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Quantifying the Occurrence and Ameliorating the Properties of Non-responsive Soils by Inorganic and Organic Fertilizers

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Authors' contributions

This work was carried out in collaboration between all authors. Author OFA prepared the review draft. Authors TF and PAN read and corrected the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Conventionally, crop production in sub-Saharan Africa (SSA) depends primarily on natural soil nutrients. Application of inorganic and organic fertilizers is an important way for maximizing agriculture in SSA that targets the full utilization of the agricultural lands for food to feed African population and to obtain surplus produces. However, it has been reported that several areas of agricultural soils fail to respond to application of fertilizers, but the specific reason remain unknown. This review paper aims at exploring techniques that can be used to amend non-responsive soils and evaluate methods of ameliorating such soils through the proper utilization of nutrients supplied from different organic and inorganic sources.

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1. INTRODUCTION

Agriculture is the main source of livelihood and income for two-thirds of Africa's population [1]. Furthermore, it has been reported that crop production should be improved in order to meet the demand of food and industrial resources for a fast growing global and as well as to obtain surplus crops. Current trend around worldwide shows that the normal consumption of food is beyond the crops produced [2]. However, it is documented that the major limitations in organic matter and other key nutrients largely constrain agricultural productivity to realize an optimum yield [3,4]. Also, it has been known that vigorous cultivation without soil replenishment is among the major driver of soil nutrient degradation in SSA. Population pressure and climate change exacerbate the condition of soils in the region. The depleted soil has caused average yields of grain crops to stagnate at around one ton per hectare since the 1960s while fertilizer use across Africa has remained at around 8 kg ha^{-1} of cultivated land over the past 40 years [3].

There are several reasons for the low level for agricultural productivity and these include availability of inputs, infrastructure and policies that affect the high cost and low accessibility of mineral fertilizers [4]. The studies also revealed that the overriding factor is that most smallholder farms have soils depleted of nutrients and soil organic carbon, following years of nutrient removal by crop harvests with minimal return of crop residues or additions of nutrients through mineral fertilizers or organic inputs [5].

All crops, particularly maize uses substantial amounts of nitrogen (N), phosphate (P_2O_5), and potash (K_2O) and relatively small amounts of secondary nutrients and micronutrients [6]. The nutrients taken up by the plants must be supplied either from soil reserves or by adding nutrients. A deficiency of any of these nutrients can reduce yields [7]. Maize production in SSA faces several production constraints which limit productivity. Poor soil fertility, drought, and parasitism all of this can reduce on-farm yield by over 70% even with the use of high-yielding varieties [8]. It was reported that Nitrogen is the nutrient most deficient in the soils and limits maize yield [9].

Despite the great importance, the growth and productivity of crops such as Soybean and Maize has been slow as a result of physical and chemical environments. The continuous intensive cultivation that mines soil organic matter and nutrients has contributed to the steady decline in soil fertility [10,11]. Soil fertility is linked to soil organic matter, whose status depends on inputs such as biomass management and outputs such as mineralization, erosion and leaching [11].

The need for intensification of agriculture in Sub-Saharan Africa (SSA) has recently gained support, because of the growing recognition that enhanced farm productivity in this region [12]. Various literatures indicated the effect of soil chemical and physical barriers that may hinder crop growth and performance [13,14] and ultimately that may negatively affect crop production. There are huge beneficial impacts from amelioration on yield, particularly those associated with such practices like incorporating with deep nutrients or liming materials [14-16]. Nevertheless, it was reported that these positive impacts may vary with the type soil at the particular location [15,17], but there is opportunity that may make studies that can bring positive results from amelioration, and also their effects may last for several seasons. In this review, some important selected soil nutrients (ameliorants) will be discussed to broadly explore the information of their contribution in the productivity of crops, and whether if the yield could be improved and sustained by using good cultural practices such as deep tillage and soil nutrients additions to the unresponsive soils.

2. OCCURRENCE OF NON-RESPONSIVE SOILS IN TANZANIA

The response of soils to management can be classified into three general categories, which are: (1) soils that may potentially respond to the applied fertilizers and (2) soils that show totally very little response to the applied fertilizers due to other constraints besides the nutrients contained in the fertilizer or non-responsive soils. Hence these soils does not respond well to the recommended doses and types of fertilizers, may be due to deficiencies in essential nutrients [12], and (3) soils that receive large amounts of organic inputs each year, where crops respond little to fertilizer as the soils are partly fertile. It has been reported that, soil fertility status varies significantly from one farm to another and from varying landscape levels in Africa particularly for the smallholder farmers, leading to variation in yield and performance of crops as they respond differently to the inorganic and organic nutrient (fertility) amendments [18]. Some challenges do exist to restore agricultural productivity for such non-responsive or degraded soils as they commonly fail to respond to NPK and other fertilizers. Deficiency in essential or major nutrients like nitrogen, potassium and phosphorus has been identified as a major problem affecting crop productivity [19]. Continuous intensive cropping with insufficient or no fertilizer input is a major contributor to progressive decline in these soil nutrients, resulting in poverty for many Tanzanian farmers [20,21]. In this aspect, the existence of the non-responsive soils in Tanzania and their underlying reasons are discussed, as well as their impact when some management practices are done. In this view, the study on fertility improvement are examined where the selected ameliorants application are studied in detail hence to come up with good common approach to improve its productivity. Soil fertility management practices on unresponsive soils in smallholder farmers are rarely studied in detail, and hence necessitate the use of combination of approaches to overcome the problems associated with some soils that fail to respond adequately to the applied nutrients.

3. CHARACTERISTICS OF NON-RESPONSIVE SOILS IN TANZANIA

Cereal crop production levels in Tanzania are reported to be below the optimum level, exemplified by the low yields of 0.905 t ha^{-1} maize and 0.458 t ha^{-1} for beans which are common to smallholder farmers [22]. It is apparent that this trend of low yield levels is associated with poor soil fertility status as well as low nutrient replenishment [23]. The work of [22] indicated that most of Tanzanian cultivated soils are prone to nutrients loss averaging the rate of 27, 9 and 21 kg N, P_2O_5 and K_2O respectively ha^{-1} in a year. It was projected that there will be an increase to 32, 12 and 25 kg N, P_2O_5 and K_2O per ha per annum respectively in the following year especially if the soil management will not be improved. These nutrient losses are generally related to crops that are harvested, the removal of the crop remains or those occurring during soil erosion activities.

It has been reported that major constraints of acrisols (soils found in in Mara, Tabora, Singida, Dodoma, Tanga, Kilimanjaro, Morogoro, Iringa, Mbeya, Ruvuma, Lindi and Mtwara regions) include low level of major and minor plant nutrients, low to moderate capacity to retain applied nutrients and high leaching losses [24]. Other problems include moderate to high fixation rates of phosphorus fertilizers, low pH and high risk of aluminium toxicity [25]. Furthermore, large areas of the Tanzanian highlands are predominated by fine-textured, P-fixing Oxisols also known as Ferralsols [26], hence making this element to become deficient to the crops grown in these regions. Despite the fact that soil fertility status of no-responsive soils in most areas of East Africa is not well known, there is no adequate research conducted to develop a multi-approach of soil fertility amelioration on unresponsive soils and hence this impose a great need for such initiatives.

3.1 Chemical Characteristics of Soils that Cause Unresponsiveness

The important indicators on soil fertility that have been reported mostly are soil pH, soil organic matter (SOM); cation exchange capacity (CEC); exchangeable bases (EB), salinity and sodicity status and the amount of extractable N, P, K, Mg, Ca and Na [4], (Table 1), [27]. These indicators are realistic in predicting plant growth and development. Hence there is a need for regular and systematic evaluation to establish their levels in the soil so as to achieve sustainable productivity in cropping systems. It has been reported that loss of Soil Organic Matter (SOM); nitrogen (N) and phosphorus (P) deficiencies, and soil acidification are considered as major factors limiting plant growth and crop production in sub-Saharan Africa [28].

According to various studies, there are established minimum levels of nutrients required to support crop growth. For example, the critical value for Mg in most crops was proposed to be 2 cmol kg^{-1} [29] and for K is recommended to be 0.20 cmol kg^{-1}, whereas the proposed critical value of Mg in most crops was 2 cmol kg^{-1} [30] and the proposed critical level of Ca for a majority of crops was 5.0 cmol kg^{-1}. Further, it is suggested that soils having total N below 2.0 g kg^{-1} and C.E.C of 6.0-12.0 cmol kg^{-l} are of poor fertility and soil organic carbon (SOM) less than 20.0 g kg^{-1} has been reported to be of poor quality [31]. Further, based on the current soil fertility recommendations, the critical P critical levels of soil P range widely depending upon soil type, extractant used, and sample timing. Published critical levels of soil P include 6 to 12 mg kg^{-1} with a Mehlich-1 extractant [32], 12 mg kg^{-1} with a Mehlich-3 extractant [33], and 14 to 32 mg kg^{-1} with a bicarbonate extractant [34]. On the other hand, for micronutrients, it has been reported that the recommended critical level (DTPA-extractable) in soil for Cu is 0.2 mg kg^{-1}, for Fe to be from 0.3 to 10 mg kg^{-1} and for Mn optimum level ranged from 2.0 to 5.0 mg kg^{-1}, whereas Zn level analyzed in the soil was found to be 0.4-0.6 mg kg^{-1} and values greater than 10-20 mg kg^{-1} were regarded as excess [35,36]. Despite this, little information is known on specific soil chemical characteristics that cause unresponsiveness and if this remain unchecked, their limitation may result in complex mineral elements imbalances, consequent poor soil quality, and decline in soil productivity and crop yields. In this regard, more studies are required on the specific and complex soil chemical limiting factors.

Table 1. Soil characteristics in two selected nonresponsive soils from sisal farms in Tanga, Tanzania

Soil depth	Bamba estate	Kwamdulu estate
	0-20	0-20
Clay (%)	35	52
Silt (%)	6	8
Sand (%)	59	40
pH(water)1:25	5	4.6
pH(Kcl)1:2.5	3.9	4
Organic C (%)	1.4	1.8
Total N (%)	0.09	Na
Available P (Bray1) mg kg^{-1}	3	3
CEC (NH4O Ac pH 7) mmol kg^{-1}	76	89
Ca mmol$_c$kg^{-1}	16	7
Mg mmolkg^{-1}	5	5
K mmolkg^{1}	1	1
Base saturation (%)	29	14
Al mmolkg^{-1}	11	8
Al saturation (% CEC)	29	37

Physical and chemical properties of selected horizons of Rhodic Ferralsols [37].

3.2 Biological Characteristics of Soils that are Responsible for the Soil Responsiveness

The importance of soil micro-organisms in nutrient cycling and maintenance of soil physical properties is well appreciated [38]. In particular, soil micro-organisms are responsible for key ecosystem functions such as decomposition of organic matter and mineralization and cycling of nutrients, humus synthesis, and aggregate stabilization, nitrogen fixation and the biological control of soil-borne pests and diseases [38-40]. It has been reported that improved soil organic matter contents through organic amendments under Integrated Soil Fertility Management (ISFM) practices enhance nutrient availability, support diverse soil biota, and improve soil aggregation and crop production [12,41]. It has been established that an acre of living topsoil contains approximately 408 kg of earthworms, 1088 kg of fungi, 680 kg of bacteria, 60 kg of protozoa, 403 kg of arthropods and algae, and even small mammals in some cases [42]. Bacteria and fungi are important microfauna in soil that live on organic matter or on living plants. Most bacteria and fungi perform useful functions such as the decomposition of plant residues, release of nutrients, and formation of aggregates. Some bacteria such as rhizobia provide nitrogen to plants [43]. Some fungi live in symbiosis with plant roots, facilitating the uptake of immobile nutrients such as phosphorus and potassium [44-46]. Studies have demonstrated that technologies such as green-manuring (biomass transfer) with shrubs or trees or crop residues increase crop yields [47,48]. These organic residues play an important role in soil fertility management through their short term effects on nutrient supply and longer term contribution to soil organic matter (SOM). Thus, the addition of organic materials to agricultural soil (with or without chemical fertilizers) is important for replenishing the annual C losses and for improving both the biological and chemical properties of the soils [49]. Although the effect of chemical and physical properties on crop response is well explored and known, a direct link between biological properties and crop response is not adequately established in nonresponsive soils of East Africa. Hence, better exploitation of soil-plant-microbe interactions for plant nutrition in non-responsive soils is crucial for enhanced agricultural productivity.

3.3 Physical Characteristics of Soils that Cause Unresponsiveness

Soil texture and structure exerts important influences on the edaphic conditions and hence crop production [5]. Soil texture is a basic soil property, which influences infiltration and moisture retention [50], and thus the availability of water and nutrients to the plant. It is well established that sandy soils cannot support good plant growth and this is attributed in part to poor moisture retention and the leaching of nutrients from the rooting zone [51]. Moreover, [52] have reported that most sandy soils are nonresponsive to nutrient additions. Sandy soils are easily and freely draining, warm in hot days, but susceptible to lack of water in dry periods while clay soils are sticky and plastic when wet and prone to drainage problems, but hard when dry. On the other hand, loams that comprise sand, silt and clay sized particles generally makes good agricultural soils. Silts are also good soils for cultivation but it is associated to structural problems like [16]. It was pointed out that aeration and impedance to root growth through soil compaction are among the dominant factors affecting plant growth [53]. Soil compaction destroys the quality of the soil because it restricts rooting depth and decreases pore size. Among the effects of soil compaction are water-filled pores that become less able to absorb water, increasing runoff and hence erosion [54].

Cropping pattern has immense effect on soil physical and chemical properties and thereby on crop productivity. For example, soil fertility may often change in response to land use, cropping patterns and land management practices [55,56]. Intensive cropping promotes high levels of nutrient extraction from soils without natural replenishment [26]. In addition, the repeated use of inappropriate tillage practices in soils with slopes, and the high intensity of precipitation are key factors for the occurrence of the soil erosion and degradation processes that may reduce the quality of the soil in terms of physical as well as chemical fertility status [57].

Therefore, improvements targeted at such limiting physical conditions of the non-responsive soils can make it possible to optimize crop production in diverse range of farming communities such as those found in East Africa.

4. IMPORTANCE OF SOIL NUTRIENT AMELIORATION TO NON-RESPONSIVE SOILS

It is well documented that the soils in Sub Saharan Africa are inherently infertile as they have been used for agricultural production for many decades with little or no addition of nutrient resources, leading to declining soil fertility [25,58]. Therefore, enriching such soils through the addition of agricultural inputs is key to tackling hunger in the continent [59]. This can be achieved through developing and disseminating appropriate soil management recommendations, detailed up-to-date and spatially explicit information about the condition and trend of soil fertility and health [60,61].

Several studies on advantages of different amelioration practices in enhancing crop yields have been reported [62-66]. For example, [60] reported that restoration of soil fertility through balanced fertilization and organic matter additions was necessary to achieve high crop productivity. Studies conducted in areas where crop growth was limited by the presence of poor physical structure such as hard pan were ameliorated through ripping and addition of nutrients such as gypsum and resulted into improved plant [15,66]. Other studies conducted on the depleted soils across Sub Saharan Africa, it was also revealed that applying N and P increased yields significantly [18]. Similarly, addition of organic soil amendments in poor soils in various forms [18,23,26,64] has increased the retention of nutrients and water, and hence created a better synchrony between the soil nutrients. According to [67] a well balanced soil (with Ca/Mg, Ca/K, and Mg/K ratios) contain the important components that enhance proper plant growth and hence yield and plant health sustenance at an adequate manner. Thus, plants grown in a soil whose cations exchange complex is not balanced, and does not contain the specified cation ratios, may lead to reduced crop yield [68]. The five most abundant exchangeable cations in the soil are calcium, magnesium, potassium, sodium and aluminium. It was reported that cations are held by negatively charged particles of clay and humus called colloids [69]. Cation Exchange Capacity (CEC) varies according to the type of soil, where as sandy soils rely heavily on the high CEC of organic matter for the retention of mineral elements as the OM has the highest CEC value, while the clay has a great capacity to attract and hold cations because of its chemical structure [70]. Cation Echange Capacity can be improved in weathered soils by adding lime and raising the pH [43] or by adding organic matter which is the most effective way of improving the CEC of the soil [71]. It was reprted that CEC of about 15 meq/100 g^{-1} has a relatively high capacity to hold cations, such as Ca^{+2}, Mg^{+2}, K^{+}, NH^{+}, Cu^{+2}, Fe^{+2}, Mn^{+2}, and Ni^{+2}[72]. Soils that are high in clay generally have higher CEC values, although the type of clay can substantially affect CEC [70]. Inadequate information is available in SSA on the importance of soil nutrient amelioration to non-responsive soils and specifically targeting spatial variability's within and between farms in different farming systems found in Africa.

5. STRATEGIES TO IMPROVE NON-RESPONSIVE SOILS USING VARIOUS FERTILIZERS: NPK

It is well established that in soils with exhausted fertility status, strategic fertilizer application with incorporation of crop residues in long period of time would be necessary to improve attainable yields over considerable period of time. This may be accompanied by alternative organic nutrient sources including animal manures and compost, and these may also play an important role in replenishing soil fertility and physical traits in Africa where inorganic fertilizers are mostly not affordable particularly to small holder farmers [73,28]. Strategic use of fertilizer to variable soil fertility conditions may combine incorporating crop residues, animal manures, and crop rotation particularly those involving leguminous crops are crucial for beneficial fertilizer use in smallholder farming systems in SSA [74-76]. In Tanzania, NPK are amongst the major limiting nutrients in the soils, in that order [77]. Nitrogen fertilizers make up the bulk of imports, where 61 percent of all fertilizers are imported [78]. Among the specific types of fertilizer imported, urea constitutes the largest portion. Nitrogen, Phosphorous and Potassium (NPK) blends make the second most common type of fertilizer imported, with 21 percent of fertilizer imports. Diammonium Phosphate (DAP) is the principal phosphate fertilizer, accounting for almost 90 percent of all such fertilizers and 8.5 percent of all fertilizer imports, while Minjingu Rock Phosphate is only P fertilizer manufactured in Tanzania [77]. Therefore, in order to attain sustainable crop production, studies on optimum fertilizer application (NPK) to increase the crop production in unresponsive soils are essential.

5.1 Improving Non-responsive Soils Fertility by Proper Application of N

All crops require essential nutrient elements in order to carry out various physiological processes. The proposed the critical level of nitrogen in the soil for most crops in Tanzania as 2.0 g kg^{-1} [79]. A study by [80] indicated that the percentage total nitrogen in the soils ranged from 0.03 to 0.06 and these values were rated as very low. Any soil with N values below the critical levels provided above may be subjected to lower yield levels and hence the amelioration of the problem through fertilization (with Urea, sulphate of Ammonia, Calcium ammonium Nitrate, and Farm Yard Manure) is of paramount importance. All of non-responsive soils have N levels far below the critical level and hence meeting N requirements through various inorganic and organic sources is recommended.

Numbers of studies have reported optimum fertilizer rates and means of their application in deficient environments [81-83]. The study by [84] reported that optimal fertilizer requirements depend on the productive potential of the cultivar, the previous cropping history and the general fertility of the fields used. In general, the fertilizer requirement for maize and most of cereal crops in tropical conditions ranges about 100-120 kg N ha^{-1}. Generally, in order to attain an optimum crop growth and development, and hence yield, it is required to supply an adequate amount of nitrogen in form of organic or inorganic sources.

According to various studies, nitrogen fertilization plays a significant role in improving soil fertility and increasing crop production [85-87]. For instance, N fertilization in maize increased the grain yield by between 43- 68 percent [88], its biomass (biological yield) between 25-42 percent [89] and boosted soil N stock by a range of 18-34 percent [85,86]. Urea ($NH_2CO\ NH_2$) is the most used fertilizer nitrogen in Africa and contains about 46% N. When urea is applied as a top dressing fertilizer, it undergoes several processes before the crop can take it up. Such processes include hydrolysis to form ammonium carbonate which is further oxidized to form nitrates [82]. During hydrolysis, ammonia gas may also be generated and lost into the air and this takes place when the urea is not fully incorporated into the soil. Therefore, due to this processes, most crops do not respond quickly to fertilizers applications and hence need proper management and timing during application [90].

It is therefore important to replenish unresponsive soils with adequate amount of N that will restore fertility by using nitrogenous fertilizers especially in areas where this nutrient has been depleted in order to attain the optimum yields.

5.2 Improving Non-responsive Soil Fertility by Application of P

Phosphorus (P) is second to nitrogen as an essential mineral fertilizer for crop production [91]. Many non-responsive soils are inherently poor in available phosphorus content, and hence proper management will contribute significantly to sustainable crop production. Studies have indicated that the sufficient P levels by Bray 1 method is above 15.0 mg kg^{-1} [89]. It was revealed that the plant available phosphorus (Olsen's P) ranging from 14.24 to 17.16 mg P kg^{-1} soil rated as medium [80].

In non-responsive soils where yield may be limited because of inherently low P contents, application of P fertilizers is the only way to enhance soil available P status to sustain reasonable plant development and finally achieving higher crop yield [91,92]. Since P is a non- renewable resource, frequent applications are necessary to maintain P levels optimally to sustain crop yields. This can only be achieved by replacing the removed P from the crop harvest through the application of organic and inorganic fertilizers [93].

In summary, steady supply of P fertilizers through inorganic sources, incorporation of plant residues and application of farm yard manures can enhance P supply in the soils and contribute to sustainable crop production in areas such as those involving non-responsive soils.

5.3 Improving Non-responsive Soils Fertility by Addition of K

To achieve or maintain maximal crop yields, supplemental K fertilization is often required, particularly on soils testing low for available soil K to provide enough K to meet crop needs [94]. It is established that the critical level below which yield are severely depressed is less than 0.4 centimole per kilogram, (cmol kg^{-1}) [95]. It has been reported that integrating K^+ in soils has a positive roles in physiological processes, such as those lead to profound effects on crop growth and development [96,97].

Many researchers have reported crop yield increases in response to K fertilization [97-99]. For example, it was reported that maize yield increase and reduced lodging with K fertilization [94,100].

Also an increased ear size with K fertilization, may also contribute to the grain yield increases in maize [94,98]. Whereas the study [98] reported K fertilization increased the stover dry matter at maturity for maize, [101] found that K fertilization did not improve leaf weight or stalk weight at silking stage in maize. Increased stalk weight or stover weight in response to K fertilization may help explain the reduced stalk lodging observed with K fertilization [94].

The presence of K in soil solution is vital for plant growth and development because K is known to be an enzyme activator that promotes metabolism and also assists in regulating the plant's use of water by controlling the opening and closing of leaf stomata's of crops such as the cereals [102]. On the other hand K promotes the translocation of photosythates (sugars) for plant growth or storage in fruits or roots. Potassium has been shown to improve disease resistance in plants, improve the size of grains and seeds of maize, sorghum, and legumes such as soybeans [94], and improve the quality of fruits and vegetables such as eggplant, tomatoes and carrots [103,104]. Plants generally absorb the majority of their potassium at an earlier growth stage. Experiments on potassium uptake by maize showed that 70-80 percent was absorbed by silking time, and 100 percent was absorbed three to four weeks after silking [105].

In agricultural systems, K supply is normally delivered in the form of inorganic fertilizers such as potassium chloride, potassium sulphate, potassium magnesium sulphate and potassium nitrate and organic forms such as compost, wood ash and farm yard manure. Although considerable data exist on the response of K on plant growth and development, little evidence is available on the effects of K on non-responsive soils such as those found in East Africa, hence need for further studies on effects of K on the performance of crop plants grown in the non-responsive soils.

5.4 Contribution of N_2 Fixation in Improving Non-responsive Soils

Biological nitrogen fixation (BNF) can play an essential role in crop establishment and yield, since no N fertilizer is applied and it fulfils most of plants need for nitrogen [106,107]. Study by [108] observed that biological N_2 fixation can contribute as much as 112 kg N ha^{-1} in a season. Generally, the response to Rhizobial inoculation in soils is controlled by the population of indigenous strains and the environmental factors. Therefore, understanding these limitations in non-responsive soils is important in realizing useful results.

Research findings have revealed that *Rhizobium* inoculation of legumes during sowing of seeds and the subsequent process could have positive effects on N_2 fixation, plant growth, uptake of macro and micronutrients and finally enhancing crop yields [109,110]. For example, it was revealed that there was a significant increase in the uptake of macro and micronutrients following inoculation with *Bradyrhizobium*in in common beans, cowpeas and soybeans [74,75,111].

Because the *Rhizobia* depends on the host plant for the energy required in nitrogen fixation, therefore anything that limits normal plant growth and development will affect nitrogen fixation. Symbiotic nitrogen fixation requires the balanced soil nutrients, oxygen, so well-aerated soils with good host plant growth provide the optimum environment [112]. Poorly drained, water-logged soils are detrimental to host plant root growth and to the *Rhizobia* bacteria. *Rhizobia* are adversely affected by very acid soils, and soil pH should be properly monitored and maintained for optimum legume production [113].

However, little attention has been paid to study the role of fixation of N_2 specifically on non-responsive soils in SSA. Hence, a need for detailed studies to tap into this cheaper alternative source of nitrogen for legumes and other companion crops.

5.5 Effects of Supplying FYM to Non-responsive Soils

According to [114] a judicious fertilization of soils with Farm Yard Manure (FYM) was reported to reduce fertilizer requirement, increase soil fertility and then crop production. It is further reported that application of farmyard manure (FYM) with inorganic nutrients may contribute to soil fertility improvement. When FYM is applied at recommended amounts, they may play an important role in replenishing the macro and micro nutrients that are deficient in soils, and in turn contributes to yield increase [115]. Applications of FYM is not only complementary but also bring synergistic effects in soils such as increasing organic inputs and also have beneficial effects beyond their nutrient content [116]. It was reported that organic materials improved soil moisture storage, decrease soil erosion and then minimize leaching losses of nutrients especially N, contribute to P availability, stimulate soil biological activities [117], (Table 2), enhance chelation and bioavailability of micronutrient elements to both plants and soil microorganisms [118,119].

It has been well established that about 84 and 78% of maize grain yield was produced in 2003 and 2004 in degraded soil incorporated with FYMbiomass respectively [120].

Other study showed that incorporation of FYM contributed 65 to 71% of the total N content to a succeeding maize crop (equivalent of 90 to 125 kg N ha^{-1}) and this suggests that the contents supplied in these organic manures has a tendency of releasing its nutrients slowly and can last in the soil for several cropping seasons [121].

Although FYM has been in use for long time, there is a need to explore more information on its effects when applied to non-responsive soils to ensure adequate nutrient supply and benefits from other aspects.

5.6 Supplying Selected Micro Nutrients (Zn, Mo and Bo) to Non-responsive Soils

It is well known that although micronutrients are required in relatively smaller quantities for plant growth, they are important to enhance crops in accomplishing their growth and production cycles. Moreover, it is well established that if one of essential element is not available in the soil or not in adequate amount or balance with other nutrients, plant growth may be limited or even may lead to complete crop inhibition [95]. Deficiencies of micronutrients in fields can be replenished with fertilizers that contain one or combination of these elements. Micronutrients often act as cofactors in enzyme systems and play an important role in reduction reactions, and in addition to having several other vital functions in plants. It is further reported that, micronutrients are involved in the key physiological processes of plants including the photosynthesis and respiration activities [95,96]. Deficiency of these nutrients may severely restrict such vital physiological processes thus limiting growth and yield gain in most of crops. For example, boron (B) deficiency can lead to yield reduction considerably in wheat and lentil crops [122,123], while in rice and maize zinc (Zn) deficiency can be a major hidden yield-limiting feature in most of the soils [124].

Therefore, although they are required in small quantities, these trace elements are important to be applied in the soils, as they are continuously being taken up by plants without being replenished [125]. While numbers of studies have targeted the relationship of macronutrients and plants growth, there is limited information for the role trace elements on non-responsive soils that might cause their deficiency and lead to poor plant nutrition, growth and production and hence need for more studies in this aspect.

5.7 Application of Zinc to Non-responsive Soils

It has been reported that significant zinc deficiencies occur in soils for different regions, and especially in sub-Saharan Africa [126]. Zinc is essential element for the proper plant growth and it has a role in important physiological processes such as the reproduction activities in most of plants. It is well documented that when the supply of zinc is inadequate in soils, crop yields are reduced and the qualities of crop products are impaired [19,127-129]. Zinc is reported to have an important key role(s) in plants particularly those related to structural constituent or regulatory co-factor of different enzymes that regulates many important biochemical pathways [130]. Losses of maize yield of 40% or more in many zinc deficient soils have a major economic impact on the farmer due to the reduced income as a result of lost yield [131]. Poor growth and small brown spots on leaves are common symptoms in rice and maize plants grown on Zn deficient soils [132].

According to studies done by [133-135], the critical level of HCl-extractable Zn and DTPA extractable Zn in the soil ranged from 0.2 to 1.0 $mg{\cdot}kg^{-1}$ and hence in this respect it is inadequate for plant growth.

Studies on the effect of zinc fertilization on growth and yield of many plants such as alfalfa, wheat, maize, barley and potato have been reported increased yield with zinc application [136-138]. Also zinc fertilization of maize and alfalfa increased herbage, hay, dry matter crude protein yields and zinc concentration of alfalfa [136]. However, there are limited studies in SSA that have reported the effect of Zn on improving crop productivity in the non-responsive soils. Hence, there is necessity for detailed studies on the effects of Zn on yield of commonly grown crops such as maize and soybean.

5.8 Application of Boron to Non-responsive Soils

Boron (B) is required for all plant to enhance growth [139]. It has been reported that adequate B nutrition is critical for high yields and quality of crops [140]. Deficiencies of B may result in many anatomical, biochemical and physiological changes in most crops [141,142]. It is well documented that Boron deficiency is among the factors that lead to low crop yield, due to interferences of activities involving B in the metabolism of food reserves such as carbohydrates and protein, and cell structural components synthesis [143,144]. For most of crops, B deficiency symptoms are related to interference in flowering and fruiting processes [145] and hence ultimately poor yields, which may be having poor grain or fruit qualities [146]. Also it has been reported that B deficiency symptoms vary among different species of crops. For instance, in soybean, B deficiency may cause empty or hollow heart seeds, while in black gram no symptoms of B deficiency may be visible in seeds, yet grain yield may be reduced considerably [147]. It was documented that the critical limit of B on maize was below 95 ppm [148]. Studies have revealed that Boron deficiency occurring in more than 30% of agricultural soils is even more widespread in SSA, affecting approximately 50% of the soils [126,149]. In order to attain optimum yields for any crop, nutrient stress should effectively be minimized. Therefore, a further investigation on supplying Boron in non-responsive soils is important to address the problems of such limiting selected micronutrients in tropical *soils.*

Table 2. Effects of FYM on improvement of the soil properties

Treatment	Organic matter	Soil bulk density	Available water holding capacity of soil
FYM	31.841*	0.487*	2332.168*
N	1.266 ns	0.002 ns	24.78 ns
P	0.477 ns	0.004 ns	4.121 ns
FYM × N	1.199 ns	0.003 ns	9.402 ns

** indicates statistical significance at P ≤ 0.05 and ns indicates non statistical significance.*
This trend in table shows positive effects of the organic manures on the soil properties [150]

5.9 Application of Molybdenum to Non-responsive Soils

Studies indicate that, Mo is an important element because it is responsible in nitrogen nutrition as it helps plants to use nitrates that are absorbed from the soil [151,152]. It is well established that legumes and other plants with no or low access to Mo can lead to poor growth, particularly, those field crops that are supplied with inadequate amounts of Mo. In such cases, nitrates tend to fail to be assimilated into protein products. In legumes, Mo plays the crucial role to help root nodule bacteria to fix atmospheric N and convert it into a usable form [153]. By counting all this merits of Mo, simple techniques such as seed coating may play an effective role in improving crop performance. However, some reports indicate that Mo can have toxic effects on bacterial strains used for inoculation in seeds of legumes coated with this element. Therefore, it is important that the efficacy of Mo seed coating with bacterial strains to be evaluated before using Mo seed coating.

Also, the study indicated that there was a significant response in yield and other yield components of *P. vulgaris L.* supplied with Mo at 0, 6 and 12 g kg-1 of seeds [42]. Further it was reported that significant interactive effect was between *Rhizobium* inoculation and the Mo on the number of seeds pod^{-1}, seed weight, and grain yield [111,154]. *Rhizobium* inoculated treatments in combination with the highest rate of Mo gave good results suggesting that significant additive results by mixing the Mo and *Rhizobium* and this corroborates with other studies that stated that Mo has a crucial role in N_2 fixation [104].

Currently there is limited research in SSA focusing on the position of Mo in non-responsive soils and hence need for detailed studies to establish the usefulness of this micronutrient in supporting plant growth in heterogeneous soil types found in Africa.

6. THE NEED FOR USE OF COMBINATION OF SOIL AMELIORANT'S TO IMPROVE SOIL RESPONSIVENESS

It is well established that crop yields can only be produced at an adequate or optimum levels, when the proper management of the soil fertility are observed and implemented in Africa [26]. Proper soil fertility replenishment in Africa requires utilization of both inorganic fertilizers and organic manures at the desirable levels [40]. In order to make pace in this, it is desirable that the sufficient levels of nutrients to be applied for the purpose of making crops to have more yields and at the desired level, thus this can enhance maximum production and hence creating the desirable profit to the farmers [4], (Table 3).

It was reported that the combined application of boron with molybdenum or zinc resulted in higher yields for some crops such as rapeseed and other grain crops yield and quality than the application of boron without molybdenum or zinc alone, and the seed yield of the B+Mo+Zn treatment was the highest in all treatments [155].

Other studies have revealed positive interactions between some inorganic minerals particularly zinc and organic manure (FYM) in cereal crops. That can be contributed by synergistic activity of the two nutrient sources. For example, the study by [156] documented an increased Zn uptake, as well as grain and stover yields with the use of 120 kg N, 10 t FYM, and 5 kg Zn ha^{-1} in the study involving maize. Further, it was also observed that combined use of 5 tons animal manure and 16 kg $ZnSO_4$ ha^{-1} resulted in higher maize yield components specifically the stems and seed yields. This effect was associated with more uptake of the Zn that resulted in increased yields. Similarly, the use of FYM had capacity to improve the uptake of Zn and other elements such as NPK uptake in plants hence enhancing positively the fertility of soils [157].

Table 3. Effects of combination of nutrient management on maize yield, and yield components

Treatment	plant height cm	grain yield t ha^{-1}	Biological yield t ha^{-1}	harvest index %	Oil contents %
Control	102.5c	0.72c	2.7d	24.29c	3.3c
Recommended dose offertilizer (200-120-125 kg NPK ha^{-1})	02.5c	0.72c	26.7c	24.29c	3.3c
Single spray of multnutrients (1.2 L ha^{-1})	154.9b	4.13b	13.75ab	30.44b	4.6b
Recommended dose NPK and 1 spray multi-nutrients	176.9a	5.78a	15.73a	36.63a	4.96ab

Means followed by similar letter(s) in a column are not significantly different. Source: [158]

Results from the research showed that there are dual mutual effects of phosphorous and zinc. It was indicated that the minimum leaf phosphorous content (0.262 mg kg^{-1}) was obtained where there was zinc, but the maximum leaf phosphorous content (0.369 mg kg^{-1}) was achieved at the application where no zinc was applied [159]. This shows that P and Zn had antagonistic effects. Similar results were also reported by [66]. A study by [160] found that maize production increased considerably by applying N, P, and Cu at rates of 120, 80, and 10 kg ha^{-1}, respectively. Similarly, it was reported that the highest grain yield (5.84 t ha^{-1}) was produced when all micronutrients (B, S, Mn, Mo and Zn) were applied in combination with NPK fertilizers at 120:60:40 kg ha^{-1} followed by those which did not receive molybdenum (Mo) at the same level of fertilizers (5.26 kg ha^{-1}) [161].

Integrated use of plant nutrients aim at combined use of inorganic and organic sources of plant nutrients to improve efficiency of applied nutrients, reduce environmental hazards and improve crop productivity [162,163]. It was also reported that the shoot and root dry matter of maize increased with increasing rate of the applied fertilizers [7]. Integrated use of organic manures and mineral fertilizer is reported to reduce the cost and amount of fertilizer required by crops [28]. Also, other study [164] reported that proper soil fertility management and sustainable agriculture can be achieved with the use of both mineral fertilizer and organic manure. It was further suggested that integrated nutrient management through combined use of organic materials and chemical fertilizers can be an effective approach to combat nutrient depletion, increase yield and promote sustainable crop productivity [165].

Study by [166] showed that when the required essential elements were applied at right time on sandy soils, the dry weight of maize was highest (5.18 t ha^{-1}) for the NPK treatment, followed by the K treatment, P treatment, N treatment, and lowest (2.54 t ha^{-1}) for the control treatment. The study revealed that dry weight for the NPK treatment was significantly higher than those for the N, P and control treatments. It was further found that, the dry weight of maize for the manure treatment was higher than that of the NPK treatment, suggesting the positive effect of organic matter application in addition to inorganic fertilizer application. In separate studies involving legumes, foliar application of nitrogen, phosphorous, potassium, and sulphur at seed filling stage [167] reported greater influence on the growth and yield of soybean. In another study involving soybean, highest seed yield of 4.21 t ha^{-1} was recorded in a combination involving cattle manure with rock phosphate at the rate of 50 kg ha^{-1} and control treatment gave 4.10 t ha^{-1} [168].

This trend indicates that the use of combined treatments of major elements such as NPK; trace elements such as Zn, Bo and Mo as well as organic manures that are readily available particularly FYM may enhance replenishment of lacking nutrients in the soil and ultimately enhance crop growth and productivity and reward farmers efforts on using inputs.

7. CONCLUSION

In conclusion, to overcome soil constraints this can be done by adapting techniques that will discover the limiting nutrients in the soil. This is important approach to maximize yield in SSA, where particularly the non-responsiveness of the soils is a common problem. The adverse soil conditions that contribute to these problems should be explored well to enhance crop productivity as ultimately the soils will respond well to the applied nutrients. Mutual scientific efforts by optimizing specific limiting nutrient use and nutrient cycling to minimize external inputs and maximize their use efficiency is a suitable approach to enhance more crop productivity.

Therefore, knowledge of soil nutrient status and the specific constraints is necessary to plan for the soil fertility management options in non-responsive soils. Therefore, it is necessary to undertake detailed analysis of soil fertility by considering spatial variability between and within sites. Amelioration of the soil fertility constraints can be achieved by supplying appropriate doses of macro and micro nutrients through organic and inorganic fertilizer formulations.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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