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The potential of anthill soils in agriculture production in Africa: A review

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Abstract

In this review, we have attempted to highlight the critical role which anthills could play in sustainable agriculture practices as a locally available resource for the benefit of financially and soil fertility challenged smallholder farmers. Examples from across sub-Saharan Africa region have been elucidated in this paper on how the anthills have been utilized as a choice of low external input farming strategy for soil fertility challenges. Data from the study was collected through literature search from past and present research work by various scientists across the globe encompassing the internet and research articles. We have become aware that anthill soils could play a crucial role as an alternative to chemical fertilizer for farmers who have no means of buying inorganics. We recommend that for effective utilization of anthills in crop production, there is need to build the capacity of extension staff and farmers on the application method using micro dosing techniques and simple estimation of quantity for determining the requirements per hectare. Raising awareness to policy makers at all levels could stimulate interest on how this resource could be integrated as one of the components of integrated soil fertility management in conservation agriculture technologies. Carrying out studies which would focus on factors that could help in fast development of anthills would be key for enhancing crop development amongst the smallholder farmers challenged by cost of fertilizer input.

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Introduction

Ajayi (2007) indicates that low soil fertility is one of the greatest biophysical constraints to agricultural production in sub-Saharan Africa and is associated with several simultaneous degradation processes which feed on each other to produce a downward spiral in productivity and environmental quality. For instance, the resultant effects of tillage and insufficient applications of nutrient and organic matter unavoidably cause a decline in organic matter of the soil. This affects retention of essential plant nutrients, the breakdown of soil physical structure and diminished water infiltration and storage capacity of the soil. Beyond this, most small-scale farmers face other degradation processes including erosion, salinization and acidification. The decline of soil fertility is also dependent on physical and biological degradation of soils and agronomic practices. A strong relationship exists between poverty and land degradation, national policies and institutional failures. The degradation of soil fertility is linked to other human and environmental problems too, of which malnutrition is a good example.

Chooye (2010) in his personal communication indicated that to avert the challenge of soil fertility farmers in southern Zambia, use anthill soil to enhance their crop productivity. Anthill soils are known to minimize nutrient losses and act as a form of manure which helps to retain soil moisture and texture (Africa Farm News, 2014). The practice of anthill soil utilization involves digging, heaping and spreading the soil on the field. Anectodal evidence in some parts of Malawi and Zambia have revealed that maize crop grown and fertilized with ant-hill soil has been observed to be with high vigor and relatively gives a high yield. One of the factors that may have prompted farmers to use anthill soil in their agriculture production could be high costs associated with inorganic fertilizer which is beyond their reach including the availability of nutrients like nitrogen. Lopez-Hernandez *et al.* (2001) found that African farmers collect termite mound soils or anthill soil and apply to cropped fields as the resource could be rich in available nitrogen, total phosphorous and organic carbon than adjacent soil. However there is little information regarding the quantities required per hectare to enhance crop productivity.

The use of anthill soil in crop production by farmers has been reported by scholars in Zambia (Siame, 2005), Uganda (Okwakol and Sekamatte, 2007), Zimbabwe (Bellon *et al.,* 1999; Nyamapfene, 1986), Sierra Leone (Ettema, 1994) and Niger (Brouwer *et al.,* 1993). Nyamapfene (1986) and Logan (1992) indicate that farmers either plant specific crops on anthills or spread soil from anthills in their fields. An example of agriculture production around anthill is the *chitemene* system of agriculture cited in southwestern Tanzania (Mielke and Mielke, 1982). Malawi farmers have been reported to plant various crops that include bananas (*Musa* spp.) near anthills. In Uganda, the scenario is quite different as farmers plant onions (*Allium* spp.), tomatoes (*Solanum* spp.), pumpkins (*Cucurbita* spp.) and maize beside anthills (Okwakol and Sekamatte, 2007). In Zimbabwe, okra (*Abelmoschus esculentus*), pumpkins, sweet sorghum (*Sorghum* spp.), and late-season planted maize, that requires good water and nutrients supply, are cultivated practically on anthills (Nyamapfene, 1986). Brouwer *et al.* (1993) also indicated that in Niger, the smallholder farmers prefer to grow sorghum on anthills than the surrounding soils.

In some areas, farmers break anthill and spread the soil in their field. For example, in southern Zambia, farmers remove portions of the anthill and make sure that the base and colony are not destroyed. This soil is then taken to the field and mixed with the top soil before the rains begin. In areas where conservation farming is practiced, soil from anthills is put in planting basins (Siame, 2005) and in ripped lines. In South Africa, some patches of excellent well-cared for sugarcane, known as “isiduli”, are prominent characteristics sugarcane fields grown on sandy soils. These correspond to some anthills normally evened by ploughing (Cadet *et al.,* 2004). Similarly, in Zimbabwe, farmers are reported to utilize soil from anthill to enhance soil fertility (Bellon *et al.,* 1999; Nyamapfene, 1986).

The farmers' practices of utilizing anthill soil in agriculture have been reported, and scientific explanations are available for most of them (Watson, 1977; Nyamapfene, 1986). For instance, some studies have indicated that sugar cane yield is five times greater if the "isiduli" is applied somewhere in the field (Cadet *et al.,* 2004). Similarly, plant biomass and grass growth have been reported to be significantly higher around anthills in comparison with the open veld found in Eastern Cape of south Africa (Steinke and Nell, 1989). Research shows that increase in growth of grass surrounding anthill is attributed to the accumulation of runoff water at the base thereby leading to increased productivity in dry seasons, making it possible for plants to survive worst drought conditions (Steinke and Nell, 1989). Researchers have also experimented on the mineral composition of anthills and the adjacent soils (Watson, 1977; Steinke and Nell, 1989; Holt and Lepage, 2000; Cadet *et al.,* 2004; Masanori and Tooru, 2004; Brossard *et al.,* 2007; Chikuvire *et al.,* 2007). There is however scanty information on the characteristics of suitable anthills for use in agriculture production.

Most studies have revealed that anthills consist of significantly higher concentrations of total nitrogen (N) and exchangeable cations than the surrounding soils (Watson, 1977; Steinke and Nell, 1989; Jones, 1990; Holt and Lepage, 2000; Chikuvire *et al.,* 2007). In tropical wet–dry climates, downslope erosion is reported to enhance soil fertility more around anthill than with leached soils away from it (Malaisse, 1978). In addition, soil from anthills has other positive effects on crops which include weeds suppression. For instance, *Cubitermes* soil was revealed to suppress the weed, *Striga* infestation on sorghum crops in West African country of Burkina Faso (Andrianjaka *et al.,* 2007).

The aim of this paper is to bring together farmers' knowledge and evidence from soil science and field experiences on anthill soil utilization and how this could be integrated into conservation agriculture for achieving sustainable agriculture goals. To this end, we undertook a comprehensive review of the potential of anthill soils in agriculture production by describing anthill formation, opportunities and constraints of using the resource in agriculture, characteristics for suitability in crop production, type of microbiota organisms found in the soil, nutrient dynamics, water productivity and soil moisture retention. Finally, we describe the potential economic benefits financially constrained farmers across sub-Saharan Africa would accrue by using anthill soils in crop production practices.

Formation of Anthills

According to various scholars, they have indicated that termites and other fauna species in the soil play a very important role in anthill formation. This process involves anthill building ants which collect woody debris for their nests and forage for large quantities of insect prey and honeydew as food for their colonies. Active anthills are reportedly enriched with soil organic matter and inorganic nutrient elements, comprising Ca, K, Mg, Na and P, in comparison with surrounding soils (Folgarait, 1998; Kristiansen *et al.,* 2001; Lobry de Bruyn and Conacher, 1990).

Ant activities effectively contribute to transforming; (i) physical soil properties, such as infiltration and porosity (Wang *et al.,* 1995), (ii) soil microbial community and faunal biomass (Laakso and Setaelae, 1997) and (iii) rates of decomposition of organic matter (Petal and Kusisnka, 1994). Soil activities of ground-dwelling ants are evident during the construction of anthills. Ants' building activities alter underneath soil into nutrient-rich pockets that favors seed sprouting (Levey and Byrne, 1993; Andersen and Morrison, 1998).

Scientists have related changes to soil physical - chemical properties with anthill building by ants (Nkem *et al.,* 2000; Lenoir *et al.,* 2001; Lafleur *et al.,* 2002), while others have linked these activities with plant distribution patterns (Culver and Beattie, 1983; Dean *et al.,* 1997; Garrettson *et al.,* 1998) and vegetation succession (King, 1977; Farji-Brener and Silva, 1995). Few scholars have associated this soil enrichment to plant growth. Therefore, there is a greater need to take appropriate actions to characterize Anthills formed in different localities if they have to be used in soil fertility programs because the nutrient content of the anthills may be related to the locality of an area.

Opportunities and Constraints of Utilizing Anthill soils in Crop Production

The opportunities of using anthill soil as an amendment in crop production have been described by various researchers. For instance, Mavehangama and Mapanda (2012) studied the nutrient status of organic soil amendments from selected wards of Chivi district in Zimbabwe and found that use of organic amendments such as anthill soil was a common practice with the goal of improving soil productivity in the communal farmlands of Zimbabwe. These scientists further observed that the differences in the nutrient supply potential of other types of animal manure and among other various types of soil amendments that include anthill soil have not been fully investigated. These differences according to Mavehangama and Mapanda would affect the optimum amounts of each type of amendment that may be needed to achieve a targeted crop yield.

Nyamangara and Nyagumbo (2010) analyzed the interactive effects of selected nutrient resources and tied-ridging on plant growth performance in a semi-arid smallholder farming environment in central Zimbabwe and found that anthill soil and leaf litter are worthwhile investments for financially constrained farmers as they could improve the soil chemical and possibly physical properties. Nyamangara *et al.,* 2001 observed that organic fertilizers such as anthill soil buffer soils from acidification better than mineral fertilizers and suggested that farmers who use it would benefit from the potential hydrogen (pH) moderation effect which in turn would ensure availability of nutrients like phosphorous that usually becomes locked up in acidic soils.

FYF (2011) carried out a study recognizing the unrecognized: farmer innovation in northern Malawi and found that some farmers rather than planting crops directly on to the anthills as other farmers had been doing, they decided to take the soil from the anthill and mix it with goat manure in the ratio of 1: 1 before applying it, thereby enhancing the plant nutrient content properties of the anthill soil and also reducing the amount of manure required. This innovation was reported to have good potential for scaling up to other resource-poor farmers, as this offers a low-cost alternative to inorganic fertilizers. In addition, significant yields were reported without scientific inquiry. Other cases, according to FYF (2011) have also been observed in the central region of Malawi where some smallholder farmers engage in spreading the anthill soil in their farms combined with compost and goat manure.

This indicates a viable low input that would counteract the impact of high inorganic fertilizer prices. However, little has been documented and researched to ascertain the use of anthill soil as a source of nutrients for maize production despite convincing literature on the nutrient status of anthill soils. In view of this, there is a need to establish viable and environmentally sound optimum rates of anthill soil application as part of the integrated soil fertility management (ISFM) component in sustainable agriculture.

Results from work by ZARI (2014) in Zambia found that anthill soil can achieve yield results beyond 1000kg/ha if well applied in agriculture fields. However, the technology requires further investigation on soil management practices, application rates and crop response in medium to high rainfall situations.

In terms of constraints, however, some farmers do not level anthills despite scientists believing that soil from anthill could provide an option to inorganic fertilizers (Logan *et al.,* 1990). Scientists have also highlighted the reasons as to why farmers do not prefer leveling anthills in order to make full use of the land and allow mechanized tillage operations (Nyamapfene, 1986). Such issues have been reported to ignore the spiritual (Geissler, 2000; Copeland, 2007) and economic importance (Nkunika, 1998) that farmers perceive of anthills.

The recommendation of scientists also leaves out the fact that leveling anthills may not be sustainable in the long span. Brossard *et al.* (2007), reports that excessive use of anthill soil can affect termite abundance apart from mining nutrients. Some farmers have also expressed labour demands of the practice, especially during digging (ZARI, 2014).

It is also indicated that the problem related to the use of anthill soil in agriculture production has often hinged on how to get the suitable quantities required to satisfy the nutritional needs of crops. The issues of transportation and handling costs are normally beyond the farmer's capacity (Lal, 1988). A study by Lee and Wood (1971) revealed that the rates of production of the anthills are too little to be utilized for annual seasonal crop production and by commercial farmers. Understanding the constraints of utilizing Anthill soils in crop production will enable the scientists to find solutions and find other methods of inducing faster development of anthills for agriculture production.

Characteristics of a Suitable Anthill for Crop Production

Chemical Properties

In soil science, chemical properties of soils encompasses measurements' of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of certain potential contaminants that may include heavy metals, radioactive compounds, etc. or those required for plant growth and development. Soil's chemical condition influences soil-plant relations, water quality, buffering capacities, nutrients and water availability to plants and other organisms, contaminants mobility including other physical conditions, such as crusting (Kheyrodin, 2014).

Eneji *et al.* (2015), carried out a comparative analysis of anthill soil and surrounding soil properties in the University of Agriculture, Makurdi, Nigeria, and found that differences in the chemical properties of the anthill and the surrounding soils was as a result of ecosystem services from termites which included among others bioturbation and soil formation, nutrient transportation and cycling, litter decomposition, soil animal and microbial diversity, amendment and remediation.

In a similar study Joseph *et al.* (2002) who evaluated termite mounds as islands: woody plant assemblages relative to *termitarium* size and soil properties found that anthills are habitat of high socio-economic importance, the *termitaria* which are richer in minerals like Ca, Mg, K, Na and also the accumulation of all these bases increase the pH value of the soil. Other studies by Kaschuk *et al.* (2006) during the assessment of termite's activity in relation to natural grassland soil attributes showed that soil samples collected from the top, middle and bottom of termite mounds or anthills and from adjacent areas exhibited more content of K, P, Mg, O.C and lowered pH.

Ekakitie and Osakwe (2014) analyzed determination of Fe_2O_3, SiO_3, K_2O, CaO, Al_2O_3 and Mg in anthill soil samples in Nigeria and found different concentrations of oxides which were due to parent materials in the soil, vegetation around, fertilizer use and bush burning. The oxides play an important function of providing the solid shape and resistance to water. Literature also reports that anthill soils have high levels of calcium, phosphorus and organic matter, which is also useful for better crop development. Plants also take up nutrients very easily from anthill soil. This soil is proving a good alternative to local farmers who cannot afford to buy expensive inorganic fertilizers. The anthill soil density is very low but soil may be collected, crushed and mixed with top soil for subsistence farming (Dhembare, 2013).

Sarcinelli *et al.* (2008) also found that pH and the contents of organic C and N, P, Ca and Mg were significantly higher in anthill soils than adjacent areas, with an inverse trend for Al content. Significant differences in pH and exchangeable Al were observed between soil and anthill across the slopes. It is however, observed that there are few studies on chemical properties of anthill soils and most have focused on macro nutrients and little is reported on the nutrient levels of micro nutrients that include Fe, Mn, Zn and Cu etc. Therefore it becomes imperative that chemical characterization of anthill soils is done. This will facilitate proper planning and utilization of this natural resource base in the integrated soil fertility management programs.

Physical Properties

Physical properties of the soil relate to the arrangement of solid particles and pores. Examples may include topsoil depth, bulk density, porosity, aggregate stability, texture, crusting, and compaction. These essentially are indicators of limitations to root growth, seedling emergence, infiltration, or water movement along the soil profile (Kheyrodin, 2014). Cammeraat *et al.* (2002) and Dashtban *et al.* (2009), indicated that ants play a big role in determining the physical soil properties of anthills soil during construction due to their burrowing habit and their ability to change physical characteristics, which include infiltration, water retaining capability, etc., of their anthills. These scholars further reported that there are a number of studies conducted on the effects of ants on soil characteristics that include bulk density, organic matter content and porosity within the anthill area. Decreased bulk density and increased soil porosity within the anthills have been reported to accelerate aeration, change temperature gradient and changes soil pH (Dean *et al.,* 1997).

Shakesby *et al.* (2003) also indicated that water infiltration rate in anthill soil and that of adjacent area is increased by ants. These creatures tend to create large macropores [biopores] and mix organic matter with mineral soil during anthill formation. Lobry de Bruyn and Conacher (1994), stressed that the cortex which act as a cover around the ant-hills is assumed to play an important role in absorbing the impact of the rain drops and in ensuring that water is infiltrated inside the ant-hills.

The impact of ants on water infiltration and erosion is crucial in agricultural soils, where heavy machinery and herbicide use are reported to reduce soil porosity and organic matter (Cerda and Jurgensen, 2008). Schaefer (2001), remarked that the results of aggregate fractioning indicated that a greater portion of anthill walls is composed of large aggregates which are cemented by termite body fluids (fraction N 2.00mm), that are rapidly disintegrated into smaller particles, thereby increasing the aggregate fractions to less than 0.500mm. This constitutes the main fraction of the stable micro-aggregates in Latosols. In the upper slope and hill top, larger organo-mineral aggregates, are formed from organic matter incorporation, which are only present at the surface, with decreasing values depending on depth (B horizon) and where minute micro-aggregates can be found. This point to the fact that fresh anthill materials are made by welded aggregates and form larger cemented clods (N 1.00 mm). These are further eroded by erosion and weathering processes after abandonment of anthills. Without much reliance on statistics, micro morphological observations strongly support this hypothesis and thin sections of anthill walls and adjacent soils clearly show smaller aggregates partially held together, when observed at Microscopic level.

In the larger aggregates, mica particles, charcoal and charred materials are observed as being randomly scattered within the clay plasma, indicating the deep turnover of soil material in the anthills, since mica is virtually absent on the surface of Latosols. The landscape stability of these top positions supports a greater degree of weathering, relatively to lower and steep positions, and thus, accelerates micro-aggregation and Latosols formation. Other researchers have shown evidence of the formation of organo-mineral micro-aggregates and their stabilization through electrochemical and hydrogen bonding via exchangeable cations and organic compounds, as a result of the passage of mineral particles along the intestinal tract of the insects during humus digestion (Garnier-Sillam *et al.*, 1985; Garnier-Sillam and Harry, 1995).

Grassé (1984) and Jungerius *et al.* (1999) also reported that soil materials which are reworked in mandibles of insects with the addition of saliva has also been classified as a process of aggregate production. However, the understanding of the action of the body fluids and digestive processes on the formation of the aggregates and their mineralogy is constrained by the lack of information on chemical composition of those fluids and insect biology (Grassé, 1984). Considerable number of researchers have reported the concentration of nutrients in termite anthills and surrounding soil (Watson, 1962; Pomeroy, 1983; Anderson and Wood, 1984; Coventry *et al.,* 1988; Hullugale and Ndi, 1993; Lobry de Bruyn and Conacher, 1995), while other scholars also report results on soil porosity transformations and particle size sorting (Anderson and Wood, 1984; Lobry de Bruyn and Conacher, 1990; Garnier-Sillam *et al.,* 1991).

In the lower slope, greater amounts of large aggregates in horizon A and B show that these kind of soils have a quite contrasting framework and field observations confirm that mildly podzolized Latosols (transitional between Oxisols and Ultisols) occur at that lower position, related to a moderate and medium sized blocky structure. This is associated to the greater intensity of wetting and drying cycles on these colluvial foot slopes, for oxic Ultisols found in that landscape position, as opinionated by Carvalho Filho (1989). With regard to Latosols (Sarcinelli *et al.,* 2008) reported that the microstructure, of these soils in anthills could be compared to a “coffee powder” which confirms that indeed the termite's activity plays a key role on such soils. In this respect, they should be considered as a factor on Latosols genesis. However, there is need for further research in order to have conclusive scientific evidence on the matter. The microstructure of the anthills should be known as this affects the physical properties such as bulk density, porosity, infiltration rate and water retention capacity in general among others.

Biological Community in Anthill Soils

Bacteria, Fungi, Fauna Biomass and other Microbiota Organisms

Sleptzovaa and Reznikovab (2006) reported that besides ants, there are a number of other organisms like bacteria, fungi, actinomycetes, microarthropod, centipedes and millipedes which are inhabitants of anthills. Kotova *et al.* (2013) studied the bacterial complex associated with several species of ants, the inhabiting soil and their anthills and found that more than 80% of the majority of anthills were dominated by *Bacillus* whereas the anthill of Formica was characterized by the Flavobacterium – Bacteroides- Cytophaga group. Further, actinomycetes were found to be widespread in the anthills of *Formica* sp and *Lasius* sp.

Numerous staphylococci (20%) were also found in the *L. flavus* anthills, but the major dominants of the bacterial community were Streptomyces bacteria (68.5%) while many Bacteroides (28%) were found in the anthills of Tetramorium. Actinomycetes from the genus Streptomyces were observed in the bacterial complexes of all studied ants, apart from *F. cunicularia*. Pokarzhevskij (1981), concluded that the abundant bacteria, actinomycetes and fungi in anthill induce many small soil invertebrates to come up, including springtails. In these anthills, ants play the role of ensuring a stable microclimatic environment (Horstmann and Schmid, 1986), which determines to a considerable extent the specific structure of a microarthropod community.

Springtails abundance and diversity depends on the growth and development of anthills. The abundance of springtails in large old domes with relatively constant humidity may significantly exceed their abundance in the surrounding soil and litter. Similarly, Stoev and Gjonova (2005) reported a diversity of Myriapods, a subphylum of Arthropoda containing millipedes and centipedes from anthills of *Formica* sp., *Camponatus sp. and Myrmica sp.* in the European country of Bulgaria. These Myriapods found dwelling in anthills encompasses *Brachydesmus* sp., *Polyxenus legurus, Megaphyllum* sp. and *Lithobius microps*. Schultz (2000) also opinionated that ants develop well in various environments including the anthills and constitute about 15-20% of the terrestrial animal biomass and this is more than that of the vertebrates. Future studies should nevertheless, consider the temperature requirements under which the fungi and ants as microbes thrive well because this may have an effect on biological community in anthills.

Soil enzymes in Anthill soils

Soil enzymes play key biochemical functions in organic matter decomposition in the soil system (Burns, 1983; Sinsabaugh *et al.,* 1991). They act as important catalyst in several important chemical reactions needed for the life processes of micro-organisms in soils and provides stability to soil structure, decomposition of organic wastes, organic matter formation and nutrient cycling (Dick *et al.,* 1994). Enzymes are continously being synthesised, accumulated, inactivated and/or decomposed in the soil, thereby playing an important role in agriculture and mostly in nutrients cycling (Tabatabai, 1994; Dick, 1997). Activities of enzymes in soils pass through complex biochemical processes accompanied by integrated and ecologically-linked processes for ensuring enzyme immobilisation and stability (Khaziyev and Gulke, 1991).

In this respect, any soil type is composed of a number of enzymes that influence soil metabolism activities (McLaren, 1975) which, rely, on the physical, chemical, microbiological and biochemical properties.

The enzyme levels in soil systems vary in amounts owing to the fact that each soil type has different quantities of organic matter content, type of living organisms and the rate at which biological processes occur. In practice, the biochemical reactions are as a result of the catalytic contribution of enzymes and different substrates that serve as energy sources for micro-organisms (Kiss *et al.,* 1978). Major enzymes in the soil may include amylase, arylsulphatases, β-glucosidase, cellulose, chitinase, dehydrogenase, phosphatase, protease and urease released from plants (Miwa *et al.,* 1937), animals (Kanfer *et al.,* 1974), micro-organisms and organic compounds (Dick and Tabatabai, 1984; James *et al.,* 1991; Richmond, 1991; Hans and Snivasan, 1969; Shawale and Sadana, 1981) and soils (Cooper, 1972; Gupta *et al.*, 1993; Gareshamurthy *et al.,* 1995).

Knowledge of the role of soil enzymes activity in the ecosystem is critical as this would provide a unique opportunity for an integrated biological assessment of soils due to their crucial role in several soil biological activities, their ease of measurement and their rapid response to changes in soil management practices (Dick, 1994; Dick, 1997; Bandick and Dick, 1999). Other studies by scholars reveal that high enzyme activity is an indicator of mineral element limitation in the ecosystem (Sinsabaugh *et al.,* 1993; Makoi and Ndakidemi, 2008). Although there have been extensive studies on soil enzymes (Lizararo *et al.,* 2005; Mungai *et al.,* 2005; Wirth and Wolf, 1992; Ross, 1976; Perucci *et al.,* 1984), there is still scanty information on their roles in agricultural development. To better understand the roles of these enzymes' activity and efficiency, studying their presence in anthill soils are critical to know for contribution to nutrients availability such as nitrogen, phosphorous and potassium etc.

Nutrient dynamics in Anthill soils

Although initial work of Darwin on the effects of earthworms on soil formation (Darwin, 1881), influenced later research developments, soil chemical, physical and mineralogical properties have still received much more little attention than soil fauna by pedologists or geomorphologists. However, many soil organisms transform the environment in which they live, through physical and biotic conditioning, in both absolute and relative terms to resources availability. Since the early days of pedology, Dokuchaev remarked that "soil animals were not merely soil inhabitants, but played a vital role in most soil reactions". Termites (Isoptera) are social insects numbering about 3000 known species, from which an estimated 75% are classified as soil-feeding termites. The diet of soil-feeding termites consists of no cellular organic material mixed with clay minerals. Their gut is formed by five compartments that present rising scales of pH, up to 12.5, and different status of oxygen and hydrogen (Brune *et al.,* 1995; Brune and Kühl, 1996; Donavan *et al.*, 2001). These attributes are surely important and could effectively be described as contributors to anthill soil chemical and physical alterations.

Termites are also referred to as “ecosystem engineers” (Dangerfield *et al.,* 1998) as they enhance soil changes by disturbance processes. Termites collect organic matter and mineral particles from different depths and deposit them in anthills, thereby accelerating the content of organic C, clay and nutrients. Also, pH and microbial population is reported higher in anthills than in surrounding soils (Lal, 1988; Black and Okwakol, 1997; Holt *et al.,* 1998). The material accumulated is redistributed by erosion, affecting soil micro-structure and fertility (Lee and Wood, 1971; Black and Okwakol, 1997; Dangerfield *et al.,* 1998; Jungerius *et al.,* 1999; Schaefer, 2001). Termites also participate in construction of galleries that increase soil porosity and water infiltration (Mando and Stroosnijder, 1999; Leonard and Rajot, 2001) and these galleries are filled up with top soil materials. Rainfall contributes to the process of formation of deep, uniform Latosols (correlated to the Oxisols in the Soil Taxonomy) (Schaefer, 2001).

The composition of clay in anthills is normally 20% higher than in surrounding soils, but it is not known whether termites choose particles, or soil undergoes a physical fractioning through their guts (Lee and Wood, 1971; Donovan *et al.,* 2001; Jouquet *et al.,* 2002). It is also true to opinionate that clay minerals are transformed as soil particles are handled in their mouths or pass through their guts. In this regard, Schaefer (2001) reported that kaolinite become less crystalline after passing through termite guts, due to high pH levels. Although literature reports the role of termites in anthill soil transportation, particle size sorting, nutrient concentration, organic matter turnover, greater porosity, organo-mineral micro aggregation, aggregate stabilization, erosion effects, among others, there is still very little information concerning pedogenesis, landscape evolution and nutrient dynamics in agricultural systems involving Anthills.

Water Productivity and Soil moisture retention in Anthill soils

Ali and Talukder (2008) indicated that in crop production system, water productivity (WP) is used to define the relationship between crop produced and the amount of water involved in crop production, expressed as crop production per unit volume of water. Crop production may be expressed in terms of total dry-matter yield or seed (or grain) yield (kg) or, when dealing with different crops, yield may be changed to monetary units (e.g USD or any other legal tender in a given situation). More options are available to define the amount of water. Different water productivity indices are from various alternatives as shown below in the following equations:

WP_1= Grain or seed yield/ Water applied to the field (kg/ha/cm) (1)

WP_2 = Total dry matter yield/ Water applied to the field (kg/ha/cm) (2)

WP_3 = Total monetary value/ Water applied to the field ($\$/m^{-3}$) (3)

With effectiveness of water use in a single crop being described, Equations. (1) or (2) is appropriate. However, if comparison is being done at regional level, or the effectiveness of water use by different ethnic groups or under scarce water situations without land limitations is studied, then we can use Equation (3) (Ali *et al.,* 2007).

Soil moisture retention is one of the key factors that affect water productivity in agriculture production. Loss of water from the soil surface through evaporation influences plant growth during germination and seedling establishment, including other growing periods. The texture of the soil and organic matter content determine the water storage and release properties. When the soil dries rapidly, it does not provide osmosis process and thus affects yield and water productivity. The nutritional condition of upcoming crops, especially nitrogen, can significantly influence the speed of development of leaf area thereby causing evaporation losses from the soil. Organic matter in soil environment undergoes chemical processes involving microbial activities and nutrients present.

In terms of water productivity and soil retention of anthill soils, there is little information reported on this aspect. However, other literature reveals that anthill soils generally have high clay content and this enhances water storage capacity.

When soils with low water retention capacity are common and anthill soil is spread on these soils it results in a higher soil moisture content and improved crop growth. This implies that anthill soils could have high water productivity. Further research is nevertheless needed to prove the effectiveness and efficiency under agricultural production conditions.

The potential of anthill soils in Integrated Soil Fertility Management (ISFM)

Place *et al.* (2003) defines integrated soil fertility management (ISFM) as a set of best cultural practices, preferably used in combination, including the use of appropriate germplasm, fertilizer and of organic resources coupled with best agricultural practices (BAPs). This aspect is seemingly becoming acceptable to development organizations in Sub Saharan Africa (SSA), and to a large extent, to the small-holder farmers. ISFM entails widening the choice set of farmers by enhancing their awareness of the variety of options available and how they may complement or substitute for one another. Vanlauwe (2015) notes that ISFM can act as a conduit for enhancing crop productivity while maximizing the agronomic efficiency (AE) of applied inputs, thereby contributing to sustainable intensification. The degree of variability in soil fertility conditions and the soil challenges which are beyond those addressed by fertilizer and organic inputs such as anthill soils are considered within ISFM amongst the smallholder farms.

Different biophysical environments that is common amongst smallholder farming systems affect crop productivity and the associated AE. In this regard, targeted application of inputs including management practices is critical for enhancing AE. Further, decisions for management squarely depend upon the farmer's capacity and production objectives. Soil fertility restoration in SSA is seen as extremely important towards contributing to the efforts of poverty alleviation. Soil fertility is crucial because poverty in Africa affects mostly the rural people where the per capita arable land has reported reduced from the initial 0.53 to 0.35 hectares during the period 1970 and 2000 (FAOSTAT, 2002).

Accelerated and sustainable agricultural intensification is required. However, intensification, increased agricultural productivity and improved rural livelihoods relies on investment in soil fertility. African soils demonstrate numerous constraints that encompass physical soil loss from erosion, nutrient deficiency, low organic matter, aluminum and iron toxicity, acidity, crusting, and moisture stress. Some of these constraints occur naturally in tropical soils, but degradation processes related to land management exacerbate them. Estimates suggest that about two-thirds of agricultural land is degraded, with 85% caused by wind and water erosion (Oldeman *et al.,* 1991). Limited use of nutrient inputs among smallholder farmers exacerbates soil nutrient deficiency.

In the late 1990s, it was reported that fertilizer use in Africa was averaging about 9kg per hectare and that this scenario does not seem to have changed (Henao and Baanante, 2001). The estimated losses, due to erosion, leaching, and crop harvests are over 60–100kg of N, P, and K per hectare each year in Western and Eastern Africa (e.g. Stoorvogel and Smaling, 1990; de Jager *et al.,* 1998). Promotion and use of locally available organic resources such as anthill soils for improving soil fertility as alternative for the cash constrained farmers who cannot afford to buy inorganic fertilizer could hold the key. However, there is less information regarding the application rates of Anthill soils and/or in combination with other soil amendments for optimum crop productivity. This calls for research on combining appropriate soil amendments practices such as organic and inorganic fertilizers with Anthill soil and come up with useful Integrated Soil Fertility Management program for use by small scale farmers where this resources are available.

Effect of Anthill Soils on Plant Growth

The ISFM concept acknowledges the need for both organic (e.g anthill soils, cattle manure) and mineral inputs for maintaining soil health and crop production as they interact and complement each other (Buresh *et al.,* 1997; Vanlauwe *et al.,* 2002a) which accelerates plant growth. The most common organically based soil nutrient practices by smallholder farmers include; cattle manure, compost, crop residue incorporation, fallowing (natural and improved), intercropping of legumes and biomass transfer. Although our focus is on soil nutrient management practices, there are a number of other management practices that contribute to soil fertility, which include soil conservation and tillage techniques, weed management and cropping strategies. The old thinking has been that organic resources are sources of major soil nutrients such as nitrogen (N).

Palm *et al.* (2001) indicated that research by other scholars has been done on quantifying the availability of N from organic resources influenced by their resource quality and the physical environment. More recently, other contributions of organics extending beyond fertilizer substitution have been emphasized in research, such as the provision of other macro and micro-nutrients, reduction of phosphorus sorption capacity, enhancing carbon/organic matter, decreasing soil borne pest and disease through crop rotations and increment of soil moisture status (Vanlauwe *et al.,* 2002a).

There are some key differences in the way that the organic systems contribute to soil fertility. Agriculture practices involving nitrogen-fixing species add extra quantities of nitrogen without depleting the nutrients from the soils it. Organic sources will differ in terms of nutrient content and how the organic compounds are made available to the crop including the provision of other soil fertility benefits (e.g. weed reduction). Agronomic practices also determine the effectiveness of organics. Other organics like anthill soils where available at farm level could also play a significant role in enhancing crop productivity owing to the fact that they have higher N content which is crucial in plant development.

It is however known that organic and mineral inputs cannot be substituted entirely by one another and are both required for sustainable crop production (Buresh *et al.*, 1997; Vanlauwe *et al.,* 2002a), due in part to (i) practical reasons fertilizer or organic resources alone may not provide sufficient amounts or may be unsuitable for alleviating specific constraints to crop growth (Sanchez and Jama, 2002), (ii) the potential for enhanced benefits created via positive interactions between organic and inorganic inputs in the short-term and (iii) the several roles each of these inputs play in the longer range. Where these are used in combination, they help to reduce the costs of crop production.

One key complementarity is that organic resources such as anthill soil enhance organic matter status and the functions it supports, while mineral inputs can be targeted to key limiting nutrients. There have been efforts made focusing on quantifying the amount of accrued including the systems responsible for creating them. Vanlauwe *et al.* (2002b) indicated clear interactions involving urea and use of organic applications such as crop residues while Nhamo (2001) reported extra benefits from manure and ammonium nitrate combinations.

Although the above list of observed strong interactions between organic and mineral inputs is not exhaustive, very often these inputs are demonstrated to have only additive effects. But because of declining marginal increases from one single type of input, the additive effects are often superior in terms of overall yields and net financial returns, as shown by Rommelse (2001) on maize in Kenya. Negative interactions are never observed.

In brief, we note that there is considerable evidence showing the key contributions of organic matter alone to agricultural crop yields. There is little, nevertheless significant proof pointing to the positive short and long term impacts of ISFM technologies integrating organic and mineral nutrient sources. More economic analyses of these systems and evidence from farmer-managed practices are needed.

One important aspect to note is that most agronomic research on ISFM has taken place on cereal crops. However, much organic and inorganic fertilizer use by smallholders is focused on higher value crops for which the effects of organics such as anthill soil and ISFM remain under-researched.

On-farm Integrated Soil Fertility Management (ISFM) practices by Smallholder Farmers

Various scholars have indicated that a number of smallholder farmers in Africa, use a wide range of ISFM practices (Place *et al.,* 2002b) and involves legume intercropping (cowpeas, soybeans, beans, groundnuts etc) and cattle manure which are well established practices. Omiti *et al.* (1999) indicated that in Kenya, farmers who utilized manure in semi-arid and semi-humid areas of Nairobi ranged between 86% and 91% respectively. However, only 40% of the farmers used compost, but by few farmers especially in the more arid sites. In severe humid western highlands, 70% of farmers were reportedly used manure and 41% used compost while 20% of them were engaged in using biomass transfer and improved tree fallows (Place *et al.,* 2002a). In a related study by Clay *et al.* (2002) in Rwanda, it was found that 49% of households' plots received organic nutrient inputs. Rotations involving legumes and green manure systems were common in 48 and 23 percent of extension sites in Zimbabwe (Gambara *et al.,* 2002). Higher practices of alley farming were reported in areas of Nigeria (Adesina and Chinau, 2002) and of *Mucuna* fallows in Benin and Cameroon (Manyong and Houndekon, 2000). Inspite of varying adoption rates between organic and mineral nutrients in terms of area, the use of organic practices such as natural fallowing and animal manure have always been more than the use of inorganic fertilizers. .

In Rwanda, the scenario was abit alarming where only 2% of plots received mineral fertilizer. There is however, less information available on the quantities of organic nutrients applied, but it is common knowledge that smallholder farmers often face the challenges of increasing opportunity costs and in this regard, the amounts produced and applied are sparingly limited. Place *et al.* (2002a) indicated that in terms of profitability, evidence of positive returns is reported for biomass transfer and improved fallows including manure (Mekuria and Waddington, 2002). Positive returns are often found for inorganic fertilizer inputs (Kelly *et al.,* 2002; Shapiro and Sanders (2002) and for integrated inorganic-organic systems (Place *et al.,* 2002a; Mekuria and Waddington, 2002). Further (Mekuria and Waddington, 2002) opinionated that, the ISFM practices of manure and fertilizer on maize in Zimbabwe was reported to have labor profitability of about $1.35 per day, while the best sole fertilizer or manure treatment produced only $0.25.

While more economic analyses of farmer-managed ISFM systems are needed, existing evidence suggests that organic or ISFM systems could be profitable where purchased fertilizer alone remains unattractive. Farmers in Kenya are known to practice ISFM on their agriculture fields. Freeman and Coe (2002) found that 37% of farmers in the relatively drier zones of Kenya integrated organic and mineral fertilizers. Additionally, 10% were using other organic sources but without mineral fertilizer.

In the western Kenyan highlands, more than 66% of farmers using mineral fertilizer also utilized cattle manure (Place *et al.,* 2002a). Murithi (1998) reported several sources of nutrients used on a number of crops in Central Kenya. This is generally true of areas where livestock are important and markets for fertilizer exist. In Western Kenya, it was also reported that where ISFM practices have been used, soils have improved and the farmers have increased their yields of maize and legume crops (soybeans, climbing and bush beans) by about 60% and 46% respectively (AGRA and IIRR, 2014). In Uganda, it was found that there is little integration of organics and mineral fertilizer, partly due to poor fertilizer availability.

In Malawi, there is utilization of green manure and mineral fertilizer systems, where farmers use both pigeon pea intercrops and fertilizer (Peters, 2002). As with manure, farmers have shifted promising innovations using integrations of organic and mineral fertilizers onto higher-value commodities such as vegetables (Place *et al.,* 2002a). Organic sources that provide a dual benefit (e.g. food) have a higher preference by farmers. Organic nutrient systems are commonly more affordable to financially constrained farmers than fertilizer options.

Mekuria and Waddington (2002), indicated that because livestock ownership is strongly related to household incomes, wealthier farmers are more likely to use manure than poorer ones. In contrast, (Place *et al.,* 2002c) found that resource constrained farmers use agroforestry-based nutrient systems and compost in Western Kenya. However, there is concern that as land sizes continue to shrink, noting niches for producing any type of organic nutrient source will become far-fetched. In brief, evidence from across SSA shows that there is considerable use of organic inputs, normally with less widely used mineral fertilizers. It should be noted here that profitability of alternative nutrient input sources depends largely on yield gains and market scenarios, as emphasized by generally more use on higher valued commodities. However, critical evidence on ISFM profitability is little, leading to a serious research gap which calls for further investigation. In addition, although farmers use organic nutrient inputs such as anthill soil in agriculture production, the rates still remain to be known.

Economic Benefits of Anthill soils

Miyagawa *et al.* (2011) in their study of the Indigenous utilization of anthill soils and their sustainability in a rice-growing village of the central plain of Laos, found that if the resource is available in abundance, it could be used as a fertilizer for rice growing to increase rice yield without buying chemical fertilizer. The scholars also observed that none of the farmers sold or gave away anthill soil from their own land. It was essentially meant for self-sufficiency in the farming systems of the local communities.

Further, the study concluded that anthills were not only used for soil amendment as a fertilizer but also as beds for vegetable production and construction of charcoal kilns. However, this depended on the architecture of the anthill. There is still little information reported on the economic benefits of using anthill soils in crop production in literature.

Conclusion and Future Prospects

This review has demonstrated that anthill soil are used in various ways in many parts of Africa for agriculture production. They possess great potential for use as fertilizer. Given that the utilization of anthills may not be sustainable at present as most of the farmers who are using the resource in crop production tend to dig up and clear the anthills subsequently affecting the ants in their construction of the nests, it is therefore incumbent that micro dosing technique in anthill soil application for crop production is taken on board as one of the options to conserve the anthills.

The International Centre for Research in Semi-Arid Tropics (ICRISAT) has promoted the efficient utilization of fertilizer at farm level called micro dosing in West, Central and Southern Africa which is about enhancing crop productivity and production through precision fertilizer use efficiency techniques and involves applying small doses of the fertilizers at planting and or after 4 weeks of planting for ensuring that the root and crop development is fast once the seed accesses the nutrients applied in small dosages (ICRISAT, 2009). This technique could be key for enhanced productivity in conservation agriculture given the circumstances under which most of the smallholder farmers find themselves in, with respect to their failure to apply precision agriculture techniques and we believe this technology could be critical in preserving the anthills from extinction which may not be used sustainably.

Further, there is need to conduct other studies which would focus on the factors that could help in the fast development of anthills. Software development for age determination of the anthill for agriculture production would also be useful in knowing the suitability of the anthills for use as fertilizer in crop production across sub-Saharan Africa.

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