	-	-	-	-	-	1.00

*Significant at $P < 0.05$, ** $p < 0.01$.

Table 5. Percent change of selected soil properties after major land use transformation from forestland to arable land with 20-30 years periods of cultivation in the top plow depth as compared to other studies.

Soil properties	Percent of soil change under the present study	Percent of soil change during the previous studies	
% Clay	15.15% increase	2.67% increase	Amir et al. (2010)
Porosity	12.15% decrease	9.44% decrease	Amir et al. (2010)
Bulk density	22.66% increase	27.40% increase	Amir et al. (2010)
Topsoil pH	20.75% decrease	10.77% decrease	Alfred et al. (2008)
Total N	63.93% decrease	26.00% decrease	Handayani (2004)
OM	72.92% decrease	75.00% decrease	Fisseha et al. (2011)
Av. P	68.00% decline	48.14% decline	Lechisa et al. (2014)
CEC	53.32% decrease	16.16% decrease	Teshome et al. (2013)

fixation. The general interrelationship between different soil fertility parameters can be depicted as in Table 4.

Quantum of soil changes with the periods of cultivation

Soil deterioration following deforestation and subsequent cultivation is a known fact. However, the degree of soil deterioration might varies depending on climatic condition, cropping intensities, periods, cropping pattern, crop rotation, crop types and crop management practices. In humid tropics, soil deterioration following deforestation is aggravated by water erosion.

Percent of change in clay content is higher in the present study than previous research conducted by Amir et al. (2010) (Table 5). This might be due to the severity of soil disturbance by tillage practices in the present study site. Decline in CEC following deforestation and periods of cultivation was higher in the present study site than reported by Teshome et al. (2013). This could be due to intensive leaching of basic cations facilitated by continuous tillage practices. Although all soil properties were affected by forest clearing and shift to cultivation, the most seriously deteriorated soil properties in the present study site include OM, total N, available P, and CEC. Therefore, as recommended by Biyogue (2016), regulating human activities across the reserve forests as well as stepping up protection of existing reserves in the area is needed to avoid further deterioration of the physical properties of the soils under these forests.

Conclusions

Intensive cultivation following deforestation has a profound negative effect on soil physical and chemical properties. Though the distribution of soil particles (sand, silt, and clay fractions) greatly affected by land use change, clay and clay loam were still the dominant soil textural classes in both land units. Decrease in OM and soil compaction in the arable land led to increased bulk density. This can reduce air and water movement in the soil facilitating water erosion.

Deforestation and subsequent intensive cultivation leads to soil acidification. This factor combined with exhaustive removal of crop residues and consequent loss of OM from soils of the arable land lead to depletion of available P and total N. The CEC of arable land was saturated with exchangeable acids while that of forestland was dominated by exchangeable bases. Presence of better OM in the forestland had increased buffering capacity of the soil, maintained soil pH and reduced the impact of acidification on other soil properties.

Therefore, to confront soil acidification and fertility decline in soils of arable land, two optional agronomic strategies can be adopted. Firstly, cultivators should give due emphasis on conservation tillage that can improve the overall quality of the soil. If farmers' traditional cultivation system inhibits use of conservation tillage, researchers need to provide a lasting solution for continuous cultivation induced soil acidification. In this case, researchers should focus on permanent solutions like breeding and development of acid tolerant crop genotypes to address resource poor farmers who cannot afford the cost of chemicals amendments like lime. Secondly, for soil sustainability and productive crop cultivation, dependence on green manuring, farm yard manuring, composting and biofertlizers should be the first priority management practices to be relied on. Protection of forest reserves and practicing conservation tillage enhances soil fertility, enriches biodiversity, and sustains productivity.

Conflict of interests

The authors have not declared any conflict of interests.

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Influence of different leguminous crop on the ultisol that had been continuously cropped to cassava /maize for over six years

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Leguminous crops play an important role in developing sustainable and low input crop production system and have shown good potential for inclusion in alley cropping systems. Hence, a study was carried out at the Teaching and Research Farm of the Faculty of Agriculture, Chukwuemeka Odumegwu Ojukwu University to evaluate the productivity of an impaired ultisol under cassava/maize for over six years planted with different legumes. The experiment was laid out in a randomized complete block design. The treatments studied were, cowpea, groundnut, bambara groundnut, pigeon pea and control which is maize. Data collected was subjected to an analysis of variance test based on randomized complete block design (RCBD) and treatment means were separated using least significant difference (LSD<0.05). The findings from the study showed that there were significant (P<0.05) differences among the treatments in growth, yield and soil chemical parameters assessed as well as the texture of the studied soil. The legume crops planted on the impaired soil had good nodulation which helped to replenish soil nutrient lost and good yield of pigeon pea (0.34 tha^{-1}), Bambara groundnut (0.17 tha^{-1}) cowpea (0.12 tha^{-1}), Groundnut (0.10 tha^{-1}), respectively. The result of the soil chemical parameters assessed from post harvest soil analysis indicated that the nutrient content of the studied soil increased except for exchangeable acidity (EA), K and effective cation exchange capacity which generally reduced in all the plots planted with leguminous crop. The plots planted with Bambara groundnut and groundnut showed a slight reduction in exchangeable Mg^{2+} relative to pre planting soil analysis which was 50% reduction relative to the control, while exchangeable Na^+ content reduced in plots planted with Bambara groundnut. Evidence from this study, then showed that leguminous crop can be used to reclaim an impaired soil and improve the fertility status of the soil.

Key words: Chemical properties, growth, legume crops, ultisol, yield.

INTRODUCTION

Humid and sub humid regions of tropical Africa are comprised of a wide range of soil types such as ultisols, oxisols and Alfisols for crop production (Kang and Juo 2011). Dudal (2010) classification showed that ultisols make up 46.6% and alfisols 12.5% of the land area in humid tropical Africa; while in the sub humid zones

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ultisols and oxisols make up 25.6% and alfisols 27.4% of the total land area. In south eastern Nigeria, more than 70% of the total land area is covered by ultisols (Mbagwu, 1992). These soils are highly weathered and have low activity clays**.** Further they are characterized by low pH, low cation exchange capacity (CEC), very low inherent fertility, low base saturation and multiple nutrients deficiencies and nutrient imbalance. According to Hartman (2011), Kang and Jou (2011), toxic levels of aluminium or manganese or both are among the main chemical constraints to growing crops on these strongly acid soils. These soils are prone to erosion and compaction, therefore soil fertility maintenance and erosion control and compaction are management problems in using the soils for crop production. Another contributory problem of the soil in the study area is the complexity of farming systems, which arise out of the small size of majority of the farms combined with management that reflect multiple objectives of the farming community coupled with the fact that the livelihood of farmers in the area study is generally poor.

As a result of the current farming system, the crop productivity and soil fertility have declined due to the shortening of fallow periods, which are needed to restore and maintain soil productivity. The implication is the increase in the use of inorganic fertilizer by the local farmers, with attendant reduction in the use of organic manure. Loss of organic matter (OM) results in soil acidity, low nutrient content and imbalance and low crop yield (Sharma and Mittra, 1991; Nweke, 2014). Also, the use of ammonium fertilizers over a long period of time in a particular piece of land causes nutrients imbalance and soil acidity. Continuous cropping and intensive land use leads to exhaustion of soil fertility, decrease in crop yield (Corsky and Ndikwo, 2008).

Thus, traditional farmers tend to retain certain trees and shrubs in their crop production systems to restore soil fertility exhausted by cropping (Moormann and Greenland, 2010). Increased cropping intensity has been found by Okigbo, (1982) to accelerate the erosion of top soil, degradation in soil physical condition, deterioration of nutrient status and changes in the number and composition of soil organisms. In view of this, there is the need to identify crop management practices that can maintain soil fertility under more intensive land use and continuous cropping activities. Legumes as it were, are important components of various cropping systems, as they fix and improve the N content of the soil and the productivity of the companion crop (Agboola and Fayemi, 2001; Crews and people, 2004; Nweke et al., 2013). However, most of these legumes require phosphorous (P) for N_2 fixation processes and growth (Nweke and Emeh 2013) which farmers fail to supply due to lack of the knowledge, management incompetence and way with all. Hence, the strategy that needs to be adopted in order to compensate for the lack of P fertilizer has been to select legumes adapted to low P soils (Sanginga et al., Therefore, the judicious management and conservation of the soil and crop nutrients to guard against crop yield decrease is a major challenging factor in intensive crop production and the involvement of N_2 fixing green legumes and their incorporation into the farming system will help in stabilizing the sustainable agronomic practices. Thus, the essence of this work is to evaluate the ability of different leguminous crops in enriching the fertility status of an ultisol at Igbariam that had been impaired to do continuous cropping to cassava/maize for over six years.

MATERIALS AND METHODS

Site location

The study was carried out at the Faculty of Agriculture Teaching and Research Farm Chukwuemeka Odumegwu Ojukwu University, Anambra State Nigeria. The site lies between latitude 06 14'N and longitude 06 45'E, the rainfall pattern is bimodal between April and October with mean annual rainfall of over 1300 mm. The relative humidity of the study area is moderately high all year round with the highest relative humidity of 85% during the wet season and the lowest 64% during the dry season. The physical and chemical parameters of the studied soil prior to treatment application are presented in Table 1.

Field method

The study area was cleared of the natural vegetation and debris removed and cultivated using hoe. The experiment was laid out in a randomized complete block design (RCBD) with four replicates and five treatments to give 20 plots, each measuring 3 m x 4 m. Plots were separated from each other by 0.5m path and each block was separated by 1 m alley. The treatments included cowpea (*Vigna unquiculata*), groundnut (*Arachis hypogeae*), bambara groundnut (*Vigna subterranea*), Pigeon pea (*Cajanus cajan*) and maize (control). The leguminous crops were planted two seeds per hole at a depth of about 5 cm at the spacing of 60 cm x 60 cm in their respective plots. The control plot was planted a hybrid maize (Oba super II) two seeds per hole, using a planting distance of 25 cm x 75 cm. Two weeks after germination, thinning and supply operation were done and 0.4 kg NPK fertilizer was applied to every plot by ring method to boast their vegetative growth. Weeding was manually done at two weeks interval till harvest. Eight plants per plot were randomly sampled for the number of nodules and root area index at 70 days after planting (DAP). At maturity, pod/grain yield per plot was measured, the pod/grain yield from the tagged plants (Eight/plot) were harvested, dried to 14% moisture content. The grain harvested from the tagged plant was weighed to get its yield per plot in tonnes per hectare. Soil samples were collected prior to the experiment from the surface of the plot in three different locations at the depth of 30 cm using auger, this was thoroughly mixed to form a composite sample. At the end of the study soil samples were collected from each plot, these soil samples were then analyzed for physical and chemical properties using standard procedure described by Black (1965).

Data analysis

Data generated from the field and laboratory, were analyzed using analysis of variance (ANOVA) test based on randomized complete block design (RCBD). Statistical significance differences between

Table 1. Physical and chemical parameters of the experimental site before treatment application.

Parameter	Value
Coarse	46%
Fine sand	43%
Silt	7%
Clay	4%
Textural class	sandy
pHH_2O	6.46%
Soil organic Carbon	0.71%
Soil organic Matter	1.23%
N	0.06%
Na^+	0.10 $CmolKg^{-1}$
K^+	0.12 " "
Ca^{2+}	2.4 " "
Mg^{2+}	2.0 " "
Exchangeable Acidity (EA)	0.40 " "
Effective Cation Exchange Capacity	8.62 " "
Base Saturation (BS)	82.29%
Available P	26.10 $mgKg^{-1}$

Table 2. Influence of different leguminous crop on the root area index, number of nodules, weight of pod (tha^{-1}); grain yield (tha^{-1}) in Ultisol cultivated cassava/maize for over six years.

Treatment	Root area index	Number of nodules	Weight of pod (tha^{-1})	Grain yield (tha^{-1})
Cowpea	41^c	2.41^d	0.47^d	0.12^c
Groundnut	38.75^c	42.91^c	0.40^c	0.10^c
Bambara groundnut	49^c	20.75^b	0.68^b	0.17^c
Pigeon pea	123.75^a	252.66^a	1.36^a	0.34^b
Control Maize	79^b	-	-	0.78^a
LSD 0.05	12.48	12.53	0.06	0.12

A,b,c,d,e figures with the same superscript in the same column are not significantly different ($P<0.05$).

treatment means was estimated using least significant difference at 5% alpha level according to Steel and Torrie (1980).

RESULTS

The result of the pre-planting soil analysis showed that the textural class of the studied soil is sandy, with a pH value of 6.46 and contain low level of major nutrient elements. The organic matter content (1.23%), organic carbon (0.71%) and percentage nitrogen (0.06%) as well as available phosphorous (26.10 $mgKg^{-1}$) at the soil were very low. The exchangeable acidity and effective cation exchange capacity (ECEC) of the soil were 0.4 $Cmolkg^{-1}$ and 8.62 $Cmolkg^{-1}$), respectively. The percentage base saturation (BS) was relatively high with value of 82.29%. Thus, the studied soil is impaired of these nutrient elements (Table 1). The result of root area index, numbers of nodules, weight of pod and grain yield were presented in Table 2. The value obtained for root area index was significantly different (P<0.05) among the crops. The pigeon pea had the highest value among the crops, the order of increase in root area index were pigeon pea>maize>Bambara groundnut>groundnut> cowpea. The value obtained from cowpea, groundnut and bambara groundnut were however statistically similar. The number of nodules and weight of pod values indicated significant differences among the treatment crops. The pigeon pea performed better than the other legume crops in the number of nodules and weight of pods, while the least value was observed in cowpea for number of nodules and groundnut for the weight of pods. The order of decrease in value relative to pigeon pea for the number of nodules and weight of pods were cowpea<Bambara groundnut<groundnut<pigeon pea and groundnut<cowpea<bambara groundnut<pigeon pea, respectively. The grain yield result showed that pigeon pea performance was higher compared to the other leguminous crops with a value of 0.34tha^{-1}, the yield value

Table 3. Influence of different leguminous crops on the chemical properties of an ultisol under cassava/maize cultivation for over six years.

1	pH (H_2O)	N (%)	OC (%)	OM (%)	P mg(Kg^{-1})	Ca Cmol(kg^{-1})	Mg Cmol(kg^{-1})	K Cmol(kg^{-1})	Na Cmol(kg^{-1})	EA Cmol(kg^{-1})	ECEC Cmol(kg^{-1})	BS (%)
Cowpea	6.76	0.140	0.65^{d}	1.11^{d}	73.40^{a}	4.00^{b}	2.00^{c}	0.102^{c}	0.113^{bc}	0.24^{b}	6.46^{c}	96^{ab}
Groundnut	6.82	0.156	0.85^{b}	1.46^{b}	51.20^{b}	3.20^{c}	1.60^{b}	0.082^{d}	0.131^{b}	0.24^{b}	5.25^{d}	95^{b}
Bambara groundnut	6.84	0.126	0.85^{b}	1.46^{b}	31.80^{c}	3.60^{bc}	1.60^{b}	0.113^{b}	0.078^{c}	0.40^{a}	5.79^{e}	93^{c}
Pigeon pea	6.90	0.070	1.05^{a}	1.81^{a}	27.30^{d}	5.20^{a}	2.40^{a}	0.077^{e}	0.191^{a}	0.40^{a}	8.27^{a}	95^{b}
Control	6.77	0.098	0.77^{c}	1.32^{c}	26.50^{d}	4.80^{a}	2.40^{a}	0.123^{a}	0.096^{bc}	0.24^{b}	7.66^{b}	97^{a}
LSD 0.05	NS	NS	0.06	0.07	0.84	0.47	0.27	0.005	0.043	0.08	0.35	1.50

A,b,c,d,e figures with the same superscript in the same column are not significantly different ($P<0.05$).

of cowpea; groundnut and bambara groundnut were statistically similar. The yield result showed significant ($P<0.05$) difference among the crops assessed. The growth and yield parameters assessed in this trial showed that pigeon pea performed competitively better in value obtained than the other leguminous crops.

The next in rank was bambara groundnut, while the least was cowpea. Table 3 shows the influence of leguminous crops on the soil chemical properties of an ultisol under cassava/maize cultivation for over six years, the result of the pH showed that the pH value increased after post harvest analysis, but was not significantly different ($P<0.05$) among the crops. The plots planted with pigeon pea, Bambara groundnut and groundnut increased respectively over the control, while the plot planted with cowpea showed a slight decrease in pH relative to the control value. The result of the total nitrogen (TN) showed non-significant difference among the leguminous crops, but the value obtained from cowpea, groundnut and Bambara groundnut showed increase in the TN content of the soil with highest value obtained from groundnut which shows a percentage increment of 37.18% over the control. The result of OC showed significant difference among the legumes, though the values of groundnut and Bambara groundnut were statistical similar, but significantly better than the control. The percentage increase in OC over the control with regard to pigeon pea, bambara groundnut and groundnut were 26.67, 9.41 and 9.41%, respectively. While cowpea showed a decreased in OC value relative to the control with a value of 18.46%.

The level of available phosphorous increased in all the plots in the post harvest soil analysis relative to the control plots. The plots planted with cowpea increased the available phosphorous content of the soil by 63.90% over the control. The percentage increases in P observed in groundnut and bambara groundnut over the control were 48.24 and 16.6%, respectively, while pigeon pea gave a slight increase with a value of 2.93% over the control. The available P result showed significant ($P<0.05$) differences among the crops, though the values obtained from pigeon pea and control were statistically similar. The result of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) showed significant differences at $P<0.05$ following post harvest soil analysis. The table indicated that the Ca^{2+} level increased in all the plots at post harvest soil analysis relative to pre-planting soil analysis. The highest value of 5.20 $Cmolkg^{-1}$ $Ca^{2+}$was recorded in the plot treated with pigeon pea, which shows a 7.69% increase over the control plot. While the plots treated with cowpea, Bambara groundnut showed a decrease of 20, 33 and 50%, respectively to the control plots. The result of exchangeable Mg^{2+} showed that the level of Mg^{2+} were slightly reduced in plots treated with bambara groundnut and groundnuts at post harvest soil analysis relative to pre-planting soil analysis. The reduction in Mg^{2+} value of these two crops relative to the control was 50%.The exchangeable K^{+} and Na^{+} result in Table 3 indicated that K^{+} level slightly reduced in all the plots treated with legumes crops relative to the pre-planting soil analysis, while Na^{+} level showed slight increase in all plots except the plot treated with Bambara groundnut relative to pre-planting soil analysis.

The percentage decrease in K^{+} value of the leguminous crops relative to the control crop were 59.74% (pigeon pea); 50% (groundnut); 20.59% (Cowpea) and 8.85% (Bambara groundnut), respectively. The highest, Na^{+} value was observed in plots treated with pigeon pea which was 49.74% increase over the control. The exchangeable acidity result showed significant

Table 4. Influence of different leguminous crop on the physical properties of an ultisol under cassava/maize cultivation for six years.

Treatment	Sand (%)	Silt (%)	Clay (%)	Textural
Cowpea	77.0[b]	7.80[b]	15.20	Loamy sand
Groundnut	78.0[b]	6.80[c]	15.20	Loamy sand
Bambara groundnut	81.0[a]	3.80[e]	15.20	Loamy sand
Pigeon pea	79.0[ab]	5.80[d]	15.20	Loamy sand
Control maize	75.0[c]	9.80[a]	15.20	Loamy sand
LSD 0.05	2.04	0.19	NS	

A,b,c,d,e figures with same superscript in the same column are not significantly different (P<0.05).

difference among the leguminous crops, though the values obtained from cowpea and groundnut did not differ with each other. Also, the EA values of bambara groundnut and pigeon pea were statistically similar but significantly better than the control. The EA result equally indicated that there were a slight decrease in the plots planted with cowpea and groundnut at post harvest soil analysis relative to pre-planting soil analysis. The result of the soil chemical parameters in Table 3 indicated that the level of effective cation exchange capacity (ECEC) reduced in all the plots at post harvest soil analysis. The percentage decrease in ECEC relative to the control plots were 18.58% (cowpea); 32.30% (Bambara groundnut), 45.90% (groundnut), the result of pigeon pea showed a slight increase over the control with a percentage value of 7.38%.

The result of base saturation (BS) value presented in Table 3 indicated an increase in the base saturation of all the plots relative to the pre-planting soil analysis data. The highest value of 96% was recorded in the plot planted with cowpea, which shows a 1.04% decrease relative to the control plots. The BS values obtained from plots planted with cowpea, groundnut and pigeon pea were statistically similar, but significantly (P<0.5) better than the value obtain from bambara groundnut treated plots. The result of the particle size analysis indicated that the legumes crops change the textural class of the studied soil from sandy to loamy sand. There was no change in the clay content of the soil indicating no effect by the leguminous crops. However, the legumes have effect on the sand and silt content of the soil. There was an increase in the sand content and decrease in the silt content of the plot planted with the legumes crops relative to the control (Table 4).

DISCUSSION

The pre-planting soil analysis of the study area showed that the studied soil was found to be impaired in major plant nutrient elements and according to soil fertility evaluation criteria of Ibedu et al. (1988) and fertility rating of Landon (1991), the studied soil is regarded as being low in these soil major nutrients. This might be due to continuous use of the land for cassava/maize production which are nutrient consuming crops and therefore, might have used most of these major nutrients in the soil over the years hence, impaired in major soil nutrients. Cultivation diminishes plant chemical nutrients, soil carbon and substantially lowers nitrogen mineralization (Majaliwa et al., 2010). From the result presented in Table 2, Pigeon pea was observed to have recorded higher values in root area index, number of nodules, weight of pods and grain yield which are significantly (P<0.05) different in comparison with the other leguminous crops assessed in this trial. The next in rank after pigeon pea is bambara groundnut with regards to growth and yield parameters. The higher values observed in pigeon pea and bambara groundnut could be attributed to more root proliferation development and nodulation, showing that the plants can explore more soil for chemical nutrients and soil water as well as more nitrogen availability.

Nweke and Emeh (2013) found out that increase in length of root of Bambara groundnut led to more nutrients absorption that transformed into higher yield observed in their study. Root distribution patterns vary with plant species, Fischler (1999) observed that canavaila have a deeper root system than several other annual legumes. The expansive root system of legumes prevent evapo-transpiration of soil water, leaching of chemical nutrients, erosion and bind soil particles together to form a stable structure (Wu and McGechan, 2009). The productivity of soils can also be improved with the use of leguminous crops. In Ghana, Kamegieter (2006) observed increases in crop yield following a short-term fallow on which leguminous cover crops was grown and in southwest, Nigeria, the works of Lal et al., (2008) and Wilson et al., (2012) showed that leguminous crops improve soil physico-chemical properties and biological activities as was measured by earthworm cast production under centrosema pubescent, cowpea, mucuna pruriens and Bambara groundnut grown only for a short period. While Agboola (2010) found out that as live mulch, calapogonum, mucunoides, bambara groundnut and groundnut gave increases in maize yield equivalent to applying 55kgNha^{-1}. The leaves can also be used for mulch, green manure and supplement high quality browse for small ruminants particularly during the dry season (Sumberg, 2004).

The nodulation efficiency of the cowpea in the studied soil was found out not to be effective, this could be attributed to both internal and external factors, this notwithstanding the result suggest that these legumes could be used as a cheap source of organic fertilizer for soil maintenance and fertility improvement in order to maintain stable and sustainable crop production in humid tropical countries like Nigeria. The following legumes: Albizia species; Peagon pea; Cassia; Cowpea; Bambara groundnut; Groundnut; Inga and Sesbaina, according to the works of NAS (2010); (2013) meet most of the required characteristics for the humid and sub-humid tropics. The result of the soil pH was observed to have increased after post harvest analysis which shows increase in soil nutrient availability, root proliferation, development and yield as indicated in Table 2 and Table 3. Low soil pH value limits soil productivity as it affects availability and uptake of nutrients by plant (Table 1). The TN result though not significantly different among the crops assessed showed increase in TN content of the soil (Tables 1 and 2). This showed that the legumes according to Crews and People (2004) may have added more nitrogen into the soil thus, increasing the N level. Legumes contribute to nitrogen economy of cropping systems when effectively nodulated. The works of Cacmakci et al. (2006) and Elkoca et al. (2008) showed that beneficial micro-organism can colonize individual plant roots and stimulate increase in plant nutrient up take which in turn improves plant size and yield, organic mulch according to Sugiyarto, (2009) support diversity of beneficial soil macro-invertebrate and nutrient to ensure the vegetative growth of plants and suitable environment. Though the activity is still under utilized in the tropics as Vallis et al., (2012) found out that in low nitrogen soils, the amount of nitrogen fixed is closely correlated with legume dry matter yield.

The observations of Lal et al. (2009) and Wilson et al., (2012) showed small increases in soil nitrogen content ranging from 0.01 to 0.06% over a 2 year of legume production. Wilson and Caveness (2010) and Hartman et al. (2011) observed that when legumes are used in live or in situ mulch the population of spiral nematode harmful to maize are suppressed. The non-significant differences may be attributed to negative N balances due to N removal in the grain. Karlen et al. (1994) found out that grain legumes obtain N from the atmosphere, but may have negative N balances due to significant N removal in the grain. The OC and OM content of the soil was found to have increased following the leguminous crop production. The advantage of this increment is the conservation of soil fertility, erosion control and enhancing carbon and nitrogen stocks in the soil, hence, remedied an impaired soil such as the studied soil. This is because organic matter is linked intrinsically to soil such as it is important in maintaining good soil physical, chemical and biological conditions. Thus, soil fertility is marked to be affected by not only quantity but also quality of the OM therefore, to maintain soil fertility planting, leguminous crops is needed as proved by the result of this study. There was increase in available P content of the soil relative to the pre-planting soil; this indicated that the leguminous crops influenced the available P content of the soil. Though the legumes require phosphorous for N_2-fixation processes and growth, there was no reduction in the P level of the soil, this might be due to 0.4kg NPK applied as blanket treatment to stimulate growth and boast vegetative growth of the crops as stated by Johnson (1968) or maybe as a result of micro-organism interaction with the plant roots leading to liberation of some weak acid chemicals, which act on insoluble soil minerals like phosphates to release P nutrient for plant growth. According to Wondewosen (2009) nitrogen and phosphorous are highly limited nutrients that support good growth and development of crops. In a P deficient soils, the available one is utilized to complete its processes and growth thereby reducing the P level in the soil (Sanginga et al., 1996), therefore, in the P deficient soils like the studied soil, P must be supplied from other sources to enable the crops to efficiently use N supplied by the legumes as suggested by Jama et al. (1998). The result of the exchangeable Ca^{2+} and Mg^{2+} showed that there was great improvement on the calcium content of the soil due to legume treatment when compared with pre-planting value (Table 1).

The concentration of Mg as observed in the study however is not of the magnitude of Ca concentration. The result could be linked to pH and OM content of the soil. The exchangeable K^+ and Na^+ result showed that the use of legumes have influenced the availability of K and Na, in the studied soil and chemical properties influenced by the leguminous plants provide sufficient nutrient to the soil organism for soil biological activity that will in turn improve the soil properties. The result of exchangeable acidity (EA), effective cation exchange capacity (ECEC) and base saturation (BS) showed a decline in the concentrations of EA and ECEC following legume treatment while there was an increase in the concentration of the BS of the soil, the nature of the results (EA, ECEC, BS) might be attributed to the soil pH, OM and interaction of other chemical nutrients in the root zone of the soil. The particle size result of the study showed that the legumes influenced greatly the textural class of the soil from sandy to loamy sand; both sand and silt content of the soil were significantly influenced by the legumes crops assessed in this study. According to the works of Smith et al. (1998), soil texture has been found to have good relationship with soil compatibility and some other properties which affect inherent productivity of the soil. While Brewbaker et al. (2012) reported that inclusion of herbaceous and woody forage legumes in crop production system improve soil structure and texture as well as develop sustainable low- input production system.

Conclusion

From the findings of this study, legumes could be used to improve soil properties. The result obtained showed that the legumes assessed improved soil chemical parameters and the soil texture. The grain yield of the legumes was equally improved; though the yield value was highest in control (Maize) when compared with the legumes plots probably the size of maize grain makes it to gain more weight. Hence, it therefore suggest that legumes can be used to reclaim degraded soil or improve the fertility status of an impaired soil like the studied soil which have been depleted of its major chemical nutrients due to continuous cassava/maize cultivation for over six years. The results of the study also show that among the leguminous crop studied, the most efficient is the pigeon pea, and this crop can therefore serve as best maize – legume combination cropping system in the region. The legume will tend to strike a balance to the exhaustive nature of soil nutrients by maize crop.

Conflict of Interests

The author has not declared any conflict of interests.

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Assessment of sedimentation in Tuli – Makwe Dam using remotely sensed data

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A remote sensing approach was used to assess sedimentation in Tuli-Makwe Dam in the semi-arid Mzingwane Catchment in the Matebeleland South province of Zimbabwe. The loss in reservoir gross capacity due to sediment deposition for a period of 47 years since the construction of the dam in 1966 to 2013 was determined to be 3.371 Mm^3 which translate to 40.84 % gross capacity loss. The revised capacity of the dam is estimated at 4.883 Mm^3. The annual rate of sedimentation was calculated to be 0.87 % per annum which translates to 0.0717 Mm^3 per annum. The specific sediment yield over Tuli-Makwe catchment was calculated to be 110.63 tonnes / km2 / year. The result of the sedimentation analysis is typical of small reservoirs in semi-arid regions in Southern Africa. The sedimentation results for Tuli-Makwe reservoir using the remote sensing approach for 2013 are comparable with the sedimentation results from the 2012 hydrographic survey. The results further confirm the applicability of remote sensing for sedimentation analysis for small reservoirs in semi-arid regions. Assuming a uniform sedimentation rate, current trends suggest that Tuli-Makwe reservoir may be filled up in the next sixty eight years from 2013, however the useful capacity of the reservoir may be lost in much less time.

Key words: Reservoir sedimentation, remote sensing, reservoir capacity loss.

INTRODUCTION

Reservoir sedimentation is a serious problem in many parts of the world compromising the useful lifespan of reservoirs (Andredaki et al., 2015). The removal of accumulated sediments is usually a prohibitively expensive undertaking (Minear and Kondolf, 2009), while on the other hand, the construction of new reservoirs to offset the loss of reservoir capacity from sedimentation is becoming a less viable option since most reservoirs have already been constructed at the most suitable sites (Rashid et al., 2014).

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The cumulative loss of reservoir storage capacity disrupts the economic model of planned investments for the reservoir (Odhiambo and Ricker, 2011). Reservoir sedimentation has other negative environmental implications both upstream and downstream of the dam wall. Suspended sediments in the reservoir reduce water quality, reduce light penetration and cause eutrophication which affect biotic life. Sediment trapping behind dams has significant implications for downstream ecosystems as sediments play an important role in influencing river and coastal geomorphic processes in large river systems (Syvitski, 2003; Vorosmarty et al., 2003).

Sedimentation causes the loss of approximately 0.5 to 2.0% of the world reservoir volume annually (Hasan et al., 2011; Issa et al., 2015), while sediment deposition rate varies from 0.1 to 2.3% for large dams worldwide (Rashid et al., 2015). However depending on the nature of the catchment, small reservoirs in semi-arid to arid areas experience much higher levels of sediment deposition. Mambo and Archer (2007) suggest that in Zimbabwe, sediment load exceed the normal design limits in many reservoirs. Reservoir sedimentation surveys of seventeen small dams in semi-arid areas in Zimbabwe and Tanzania showed annual sedimentation rates ranging between 0.5 and 50% with a median of 2.6% translating to sedimentation life span for a “typical” small dam of 38 years, and an even shorter “useful” life span (Wallingford, 2004).

Wallingford (2004) further suggested that 15% of the small reservoirs are silted up in the first twenty years of construction. The effects of sedimentation are especially precarious in semi-arid and arid environments as many small reservoirs have been built to improve rural livelihoods (Senzanje and Chimbari, 2002). Small reservoirs provide water for multiple functions such as small-scale irrigation, domestic water supply, livestock watering, building and other socio-economic activities (Eilander et al., 2014).

In addition to improving the livelihood of the people, small dams also contribute to the sustainable management of the environment. Dalu et al. (2013) identified reservoir sedimentation as a major problem reducing the storage capacity and life span of agricultural dams in Botswana. When reservoirs are silted up, rural communities are deprived of their livelihood.

For sustainable management of reservoirs, an up to date knowledge of sedimentation levels is fundamental (Chitata et al., 2014; Onwuegbunam et al., 2013). Accurate quantification of sediment trapping in reservoirs improves the estimates of river sediment export, allows the useful life of reservoirs to be determined and provides insights into sediment transport and dynamics of watersheds (Lewis et al., 2013). This requires efficient and cost effective tools for systematic and timely reservoir capacity surveys to identify reservoirs that are most vulnerable to rapid sedimentation (Minear and Kondolf, 2009).

Analysis of sedimentation has traditionally been done through direct and indirect methods. Direct methods include actual measurement of volume of sediments deposited in the reservoir through mainly hydrographic surveys (Vente et al., 2003). Indirect methods include sediment budgets which involve the analysis of the inflow and outflow sediment samples collected at gauging stations upstream and downstream of the reservoir, and also the various models that have been developed to estimate sediment yield in to reservoirs (Adam et al., 2014; Bronstert et al., 2014; Weerakoon, 2005).

Hydrographic surveys involve measuring the depth from the water surface to the settled sediments at the bottom of the reservoir along range lines. Measurements are typically taken from a boat using echo sounders or a tape measure with a weight attached at its bottom end. At the end of the survey a new capacity of the reservoir is calculated based on the bathymetry data collected. The difference between the previously known capacity of the reservoir and the new capacity represents reservoir capacity lost due to sedimentation. Depending on the size of the reservoir, hydrographic surveys may take from a few weeks to a few years. While hydrographic surveys have been proven to be quite accurate in sedimentation analysis (Vente et al., 2003), specialized equipment such as boats, echo sounders and GPS receivers are not readily available in many developing countries. Hydrographic methods are also cumbersome and time consuming. In this regard, hydrographic surveys are seldom done or are done after long periods of time such as one in 15 to 25 years.

On the other hand, sediment budget methods require manned station so that sediment samples are collected and sent for analysis consistently during periods of river flow. However, in many developing countries there is lack of well-developed institutional infrastructure to operate monitoring systems efficiently in terms of manpower development and financial constraints in the procurement of equipment and materials required for a monitoring system and for data analysis. Chikwanha (1996) highlights that in many developing countries, the process of sediment samples collection is fraught with challenges arising mainly from financial constraints which in the end results in poorly collected data with too many gaps. While a large number of models have been developed and are available for estimation of reservoir sedimentation process in catchments, the data requirements and computational modelling skills required make the application sediment yield models difficult in most catchments (Jothiprakash and Garg, 2008). As a result, despite their crucial importance, many reservoirs are not monitored for sedimentation regularly. The situation is much direr for small reservoirs in developing countries where governments seldom avail resources to setup and manage sediment monitoring networks (Amitrano et al., 2014) making up to date information about sedimentation for timely interventions unavailable. There is a need to apply cost effective, simple, reliable and sufficiently accurate methods, which require less time, depend on less field data and are easily adaptable to different catchments (Jain et al., 2002; Weerakoon, 2005).

Remote sensing techniques have emerged as an alternative expedient and proficient option to assess sediment deposition and distribution pattern in reservoirs. Remote sensing data provides repetitive, synoptic, timely and relatively cheap information for detection of water bodies that is useful for assessment of sedimentation (Arledler et al., 2010). Assessment of sedimentation using remote sensing is premised on the fact that water spread area of a reservoir at given elevation reduces with the sedimentation indicating deposition of sediments at that elevation (Pandey et al., 2014). Water spread area at different elevations is used to calculate new elevation-area-capacity relationship for the reservoir based on methods such as the prismoidal formula, the Simpson formula and the trapezoidal formula. Satellite data from remote sensing techniques provide important capabilities to map surface water features and monitor the dynamics of surface water (Ji et al., 2009).

Dalu et al. (2013) used the normalized difference water index (NDWI) developed by McFeeters (1996) to successfully map surface water bodies in the Yangtze River Basin and the Huaihe River Basin in China using the recent Landsat 8 Operational Land Imager (OLI) multispectral images and obtained overall accuracy of above 95%, kappa coefficient of 0.89 and producer's accuracy of 95%. Rathore et al. (2006) used water index (WI) to identify water pixels for sedimentation analysis of Harkud dam in India. The NDWI and WI are derived from arithmetic operations based on the Near Infra-red (NIR), green and red wavelengths of the electromagnetic spectrum to enhance the presence of water surface in satellite data. An appropriate threshold for each index is established to separate water bodies from other land-cover features based on spectral characteristics. The establishment of spectral indices that delineate water bodies are based on the fact that water absorbs energy at near-infrared (NIR) while it reflects more in the optical range of the green and red wavelengths (Xu, 2006). However, studies show that the method yields best results for deeper water while they do not do so well for shallower water bodies (Du et al., 2014). The water spectral indices not only enhances the spectral signals of water, but also cancels out portions of the noise components that are common in different wavelength regions such as soil and terrestrial vegetation features.

The results obtained from the application of remote analysis have been found to be accurate in comparison with hydrographic surveys. Rodrigues et al. (2012) used Landsat images with spatial resolution of 30 m to estimate small reservoir storage volumes in Preto surface area. The method was validated with a subset of reservoirs for which surface areas, shapes and depths were determined with ground-based survey measurements and the results were found to be accurate. Pandey et al. (2014) used the Normalized Difference Water Index (NDWI) to delineate open water spread area to assess reservoir sedimentation of the Patratu Reservoir in India from 2006 to 2012 using Landsat TM satellite data and reported that the area-capacity curves derived using remote sensing data were similar to the curves obtained from hydrographic methods.

Jain et al. (2002) used supervised image classification on the IRS – 1B LISS II satellite data with a spatial resolution of 36,25m to determine water spread area to carry out a study on the sedimentation in Bhakra reservoir in India. The results obtained from remote sensing technique were slightly higher at 25.23 Mm^3 / year over the 32 years study period compared to the hydrographic survey results 20.84 Mm^3 / year over the same period. The higher results were attributed to the lower accuracy attained in determination of water spread area due to the lower spatial resolution of the satellite data used. Mixed pixels around the edges of the reservoir that are occupied by water and other land cover types greatly affect the classification exercise. The accuracy of the remote sensing technology for reservoir sedimentation analysis is hinged on accurately determining the water spread area at different reservoir levels. This can be achieved with the use of higher spatial resolution images.

Remote sensing therefore proves to be a powerful technology allowing a reduction of costs and time necessary to obtain relevant information for an effective reservoir sediment management. This situation has been made more possible thanks to the availability of free imagery such as Landsat imagery (Amitrano et al., 2014). However, remote sensing techniques can be used to analyse sedimentation only within the water level fluctuation zone. Information on water level below the minimum draw down level (MDDL) is usually not available as most reservoirs rarely reach this level except when extended drought periods are experienced. Thus sedimentation analysis using remote sensing is rarely used to assess sedimentation below the MDDL. Information on capacity below MDDL that is, in the dead zone could be taken from the most recently conducted hydrographic survey.

The objectives of this study were to apply a remote sensing approach to assess the rate of reservoir sedimentation of Tuli-Makwe Dam and to define a current elevation-capacity relationship for the dam for the year 2013.

METHODOLOGY

The SRTM DEM was used to generate the drainage area of Tuli-Makwe Dam using Arc Hydro Tools in order to identify the drainage area for the dam. This represents the area that contributes sediments to Tuli-Makwe Dam. A detailed description of the processes followed is found in (Li, 2014).

Table 1. Water spread area at different reduced water levels and corresponding revised reservoir capacity calculated from remote sensing for the year (2013).

Date of satellite pass	Reduced reservoir elevation (m)	Average water spread area (Mm2)	Elevation difference (m)	Volume between successive elevations (Mm3)	Revised reservoir capacity (Mm3)
01/10/2012	96.000	0.3724		-	-
02/11/2012	96.315	0.3942	0.315	0.121	1.610
04/12/2012	96.615	0.4124	0.300	0.121	1.820
21/08/2012	97.461	0.5055	0.846	0.388	2.579
10/09/2013	98.250	0.6654	0.789	0.460	3.040
08/07/2013	98.720	0.8068	0.470	0.345	3.385
19/04/2013	99.524	1.2178	0.804	0.809	4.194
15/12/2013	100.038	1.4715	0.513	0.689	4.883

Water spread area was analysed from the downloaded Landsat images. Prior to water spread area analysis all the images were geometrically corrected based on the Universal Transverse Mercator (UTM) projection and the WGS84 datum. Georeferencing was done using the nearest neighbour resampling method using ground truth data obtained from the catchment using a hand held GPS receiver and from Google Earth. A root mean square error of less than 0.18 pixels was achieved for all the images. Water spread area of the reservoir was analysed using the supervised image classification method and the water index method. Table 1 shows the dates of satellite pass corresponding with the reduced reservoir water levels selected for the study.

Supervised image classification

Landsat imagery bands corresponding to the blue, green, red and near infrared (NIR) wavelengths of the electromagnetic spectrum were selected and combined into a multiband image using layer stacking in ENVI 4.7 software. The area covering Tuli-Makwe Dam and surroundings areas were extracted by masking from the multiband images using image sub-setting. A false colour composite with band combination of NIR, Red and Green in the (Red; Green; Blue) format was adopted prior to image the classification. The adopted false colour composite enhances visualisation of vegetation pixels with a red colour and water pixels with dark pixels. Supervised maximum likelihood classification algorithm was used for image classification as it had a good separation of water pixels. The images were classified into three classes (water; vegetation and other). The producer and user accuracy for the water class for all classified images were all above 85%.

Water index method

Using the water index method (Rathore et al., 2006), water pixels were identified by calculating the band ratio of Green/Near Infrared to be very low compared to DN values in the Green band. The ratio distinctly separates water bodies from soil and vegetation with very bright pixels. The WI image was then reclassified to show water pixels as a separate class by assigning the value 1 for water pixels and 0 for the remaining area which is not covered by water.

Water spread area in each image was calculated in ArcGIS by multiplying the number of water pixels and the pixel area. Isolated water pixels noted around the reservoir and along the tributary rivers were not considered to be part of the reservoir. Finally water spread area for each reduced reservoir level was obtained by averaging water spread area for that level from the two methods used. Reservoir water storage capacity between consecutive levels was calculated using the trapezoidal formula as follows:

$$V_{12} = {}^{H_{12}}/_{3} \left(A_1 + A_2 + \sqrt{A_1 * A_2}\right) \quad (1)$$

Where V_{12} is the volume of water present in the dam between two consecutive water levels taken as H_1 and H_2. H_{12} is the difference in water levels between consecutive water level H_1 and H_2. A_1 and A_2 are spread area at water level H_1 and H_2 respectively (Figure 1). Storage capacities between consecutive levels were summed up to arrive at the revised capacity at the full supply level.

Study area

Tuli-Makwe Dam is located 30 kilometres from Gwanda town due West in the Mzingwane catchment in the agro-ecological region (Natural Region) IV in Zimbabwe. This is a semi-arid agro-ecological zone characterised by low and erratic rainfall which makes rain-fed agriculture difficult. Thus surface runoff harvesting through dam construction is an important strategy for the region that has been adopted by the Government of Zimbabwe (GoZ) to increase the level of water security and improve livelihood for the region (GoZ, 2000). The dam was constructed in 1966 by the then Ministry of Water Development. The dam wall spans a natural rocky gorge at approximately two kilometres from the confluence of the Thuli and the Mtsheleli rivers. Thuli River is a major tributary of the Shashe River. Major tributaries of the Thuli River are Mtshabezi, Mtsheleli and Mwewe rivers. The reservoir capacity at construction was 8 254 000 m^3 and has a catchment area of 778 km^2 Figure 1.

Thuli-Makwe Dam provide many benefits and contribute significantly to the socio-economic development of the local rural communities (Rusere, 2005). The dam was designed to supply irrigation water to the 229 hectare Makwe and 50 hectare Thuli irrigation schemes and for other socio-economic activities such as domestic water supply, livestock watering, building water and fisheries. A nearby mining enterprise (Freda Rebecca Mine) also abstracts water from the dam. Natural region IV receives low annual rainfall that varies from 250 to 550 mm per annum. It is also characterised by a low rainfall-runoff conversion with mean runoff varying from 17 mm to 19 mm per annum and high evaporation losses with a mean evaporation of 1800 mm per annum (Love et al., 2005). As a result of these factors, Mzingwane catchment experiences water scarcity (Mazvimavi, 2003). The mean annual temperatures ranges from 12°C to 29°C with the lowest temperatures recorded between June and July, and the highest

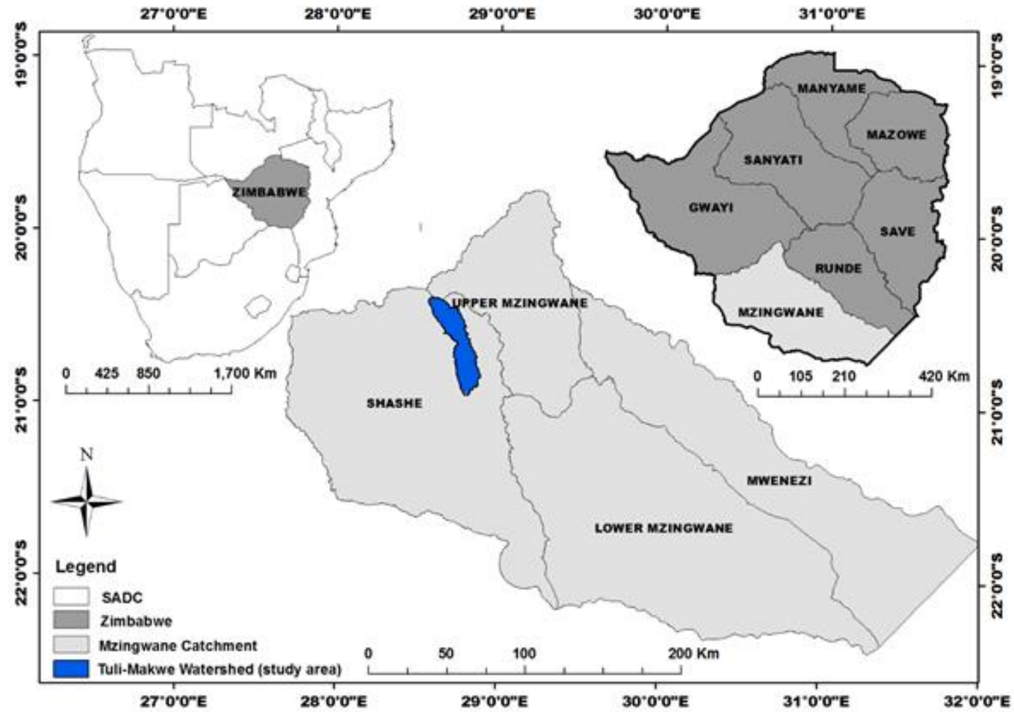

Figure 1. Map showing the study area (Thuli-Makwe watershed) in Mzingwane catchment with respect to Zimbabwe and Southern Africa.

during October. The catchment is characterised by low open woodland of Combretum-acacia- terminalia associated with granitic or gneissic derived sandy soils on the upper part. The upper part normally experiences moderately high rainfall. On the lower part of the catchment is sparse low Mopane woodland gradually replaced by terminalia- sericea and open woodland. Mzingwane catchment has been characterised by shifts in land uses since the construction of the dam. Government initiated land resettlement programmes including the Fast Track Land Reform (FTLR) programme that started in 2000 and was aimed at de-congesting some communal areas and redistributing land to landless natives had negative impacts on the catchment. The programme has left most of the country forests facing serious threat of deforestation increasing from 1.41% (1990 to 2000) to 16.4% (2000 to 2005) (Dalu et al., 2013). More communal areas have been introduced into the catchment. The sparse natural vegetation in the catchment has been converted into other land uses such as arable land, grazing land and mining as a result of anthropogenic activities. Alluvial mining is also a major practice along river courses within the catchment. The region is characterized by deforestation that makes reservoir sedimentation a major threat to the economic life span of reservoirs

Since the dam construction in 1966, two hydrographic surveys have been conducted on Tuli-Makwe Dam. The results of the hydrographic surveys carried out in 1991and 2012 by department responsible for water resources management in the country showed that the dam had a revised gross capacities of 6.182 Mm^3 and 5.206 Mm^3 respectively down from the original design gross capacity of 8.254 Mm^3 highlighted above.

Data

Daily observed water level data for Tuli-Makwe Dam for the period from January, 2012 to December, 2013 was obtained from the Zimbabwe National Water Authority (ZINWA), Data and Research Office. The observed data ranged from reservoir reduced level of 96.00 m to 100.000 m at reservoir full supply level (FSL). The FSL at Tuli-Makwe Dam and many other state owned dams in Zimbabwe is given an arbitrary value of 100.00 m. Revised reservoir capacities from the hydrographic surveys carried out in 1991 and 2012 were obtained from the same office. However, reservoir elevation-capacity relationship for 2012 hydrographic survey and the original design elevation-capacity relationship for the year 1966 could not be located.

Satellite imagery from Landsat Thematic Mapper (TM) and Landsat Operational Land Imager (OLI) taken over Tuli-Makwe Dam on the days corresponding with selected observed levels were downloaded from the United States Geological Survey (USGS), Global Visualisation Viewer (GloVis, website: www.glovis.usgs.gov). The images covered Landsat path 170 and row 75.

Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) at 90 m spatial resolution was obtained from the Consortium for Spatial Information (CGIAR-CSI) website. The STRM data is provided “finished grade” meaning it has been processed to fill data voids. Digital elevation models (DEM) covering all of the countries of the world, are available for download on this site.

RESULTS AND DISCUSSION

Table 1 shows the observed reduced reservoir water levels and the corresponding water spread area obtained from remote sensing for 2013. The table also shows the revised reservoir capacity calculated at the different

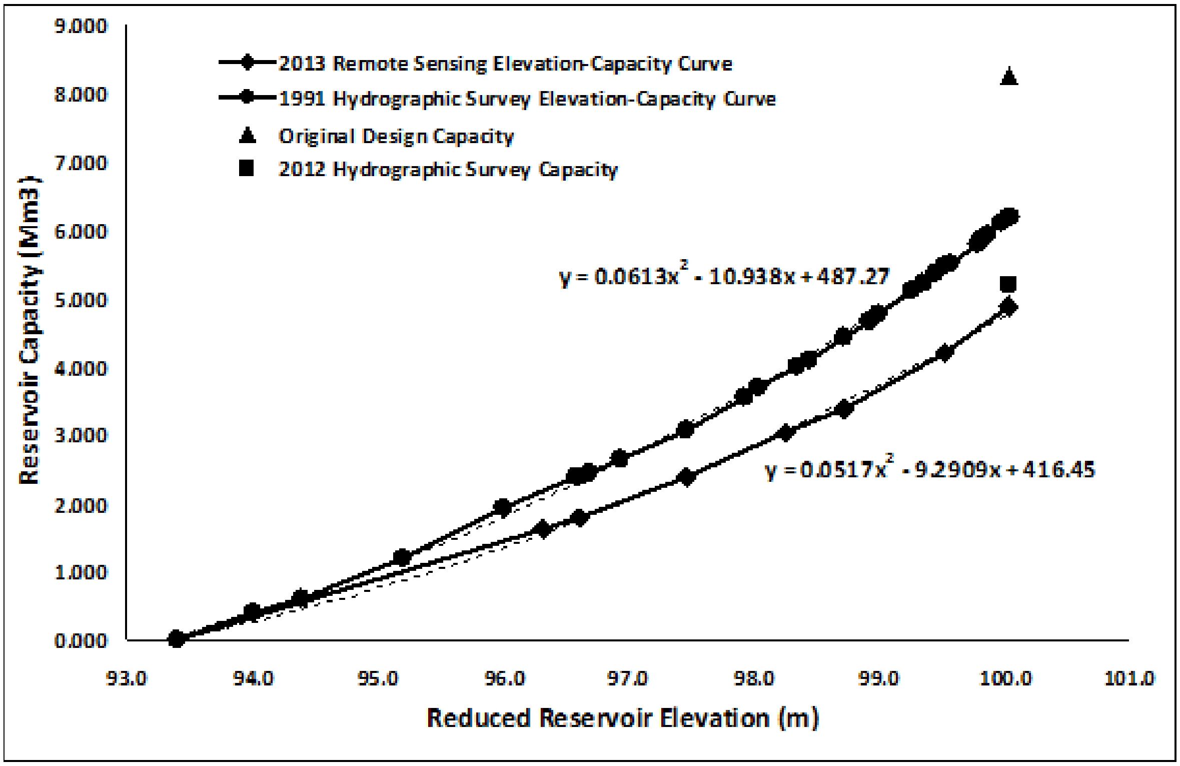

Figure 2. Elevation-capacity curves for Tuli-Makwe Dam from 2013 obtained using the remote sensing approach (capacities at 96 m and below area extrapolated) and from the 1991 hydrographic survey.

levels from remote sensing for the same period. Figure 2 shows the revised elevation-capacity curve for 2013 obtained using the remote sensing approach prepared from Table 1. Reservoir water capacity at the minimum observed water level of 96 m and below were extrapolated. The elevation-capacity curve is compared with the elevation-capacity curve based on the hydrographic survey of 1991. The original design capacity as well as the 2012 hydrographic survey capacities are also shown.

The results show that using the remote sensing approach, Tuli-Makwe Dam has a revised gross reservoir capacity of 4.883 Mm^3 for the year 2013 at the full supply level of reduced reservoir level of 100.00 m. It is thusobserved that during its 47 years of operation since its construction in the year 1966 to 2013, the reservoir lost 3.371 Mm^3 through sedimentation thus reducing the original gross design capacity of 8.254 Mm3 by 40.84%. The annual rate of capacity loss is calculated to be 0.87% per annum which translates to 0.0717 Mm3 per annum.

The equation for the elevation-capacity curve for 2013 obtained from the remote sensing approach is similar to the equation obtained for the 1991 hydrographic survey, and follows the general reservoir capacity parabolic function as outlined by Kaveh et al. (2013). The general form of the capacity equation has three coefficients as follows:

$$V_x = k + mx + nx^2 \quad (2)$$

Where V_x is the reservoir capacity at depth x and k, m, and n are coefficients, respectively. The depth x represents the water depth above the stream bed or the water level elevation as used in Figure 3. Using the equation, the capacity of the reservoir can be calculated for any level of the reservoir. The difference between the curves at any level represents the loss of capacity due to sedimentation at that level from 1991 to 2013.

The revised capacity for Tuli-Makwe reservoir using the remote sensing approach for 2013 is comparable with the results from the 2012 hydrographic survey which suggests that the reservoir had a capacity of 5.201 Mm^3 in 2012. The two methods show a difference of 3.85% for the estimated reservoir capacity lost in a period of 47 years since construction. This agreement further confirms that remote sensing approach can be adequately used to assess sedimentation in reservoirs as highlighted by various authors (Jain et al., 2002; Rodrigues et al., 2012). The results of the remote sensing approach are also in agreement with the assertion from Zirebwa and Twomlow (1999) that small reservoirs in Southern Africa lose about 30% of their capacity over a period of 40 years due to siltation. This assertion results in an annual reservoir capacity loss of 0.75% per annum which is comparable

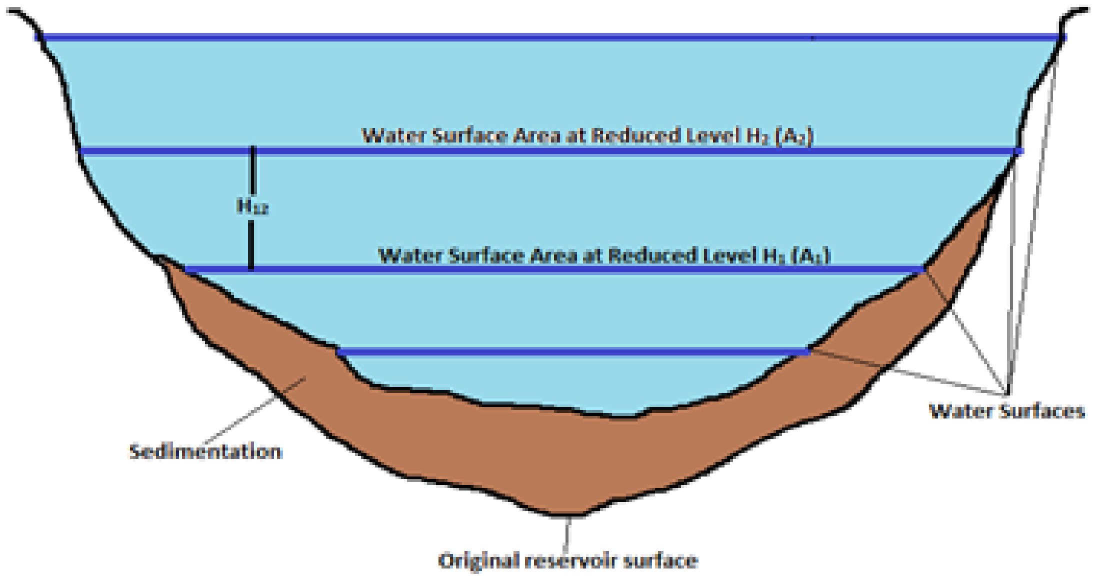

Figure 3. Sketch of the reservoir sedimentation and effects on reservoir water surfaces areas.

to the 0.87% per annum calculated for the 47 years of reservoir operation. Assuming a uniform sedimentation rate, current trends suggest that Tuli-Makwe reservoir may be completely filled up in the next sixty eight years from 2013, however the useful capacity of the reservoir may be lost in much less time.

Wallingford (2004) studied reservoir sedimentation in small to medium sized dams in semi-arid areas in Zimbabwe and Tanzania, and suggested that the settled density for sediment deposited in the reservoir could be adequately estimated at 1.2 tonnes/m^3. Based on this assumption, and also assuming a uniform rate of sedimentation over 47 years, the specific sediment yield over Tuli-Makwe catchment is calculated at 110.59 tonnes / km^2 / year. The sediment yield is comparable with the sediment yield results of 120 .1 tonnes / km^2 / year obtained by (Dalu et al., 2013) in Malilangwe Dam catchment located in the Chiredzi district in the south-eastern lowveld of Zimbabwe. While in different geographic locations, Malilangwe and Tuli-Makwe dams are both in the semi-arid agro-ecological region IV of Zimbabwe. Wallingford (2004) also obtained specific sediment yields ranging from 120 tonnes / km^2 / year to 3400 tonnes / km^2 / year, with a median of 290 tonnes / km^2 / year were for small dams. The slightly lower sediment yield for Tuli-Makwe catchment may be due to the low rainfall-runoff conversion due high rates of evaporation experienced in the catchment.

The hydrographic survey of 1991, shows that Tuli-Makwe reservoir lost 2.072 Mm^3 which is 25.10% of its original capacity in the first 25 years of operation since construction in 1966. The new capacity of the dam was 6.182 Mm^3 and the annual rate of capacity loss is 0.0829 Mm^3 / year (1.004% per annum). The specific sediment yield is calculated at 127. 84 tonnes / km^2 / year under the same period. The results from remote sensing approach suggest that the in period from 1991 to 2013 the reservoir lost a further 1.299 Mm^3 equivalent to 15.74% of the original design capacity in 22 years. The annual sedimentation rate is calculated at 0.0591 Mm^3 / year (0.715% per annum). The specific sediment yield is calculated at 91.07 tonnes / km^2 / year under this period. Whilst the sedimentation rates after 1991 seem to be slightly lower than those prior to 1991, this situation may not necessarily imply that the Tuli-Makwe catchment is becoming more conserved due to appropriate soil and water conservation practices in the catchment. On the contrary such a scenario may point to the temporal variability of sediment trap efficiency. Trap efficiency measures the percentage of the incoming sediment trapped by a reservoir. Trap efficiency is usually 100% for the bed load sediment except for very low-head dams mainly designed for navigation purposes. However, suspended sediment trap efficiency varies roughly with the ratio of reservoir capacity to river inflow. Small reservoirs will have trap efficiency that decreases significantly over time as the reservoir capacity reduces. Vorosmarty et al. (2003) suggests the variability of trap efficiency over time is an important consideration that many reservoir sedimentation models have erroneously assumed to be constant. Another possible factor to consider is the reduction in the overall sediments reaching the reservoir as more reservoirs are constructed upstream of the catchment. Haregeweyn et al. (2012) and Minear and Kondolf (2009) attributed the relatively decreasing trend in sediment yield to the effects of sediment trapping by upstream reservoirs. This effect is particularly important in areas with numerous reservoirs within the same watershed.

Conclusion

Sedimentation results for 2013 from remote sensing techniques that are comparable with 2012 hydrographic survey further confirms the applicability of remote sensing for sedimentation analysis for small reservoirs in semi-arid regions. Small reservoirs play an important role in the livelihood of rural communities, and should be regularly monitored for sedimentation to ensure that corrective measures are taken in time. The results also show that sedimentation rates in Tuli-Makwe Dam are comparable with sedimentation rates recorded within the country and region. Corrective measures have to be put in place to ensure that the useful life of Tuli-Makwe reservoir in not compromised in the near future.

Conflict of Interests

The authors have not declared any conflict of interests.

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