IDENTIFYING INNOVATIVE COST-EFFECTIVE TECHNOLOGIES TO MANAGE SOIL ACIDITY IN SIERRA LEONE

A research project proposal
submitted to

NATIONAL SCIENCE TECHNOLOGY AND INNOVATION COUNCIL (NSTIC)
Ministry of Technical and Higher Education
Government of Sierra Leone

Under the
"CALL FOR FULL PROPOSALS TO FUND A PROJECT THAT PROMOTES FOOD SECURITY AND MODERN AGRICULTURE"

1. Name and Address of the Organization

Eastern Technical University of Sierra Leone
Combema Road, Kenema, Sierra Leone.

2. Duration of the Project

2 Years (2024 – 2025)

3. Total Cost of Project

USD 44,810 (Forty-Four Thousand, Eight Hundred and Ten US Dollars)

4. Name of the key person, who will be the In-Charge of implementation of the project

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Technical Staff

Name and Qualification	Position	Task
Dr. Denis M.K. Amara PhD. Soil Science Soil resource inventory and climate change modelling	Team Leader (Principal Investigator)	The Team Leader and Lead Researcher will bear principal responsibility for the delivery of the project. He will lead in all aspect of project implementation, negotiations (if any) and coordination with sponsors and other relevant stakeholders. He will provide overall leadership and guidance for data quality and results delivery.
Mr. Emmanuel Alpha MSc. and MPhil. Crop Science	Co-Investigator I (Qualitative Data Analysist)	As Co-Investigator I, he will be responsible for the design and development of tools and training materials, support data transcription, data processing, analysis and drafting of qualitative report component. Support the Team Leader in designing training programme for students, farmers, and other stakeholders.
Mr. Osman Sidie Vonu MSc Soil Science	Co-Investigator II (System Agronomist)	As Co-Investigator II, he will support the Team Leader in setting-up crop cutting experiments, monitoring, data collection, analysis and interpretation of results. He will assist in the preparation of technical reports, workshop outlines and reports

OCTOBER, 2023

1. EXECUTIVE SUMMARY

Seventy-five percent of Sierra Leone's total land area comprising of 80% upland and 20% lowland, is potentially arable. However, the country faces a wide range of soil health and fertility-related issues including soil erosion, soil acidification, depletion of organic matter, deterioration of soil biophysical properties, and inherent low fertility. Among these, soil acidity and associated low nutrient are major constraints to improving crop productivity. There is a wide gap between potential and actual yield of major crops due to soil acidity and associated low nutrient reserves. Every year, farmers receive fertilizers from the Ministry of Agriculture and Food Security (MAFS) to boost their soil nutrient reserve. While this is good, it should be noted that acidic soils are unresponsive to applied inorganic fertilizers and without amendments, such effort leads to wastage of resources. Hence, developing effective and efficient acid soil management practices that area suitable for Sierra Leone situation is indispensable for enhancing crop productivity and sustainable yield. This project seeks to characterize soil acidity, diagnose nutrient deficiencies, design and test innovative cost-effective soil acidity management technologies to improve crop productivity, and soil health and fertility.

The project is designed to generate both qualitative and quantitative data on soil health and fertility using conventional as well as remote sensing and GIS techniques. Prior to field work, desk survey and GIS work will commence followed by a reconnaissance survey. Soil samples will be will be collected and analysed, and the results will be interpreted to provide guidelines for crop adaptation to acid soil conditions in Sierra Leone.

The experiment will be conducted in two phases; namely, a greenhouse phase that would involve pot experiment and a field phase that would be designed and managed by the project technical staffs and MSc student. Soil samples will be collected at both phases and analyzed for soil acidity, Al toxicity, and nutrient status. Agronomic data will be correlated with soil data to evaluate the impact of soil acidity on nutrient availability and crop growth. Soil acidity, Al toxicity and soil fertility atlases will be prepared to explain their spatial variability. Based on the crop cutting experiments, innovative and cost-effective ways of managing soil acidity in Sierra Leone will be identified and recommended. Post-field work will involve capacity building of farmers, students and subject matter specialists in MAFS to address soil fertility problems related to soil acidity and Al toxicity.

2. BACKGROUND AND RATIONALE

Soil acidity and associated low nutrients are topical issues and major constraints to improving crop productivity in Sierra Leone, accounting for about 75% of the total arable land area and is widely distributed across the five main agroecologies causing about 50% yield loss (SSL, 2017). Soils of Sierra Leone are generally low activity clay soils, highly weathered and acidic Ultisols and Oxisols (Odell *et al*. 1974, Sutton *et al*., 1989), low in available nutrients and crop yields. These soils are quite strongly acidic, having an exchange complex dominated by exchangeable aluminium with values of 2-6 cmol kg^{-1} and pH in water of less than 4.8 not being uncommon. The severity varies, but reports from MAFS indicate that about 60% of smallholders grow crops on soils with pH below 5.5, though the optimum pH requirement for plant growth is 6.5. At such low pH, nutrients become unavailable for plant's use, plant availability of nutrients diminishes, and some nutrients e.g., aluminum may become toxic. These frequently result in plant nutrient deficiencies, low fertilizer use efficiency, poor yields, low farmer income and food insecurity. The prevalent high rainfall regime and low cation retention capacity, favour high leaching losses of basic cations (nutrients) and development of soil acidity. For several decades now, farmers have struggled with low yield leading to poor income and low farming turn out. For instance, the average yield of rice (the staple food) is 1.25, 2.50. 2.25, 2.50, and 1.50 tonnes/ha in uplands, inland valley swamps (IVS), mangroves, riverine grasslands, and bolilands, respectively. These figures are far below those of other sub-regional countries in Africa.

Research on soil acidity and its control has been going on in Sierra Leone for several years, but at a very low scale. Odell *et al* (1974) first reported the presence of strongly acidic soils with pH in top soils ranging from 3.03 to 5.30 with a mean of about 4.58 and exchangeable aluminium between 0.31-6.27cmol kg^{-1} of soil with a mean of 2.01 cmol kg^{-1}. Rhodes (1984) underscored the importance of exchangeable Al in soil acidity within the pH range of 4 to 5, noting that exchangeable Al was the dominant component of 1M KCl exchangeable acidity (Al+H) in top and subsoils of the Momenga series in the Njala University area of Sierra Leone. National figures reported for yield indicate a wide gap between potential and actual yield due to soil acidity and associated low nutrient reserves. Limited trials have been conducted at various locations, aimed at raising soil pH and ameliorating the negative effects of soil acidity using imported calcium carbonate, basic slag and locally available ground oyster shell. Lime application rates between 0.5 to 4.0 tons ha^{-1} proved effective to reduce aluminum saturation and raise soil pH to 5.5. However, the need for cost benefit analysis of liming materials remains indispensable. While small-scale farmers have not adopted liming on the large scale, commercial farmers to some extents do sometimes apply lime to high value crops such as rice and groundnut. Through this, the Faculty of Development Agriculture and Natural Resource Management at the Eastern Technical University of Sierra Leone (ETU-SL) has been providing consultancy support to several agro-industrial companies in the Eastern region of the country. In addition, we have used organic amendments such as chicken manure, palm kernel cake, biochar, prunnings and residues from N-fixing trees such as gliricidia to counter the effects of soil acidity at the experimental farm of Njala University. Results from these experiments indicated the possibility of lowering Al^{3+} concentration, and increasing soil pH and soil nutrient levels through the use of these materials, though these results have not been widely tested or promoted.

To counter the low crop yields, MAFS has promoted the use of NPK fertilizers among farmers for decades through fertilizer subsidies, although its adoption on a national scale is still very low. At present, correction of soil acidity by liming is not popular among small-scale farmers, but few commercial agro-investors are doing so for high value crops like sugar cane and turmeric. Hence, a good soil fertility management involving the management of soil acidity and nutrient supply is crucial for boosting agricultural productivity on sustainable basis. On this note, this project is proposed to characterize soil acidity, assess soil fertility, design and test innovative cost-effective soil acidity management technologies to improve soil health and fertility, and crop productivity. The project will map soil acidity, identify nutrient deficiencies, evaluate the impact of soil acidity on nutrient availability, identify best management practices for soil acidity, and enhance the capacity of farmers and subject matter specialists in MAFS to address soil acidity related problems. This will enable farmers to understand soil pH variability across their lands, identify acid soils and assess the best ways to treat them.

3. PROJECT GOAL AND SPECIFIC OBJECTIVES

3.1. Development Goal

The development goal is to characterize and map soil acidity and Al toxicity, diagnose nutrient deficiencies, design and test innovative cost-effective soil acidity management technologies to improve crop productivity, and soil health and fertility.

3.2. Specific Objectives

The specific objectives of this project are:

1. To characterize and map soil acidity and Al toxicity and prepare a soil acidity atlas for Sierra Leone.
2. To assess soil fertility status, identify major nutrient deficiencies and evaluate the impact of soil acidity on nutrient availability.
3. To identify best management practices for managing soil acidity based on soil-test results.
4. To enhance the capacity of farmers and subject matter specialists in MAFS to address soil fertility problems.

3.3. Research hypothesis

1. Ho: A significant amount of soils in Sierra Leone are acidic and are responsible for the low crop yield.
2. H_o: Amending acid soils with agricultural lime and other local materials can significantly lower exchangeable acidity and raise pH.
3. H_o: Correcting soil acidity can significantly improve nutrient availability and crop growth, enhance microbial population, increase crop yield and farmers' income.
2. H_o: Vermicomposting is a sustainable business for small-scale farmers of Sierra Leone.

4. PROJECT METHODOLOGY/ APPROACH

4.1. Conceptual and theoretical framework

The project is designed to generate both qualitative and quantitative data on soil health and fertility using conventional as well as remote sensing and GIS techniques as explained below. Previous soil surveys in Sierra Leone have used conventional/traditional methods, which are extremely tedious, time-consuming, expensive, and limited by lack of accuracy and low repetitive value. In addition, the reports of such soil surveys were produced in formats that are not user-friendly. Considering the need for timely availability of user-friendly information on soil resources of any geographical area, it is of essence to assess and map soil resources and make this information available on time to the relevant stakeholders in the agriculture and related sectors for various policy planning and decision-making purposes. The uniqueness of this project is that it will use geospatial technology involving the use of remote sensing, GIS and GPS techniques to generate detailed spatial information on soil resources of the target areas. This approach is more cost effective, accurate and reliable, timely and faster than conventional ground-based surveys. Geospatial techniques are digital innovations that have rapidly evolved over the years and have proven to be very efficient and effective in assessing and mapping natural resources in many parts of the world. Through these technologies, several developing countries have been able to monitor and analyze their natural resources and produce timely and high-quality information with much accuracy. While these innovations have been rolled out in several West African countries, Sierra Leone has not fully grasped this advantage. This project will therefore generate detailed spatial data on soil acidity, Al toxicity, and soil fertility of Sierra Leone (which never existed before) in a short time and in a cost-effective manner. This spatial soil information will contribute significantly to soil resource conservation and management. In addition, capacity building of farmers, students and subject matter specialists in MAFS to understand soil pH and Al toxicity variability across their lands, identify acid and Al toxic soils and assess the best ways to treat them, is a new innovation.

4.2. Reconnaissance survey

Prior to field work, desk survey and GIS work will commence in order to delineate arable areas that are fit for agriculture using georeferenced cadastral maps, toposheets, aerial photographs and satellite imageries as input maps using both visual and digital image interpretation techniques. This will be followed by a reconnaissance survey to identify major landforms, geology, drainage pattern, slope characteristics and land cover/land use, etc. Areas having similar landforms, geology, drainage pattern, slope characteristics and land cover/land use, etc. will be identified as soil mapping units. Using this information, a preliminary legend will be developed for detailed soil sampling. The collected samples will be analysed and results interpreted for informed decision making.

4.3. Soil sampling

Soil sampling will be conducted from January to April of every year before the commencement of the rains. Prior to this, a base map with a grid sampling frame of 500m x 500m will be prepared to guide soil sample collection. Soil samples will be collected at each grid intersection with the help of the Sirrus software navigation system installed in an IPad device. At each grid observation point, a representative composite soil sample will be collected within a radius of 50m to 100m from a depth of 0-20cm and 20-40cm together with relevant information on land use and management practices. The samples will be placed in zip-lock bags and labelled with their location features for laboratory analysis. The geographic location of each grid point (longitude and latitude of sampling locations) will be recorded using hand-held GPS devices.

4.4. Experimental design and layout

4.4.1. Greenhouse Pot Experiments

The pot experiments will be established in January 2024 at ETU-SL campus. About 5 kg of soil sample will be weighed from the bulk soil sampled from benchmark soil profile locations and famers' fields and put into each pot. A greenhouse of dimension 8m x 16m will be established and maintained in favourable and controlled microclimatic conditions.

The treatment will include grinded oyster shell at 6 levels (0, 250, 500, 1000, 2500, 5000 kgha^{-1}), basic slag at 6 levels (0, 50, 250, 500, 750, 1500 kgha^{-1}), green manures of *Gliricidia sepium at 6 levels* (0, 2.5, 5, 10, 20, 30 tha^{-1}), palm kernel cake at 6 levels (0, 2.5, 5, 10, 20, 30 tha^{-1}), biochar at 6 levels (0, 2.5, 5, 10, 20, 30 tha^{-1}), agricultural lime ($CaCO_3$) at 6 levels (0, 2.5, 5, 7.5, 10, 12.5 Mgha^{-1}) and 4 crops (rice, maize, groundnut, and cowpea). The pot locations in the greenhouse will be rotated twice per week to minimize the effect of variations in ambient light and temperature conditions. NPK fertilizers will be applied at recommended rates in splits. The pots will be arranged in three rows following a Complete Randomized Design (CRD). The spacing between the rows and between pots in a row will be 0.5 m. For maize and cowpea, three seeds will be sown per pot and thinned to two after emergence in order to mimic field spacing such that 1 ha can hold 26,600 pots each with two plants. For rice and groundnut, two seeds will be sown per pot and thinned to one after emergence in order to mimic field spacing such that 1 ha can hold 26,600 pots each with one plant. The crops will be irrigated twice a week. Biomass harvesting and oven drying will take place at 4 weeks after planting (4WAP) and 8 weeks after planting (8WAP).

Plant tissues will be sampled at 4WAP and 8WAP. One plant per pot will be randomly selected and harvested at 4WAP and 8WAP, respectively. The plant height will be measured from the soil level to the tip of the youngest leaf. At 8WAP, the roots will be retrieved from the pot by splitting the pot open and the soil will be carefully separated from the fibrous roots. The bare roots will then be placed on a table and their lengths measured. The mean length of roots will be measured from the main stocks up to the tips and recorded. Finally, all the shoot and root materials from each pot will be separately chopped into small pieces, placed in sampling brown paper bags and oven dried at 50 °C for 48 hours. Their dry weight will be recorded in grams per pot and converted to kg/ha by multiplying by total number of plants per ha (i.e., 53200 for maize and cowpea, and 26,600 for rice and cowpea).

4.4.2. Field Experiments

4.4.2.1. Design and set up

The field experiment will be designed and managed by the project technical staff and one MSc student but assisted by the farmers. After soil analysis of the first set of soil samples collected in the first year would have been completed, the major soil bodies will be identified based on soil-test results, and these will form the mapping units. Within each mapping unit, farmers growing rice, maize, groundnut and cowpea will be selected and their farms mapped for experimentation. The experiment will be conducted during the May–July (as first season planting) and September-November (as second season planting) of 2024. The experiment will be repeated during the same seasons in 2025. The objective is to verify the outstanding good results from the greenhouse studies under the real-world farmer's conditions in the field and to have a pooled data of two years to validate statistical significance testing. To control variability between greenhouse and field data, similar inputs as those of the greenhouse experiment will be used. In addition, experimental set up, treatment application and planting will be done by both project technical staff and the farmer. The farmer will carry out all other agronomic practices like weeding and thinning in consultation with the project technical staff. However, all data collection will be exclusively done by the MSc student. Three out of the 18 best performing treatment combinations will be evaluated on farmer's field in a complete randomized block design (CRBD) with three replications per treatment for precision. The dimension of the plots shall be 4.5 x 4.0 m with a 1.5 m footpath between the plots. A control plot will be included as well.

4.4.2.2. Land preparation, planting and inputs application

The land will be prepared by hand hoeing to satisfactory tilth in May 2024 and 2025 at onset of raining season. The soil amendments at targeted levels will be added to the topsoil as starters and these will be thoroughly mixed. Planting holes at a spacing of 0.75 m and 0.5 m for inter and intra-row, respectively, will be dug and the mixture will be added to the holes. The crops will be planted and all agronomic practices will be applied.

4.4.2.3. Sampling and data collection

Initial soil sampling and analyses will be done at the beginning of each year in January-April. The final soil sampling and analyses will be conducted in October-December of each year at the end of field experiment. Here, each field shall be gridded on 50m x 50m scale to give a sample size of 4 sample per hectare. Soil samples will be collected at each grid point and the geographic location of each grid point (longitude and latitude of sampling locations) will be recorded using hand-held GPS devices. Data on dry matter weight (DMW) will be collected also. In each field, twenty-four plant stands will be selected for sample collection leaving out one row on each side of the plot and the first two hills from either side of the rows to minimize border effect. From the 24 stands, a sub-sample of eight stands will be selected at random for the determination of growth parameters. The data from the eight stands will be averaged per plant to calculate the biomass weight. The DMW of biomass will be further converted to kgha^{-1} using the formula below.

$$DMWha^{-1}\ (Kg) = \frac{H\ ha{-}1\ x 2/1\ x\ N}{8\ x\ 1000} \qquad \text{equation (1)}$$

Where;

DMWha-1(Kg) = Oven dry weight of biomass ha^{-1}

H ha-1 = No. of planting holes ha^{-1} at a spacing of 0.75 m by 0.5 m (=26600)

2/1 = Number of plants per hole (i.e., 2 for maize and cowpea; 1 for rice and groundnut).

N = Weight in g of DM from 8 randomly selected plants per plot.

8 = No. of plants randomly selected per plot.

1000 = A factor incorporated to convert g plot^{-1} of DM into kg ha^{-1}

4.5. Laboratory analysis

The soil and various soil acidity amendments (i.e., grinded oyster shell, basic slag, green manures of *Gliricidia sepium*, palm kernel cake, biochar, and agricultural lime) will be analyzed for their pH and nutrient status. The soil samples will be air-dried until a constant weight is obtained, after which they will be grinded and passed through 2 mm sieve and stored in plastic bags (dimension: 5 × 7 cm). These samples will be analyzed following standard analytical procedures. The pH of the soils will be measured in water, 1M KCl, 0.01M $CaCl_2$, 1M NaF (Black, 1965; Page *et al*., 1982). CEC will be estimated using neutral normal ammonium acetate (Black, 1965). Exchangeable Ca and Mg will be estimated from the ammonium acetate extract for CEC determination by Atomic Absorption Spectrophotometer (Model GBC, Avanda). Sodium and K will be estimated from the same extract by Flame Photometer. Percentage base saturation will be calculated using the equation outlined in Jackson (1958). Mechanical analysis of the soil samples will be done by international pipette method (Jackson, 1958). Organic carbon will be estimated by Wakley and Black method (Jackson, 1958). Total potential acidity will be estimated by Peech method (Peech *et al*., 1962), exchangeable acidity by Mc Lean method (Mc Lean, 1965), and the difference between total potential acidity and exchangeable acidity will be taken as the pH dependent acidity. Exchangeable and extracted Al will be determined by Mc Lean method (Mc Lean 1965), and the difference between extractable Al and exchangeable Al forms will be taken as the non- exchangeable Al. For estimating soluble Al, the soil will be extracted with 0.01M $CaCl_2$ (soil solvent ratio 1:2.5) by shaking for 5 minutes and the Al in the extract will be estimated calorimetrically by aluminon method. Total Al will be determined by HCl-HF method as per Hossner (1996) and estimated by aluminon method. The oxalate Fe and Al (Fe_o and Al_o) will be determined by extraction with ammonium oxalate in the dark (Mc Keague and Day, 1966) and the dithionite citrate bicarbonate extractable Fe and Al (Fe_d and Al_d) will be determined by the method of Mehra and Jackson (1960). Total Mn and Fe will be estimated by HCl extraction (Jackson, 1958). DTPA -

extractable Mn and Fe will be determined by Lindsay and Norvell (1978). Exchangeable Mn and Fe will be extracted with neutral normal ammonium acetate in soil solvent ratio of 1:10 and the concentration of Mn in the extract will be estimated by Atomic Absorption Spectrophotometer. Effective CEC will be determined by summation of exchangeable Na, K, Ca, Mg and Al in the 1M KCl extract (Reeuwijk, 1993), and Aluminium saturation percent will be expressed as per cent of the ECEC

4.6. Assessing soil acidity status and acidification risk

4.6.1. Assessing soil acidification risk

Risk to soil acidification depends on 3 different issues: 1) the initial pH, 2) the soil's pH buffering capacity (pHBC), and 3) net inputs of acid or alkali. This research aims to assess potential soil acidification risk by estimating the initial pH and the vulnerability of the soil to pH change, which is reflected in its pHBC.

To assess the impact of soil pH on soil acidification risk, the study will be based on the nature and efficiency of the most active buffer reaction in each pH range as given Ngendo (2013). To assess the impact of soil pH buffering capacity on soil acidification risk, the equation of Helyar et al. (1990) developed for soils in the tropics will be used. The potential acidification risk will be categorized based on pH buffering capacity ranges recommended by Singh et al. (2003).

Soil acidification rate reflects the decrease in soil pH or change in H^+ activity in the soil. This will be calculated from the pHBC values. The number of years to reduce the pH by one unit will be estimated as recommended by Singh et al. (2003) and Helyar et al. (1990). In addition, the risk for Al toxicity will be estimated using the pH value. In fact, soils with pH value lower than 5.5 are deemed to have high risk of Al toxicity. To this, values of Al saturation would be used with a threshold of 15%.

4.6.2. Mapping soil acidity and acidification risk

Acidification risk mapping is a management tool for providing optimized strategies with respect to acidification risk. To map soil acidity status and identify potential acidification risk areas using the generated dataset, several GIS data modelling techniques will be applied and the best performing models will be used in final map production.

Maps and their related attributes datasets will be geo-matched. After analyzing the soil samples, the results will be compiled in excel file. Quality checks will be conducted and the verified data will be saved in DBF file format for use in ArcGIS. The data will be opened in ArcGIS interface and subjected to spatial modelling tools such as interpolation toolbox using Inverse Distance Weighted (IDW) technique. This interpolation method explicitly implements the assumption that sample locations that are close to one another are more alike than those that are farther apart. In this way, thematic maps of soil health and fertility will be generated.

Maps showing the spatial distribution of soil health and fertility indicators and their calculated average values will be produced by matching the measured soil properties with their critical values. These classes will indicate the deficiencies, sufficiency and toxicities of nutrients as well as other soil physical and chemical parameters that limit nutrient availability in soils.

In order to combine both numerical and categorical variables in the assessment of soil acidification indicators, a classification tree-based approach will be adopted as well. This method allows the assessment of the impact of each soil acidity indicator in a decreasing order and also enhance the interpretation of results. To check the quality of the tree, the risk estimate and standard error will be used as a measure of the tree's predictive accuracy.

The mean absolute error (MAE) and root mean square error (RMSE) will be used to check the quality of the maps.

4.6.3. Estimation and mapping of liming requirements (LR)

After identifying acidification risk areas and hotspots, strategies for optimizing soil protection and management will be recommended. Before the estimation of lime requirement, the soils will be categorized into two classes; 1) soils that require liming (pH < 5.5) and 2) soil that do not require liming (pH < 5.5). To calculate lime requirement for these risk areas, several equations will be modelled including Yost method (Yost et al., 1988), Peech method (Peech, 1965), Adams and Evans method (Adams and Evans, 1962), and exchangeable Al method (Kamprath, 1970).

4.7. Effect of liming

4.7.1. Effect of liming on nutrient availability

This will be an incubation experiment, where the lime requirement (LR) of the soils will be estimated by Peech method (Peech, 1965). The treatments will comprise of four levels of lime, at the rates of 25, 50, 75 and 100 per cent of the lime requirement and a no lime control. Agricultural lime ($CaCO_3$) will be used as the source of lime. In each treatment the required dose of lime will be thoroughly mixed with 1 kg soil and incubated in the laboratory at ambient temperature of 24 - 28° C for a period of 90 days. Moisture level will be maintained at field capacity throughout the period of incubation. The design of the experiment will be a Completely Randomized Design (CRD) with six replications.

The initial soil properties will be determined by standard procedure outlined in Jackson (1958). The incubated soil samples will be collected at 15 days intervals up to 90 days and analyzed for organic carbon, available P, K, Ca and Mg (Jackson, 1958). Available P will be extracted using Bray – II extractant (0.03 N ammonium fluoride in 0.1N HCl) (Bray and Kurtz, 1945) and estimated calorimetrically by molybdenum blue method at 660 nm wavelength. Available K will be extracted by Morgan's reagent (sodium acetate + acetic acid buffer of pH 4.8) (Morgan, 1941) and estimated by flame photometer. Calcium and Mg from the Morgan extract will be estimated by atomic absorption spectrophotometer. The soil pH (1:2.5, soil: water ratio) will be measured by glass electrode method. Exchangeable Al will be extracted with 1M KCl and estimated by aluminon method (Hsu, 1963; Jayman and Sivasubramanian, 1974) and available Mn, Fe, Cu and Zn will be estimated by DTPA extractant (Lindsay and Norvell, 1978) after 90 days of incubation.

The individual parameters will be statistically analyzed in CRD and the changes over a period of time will be estimated by factorial analysis (Snedecor and Cochran, 1967).

4.7.2. Effect of liming on availability of nutrients and crop growth

Field experiment will be conducted during the May–July (as first season planting) and September-November (as second season planting) in 2024 and 2025. Lime requirement estimated by Peech method (Peech, 1965) will be used as a baseline data. There will be five treatments including an absolute control (no lime, no fertilizer), fertilizer and three levels of agricultural lime ($CaCO_3$) viz., $^1/_3$, $^2/_3$ and full LR alone and in combination with fertilizer. The design of the experiment will be a randomized block design with three replications.

Beds with dimensions of 4.5m x 1.5m will be prepared following appropriate agronomic practices and agricultural lime ($CaCO_3$) will be incorporated with a fork as per the treatments. Two weeks after liming, rice, maize, groundnut and cowpea seeds will be planted using standard spacing. Fertilizers application will be done as per recommended rates. All cultural operations will be strictly followed and biophysical data will be collected at 4WAP and at harvest.

Soil samples from 0-20 cm and 20-40 cm will be collected at two weekly intervals during the growth of the crop and these will be analyzed for physicochemical properties using standard analytical methods. Leaf samples will be collected and analyzed for total nutrient concentration (Piper, 1942). The data will be analyzed statistically.

4.7.3. Comparative evaluation of liming materials on nutrient availability and crop growth

Field experiment will be conducted during the May–July (as first season planting) and September-November (as second season planting) in 2024 and 2025. Lime requirement estimated by Peech method (Peech, 1965) will be used as a baseline data. There will be five treatments including an absolute control (no lime, no fertilizer), fertilizer alone and three sources of lime viz; agricultural lime (quick lime), dolomite and phosphogypsum @ of 100 per cent lime requirement with and without fertilizer. The experiment will be laid out in a randomized block design with four replications.

Beds with dimensions of 4.5m x 1.5m will be prepared following appropriate agronomic practices and agricultural lime ($CaCO_3$) will be incorporated with a fork as per the treatments. Two weeks after liming rice, maize, groundnut and cowpea seeds will be planted using standard spacing. Fertilizers application will be done as per recommended rates. All cultural operations will be strictly followed and biophysical data will be collected at 4th week after planting and at harvest.

Soil samples will be collected from 0-20 cm and 20-40 cm at the time of planting, before fertilizer application and at time of harvest. These soil samples will be analyzed for physicochemical properties using standard analytical methods. The data will be analyzed statistically (Snedecor and. Cochran1967).

To study the residual effect of liming materials, the experiment was repeated in the same beds in 2025 planting seasons also. As in previous seasons, the plant biophysical data will be collected at 4th week after planting and at harvest and soil samples from 0-20 cm will be collected at the time of planting, before fertilizer application and at time of harvest and analyzed for pH and availability of nutrients. The data will be analyzed statistically (Snedecor and. Cochran1967).

4.8. Statistical analysis

The biophysical data obtained in this study (i.e., biomass yield, plant height, root length, microbial density, soil pH, etc.) will be compiled in excel. These will be tested for normality and then subjected to ANOVA to separate the treatment means found to be significantly different from each other using least significant difference (LSD) at $p < 0.05$ (Buysse *et al.*, 2004)

Descriptive statistics (i.e., mean, standard deviation, minimum and maximum) of acidity indicators will be calculated using SPSS statistical package. Correlations among these acidity indicators and between these indicators and other environmental variables, will also be evaluated using the guidelines for classification of correlation strength as Class 1: 0 - 0.2 (very weak), Class 2): 0.2-0.4 (weak), Class 3: 0.4-0.7 (moderate), Class 4: 0.7-0.9 (strong) and Class 5: 0.9-1 (very strong). The potential interaction effect of categorical variables on soil acidity will be analyzed using Analysis of Variance (ANOVA). The significantly different soil pH means depending on each environmental variable will be assessed as well using Tamhane's post-hoc test. Soil pH means of various agroecologies will be compared at probability $p < 0.05$ using Fischer's least significant difference (L.S.D).

5. ANTICIPATED OUTPUTS AND OUTCOMES

S.N.	Activity	Output(s)	Outcome(s)	Impact	Risks and Assumptions
1.1	Characterizing and mapping soil acidity and Al toxicity	Soil acidity and Al toxicity characterized and mapped.	Informed decision making on the use of soils	Farmers are guided on the type of crops to grow and type of soils to select	Climate change may affect the status of soil acidity and Al toxicity.
1.2	Assessing soil fertility status, identifying major nutrient deficiencies	Soil fertility status	Farmers applying nutrients based on soil-test results and recommendations	Increased crop production and productivity	Farmers would afford nutrients on their own or subsidized by government
1.3	Evaluating the impact of soil acidity on nutrient availability	Knowledge of the impact of soil acidity on nutrient availability generated	Farmers growing their crops based on recommendations	Increased crop production and productivity	Willingness of farmers to adopt recommendations and availability of funds to implement recommendations
1.4	Identifying best-bet practices for managing soil acidity based on soil-test results.	Best-bet practices for managing soil acidity identified	Improvement in the knowledge level of famers and extension agents in appropriate climate smart crop production and management practices	Increased in climate resilient cropping systems	Willingness of farmers to adopt the introduced technologies.
1.5	Capacity building programmes.	Training in soil acidity assessment and best-bet management practices conducted	Farmers applying acquired skills in their farming systems and helping other farmers with learn from the lesson	Increased knowledge of handling acid soils and the type of crops to grow	Willingness of farmers to fully participate in the training as many would be expecting per diems
1.6	Establishment of Center of Excellence in Soil Health and Fertility Management	Network of information on soil resources generated	Farmers using the facility in the improvement of their cropping systems	Adequate and reliable information on use of soil resources sustained	Farmers are willing to seek and apply technical advice

6. KNOWLEDGE UTILIZATION AND DISSEMINATION PLAN

Communication plays a key role in the effective dissemination and adoption of innovation. The plan for communication will involve the engagement of public and private extension service providers, traditional mass media such as radio, television, newspapers; and digital agriculture involving the use of social media via channels such as telephones to disseminate information to farmers.

The bias for mass media and digital agriculture is emphasized because of their rapid and efficient means to inform audiences and their ability to reach millions of farm families in areas which are beyond the reach of extension personnel. Besides extending the reach of the extension network, communication media can play a wide range of roles in the development process. Their ability to penetrate remote rural areas and transcend the illiteracy barrier has made the media a primary vehicle for bringing new ideas and knowledge, events in government and the outside world, and possibilities for improvement to the people in the countryside. The following activities are proposed in the communication plan:

i. **Development of websites and setting up of social media platforms:** A web portal will be developed to share progress and results of the project to a wider audience. The web portal will host social media platforms of the project such as Twitter, Facebook, LinkedIn, YouTube, and TikTok.
ii. **Newsletter:** A quarterly newsletter will be produced to further share the innovations and progress being made to farmers and the wider public.
iii. **Establishment of video viewing center:** In several communities in sub–Saharan Africa, there are several private-owned video viewing centers that show football matches. The project will work with such centers to ensure that videos produced by the project on new innovations are aired before premier, champions, LaLiga, and F.A. cup matches.
iv. **Radio slots:** Radio is one of the communication channels that reaches farmers at wider scale in Africa, especially in rural areas. The project will work with radio stations to ensure that the contents generated by the project are aired periodically.
v. **Digital tools such as WhatsApp**: The use of cellphone has grown astronomically in sub-Saharan Africa. The WhatsApp platform will be used as a tool for dissemination of project information to farmers. The project will develop a WhatsApp platform to share videos and messages to farmers.
vi. **Visibility/production of other extension materials**: This includes caps, T-shirts, handbills, flyers, almanac etc. These materials will be developed and shared with farmers.

7. PROJECT GOVERNANCE

A Project Steering Committee (PSC) will be set up that will comprise of key stakeholders including the ETU-SL team (Vice Chancellor and Principal (VC&P), Director of Research and Innovation (DRI), Director of Partnership and Resource Mobilization (DPRM), Finance Director, Internal Auditor), District Agriculture Officers (DAOs), and farmers' representatives. The PSC will provide guidance to the implementation of this project. It will advise on issues and problems arising during project implementation; facilitate cooperation among project partners and collaboration between the projects and other relevant programs, projects and initiatives in the countries. The ETU-SL team through the Principal Investigator, will be responsible for overall project management and overall coordination of activities. The DRI will be the secretary of the PSC and he shall present a quarterly report to the PSC. The DAOs will play a vital role in the selection of target communities and beneficiaries due to their long-standing experience in dealing with famers in their districts. The farmers' representatives will serve as points of contact (POC) for their FBOs. They will be responsible for organizing members of their FBOs, and facilitating communication between farmers and the technical team. The PSC will also conduct a regular monitoring and evaluation of the project in line with project outputs, indicators and activities.

8. SUITABILITY OF THE HOST INSTUTUION

The ETU-SL is a technical university that is located in the eastern region of Sierra Leone, which tends to be the bread basket of the country. The institution has campuses located at Bunumbu Campus having 615 acres in Kailahun district, Woama Campus having 317 acres in Kono district, and Kenema Campus with two locations, namely Kenema having 25 acres and Panderu having 100 acres. The region is also endowed with adequate climatic and environmental conditions that favour the growth of crops and general agricultural development.

ETU-SL has well-structured faculties and programmes that are career-driven, with qualified staff for teaching, research and community services. As a technical university, it caters for the development of the middle man power and contributes to improving the quality of life for citizens, increasing agricultural productivity, promoting the environmental well being of families and conserving the natural resources. Project of such nature is well suited to the mission and development objective of the institution and could serve as a gateway to the eastern region and the country as a whole.

Lastly, the university has undertaken a series of project since its inception in collaboration and partnership with several national and international, governmental and non-governmental organizations including MAFS, MTHE, Ministry of Youth, Gola Forest, WHH, BADIA etc. The university also has standard infrastructure that could facilitate the implementation of this project.

With these potentials and experiences, the university is well positioned and capacitated to undertake such project.

9. CAPACITY BUILDING

The project will base its implementation strategy on the core principles of a livelihoods framework. This framework will guide project interventions in support of technical innovations, through a process of building human skills and improving the capacity of local institutions. Major activities will include technical innovations such as introduction of new crop varieties and improved crop management practices, and institutional strengthening. The proposed project will contribute towards individual and organizational capacity building in several ways including hands-on practical demonstration of appropriate climate smart technologies for individuals such as project staff, students, and farmers to institutional capacity building in terms of infrastructural development through the provision of relevant and appropriate science tools and training extension staff of MAFS. The project intends to offer scholarship to one Junior Lecturer in the Faculty of Development Agriculture and Natural Resource Management to pursue an MSc in Soil Science. In addition, the project will train farmers, students and extension staff of MAFS in several aspect of climate smart agriculture including appropriate climate smart crop production and management practices, production and marketing of specific value-chain crops such as maize, pearl millet, sorghum, groundnut and cowpea, integrated pest management such as monitoring, surveillance and scouting for the identification, early warning and appropriate control measures for Fall Army Worm, and interpretation of weather forecasts.

10. MONITORING AND EVALUATION STRATEGY

The proposed monitoring, evaluation and learning (MEL) plan will be designed to produce accurate, valid and timely information that would inform the key project outputs and results; to track progress and make mid-course corrective actions where necessary. The MEL plan will also provide relevant information needed to assess and report progress towards the expected project impact of improved rural livelihoods and food security. The MEL plan will also clearly identify the common indicators to be reported by partners involved in the implementation of the project. The Logframe Matrix identifies the key performance indicators and their corresponding data sources, methods of data collection and the means of verification needed to obtain and report performance data that will inform progress achieved for measuring the stated results. Baseline data for the proposed performance indicators will be collected within 3-6 months after the start of the project. This will be followed by setting of realistic targets in line with the established baseline figures. The overall MEL plan will entail use of mixed methods (quantitative and qualitative) data collection approaches.

These consist of the following:

i. **Performance monitoring:** This relates to implementation monitoring comprising of tracking of milestones and outputs by using several data collection methods such as reviewing project and training records, collecting quantitative data from beneficiaries, and conducting special studies. Some of these studies are meant to address issues not informed by routine monitoring. The special studies will also be used to inform key learning questions identified for the project, and/or testing of the critical assumptions implied in the Theory of Change (TOC).

ii. **Conduct of the baseline and other relevant Surveys**: Here, a desk survey of relevant information on production, adoption, market, household and value-chain will be conducted at the beginning of the project in project locations (interventions) and some adjacent communities (non-interventions) to determine the benchmark values of the key performance outcome indicators.

iii. **Conduct of an endline survey:** This will be done during the last quarter of the project in the same communities where baseline information was collected to allow measuring of changes in key performance indicators in both project intervention sites and non-intervention ones.

11. GENDER, ETHICS AND SUSTAINABILITY

11.1 GENDER

Gender aspects and youth issues are considered important by the project. To sustain project activities, the project will develop a gender mainstreaming strategy to reduce gender inequalities through participation in identifying relevant interventions for achieving gender equity, encouraging gender-specific activities and increased participation by women. The increased participation of women and youths in the project will help increase the benefits among households, thus leading to more investments in technologies being promoted. For this reason, both male and female will be incorporated into the project based on skills requirement. During the start of the project, baseline survey on key agricultural attributes will be conducted. Through this, the project will provide job facilities for male and female youth that will comprise of students.

11.2 ETHICAL ISSUES

The proposed project involves the deployment of innovative technologies which are well known and widely tested in similar agro-ecologies in West Africa and other subregional countries. They have been widely accepted as safe and offer a range of options for better productivity of crops combined with good resource management. They are based upon existing changing climate, in the context of farming systems that are evolving. In addition, participatory mechanisms of technology transfer which treat farmers as equal partners in project implementation will facilitate technology adoption. However, the efficiency of these technologies depends both on scale of production and on the organization of work. The project would pay attention to these issues to ensure that the local communities participating in the project are aware of these factors of productivity.

11.3 SUSTAINABILITY

Five key elements will contribute to the sustainability of this project after its lifespan. These are 1) the development of strong partnerships, 2) the use of participatory approaches, 3) strengthened community-based organizations, 4) the mainstreaming of gender, and 5) the use of research knowledge and proven technologies. The project will forge a partnership with relevant stakeholders to work together to deliver the outputs targeted by the project. The stakeholders will participate in the identification of the problem and work together to provide solutions through technology deployment. Farmer participation in the process will provide feedback to researchers to fine tune technologies for deployment. Working with existing groups and encouraging the formation of new ones, building their capacity through technical, organizational and leadership training will lead to the formation of common interest groups, which will evolve into farmer-owned and managed organizations that are capable providing services to members. Training will be undertaken in ways which will reinforce each other based on the principles that people learn from practical experience and better from their peers. A gender mainstreaming strategy will be developed to reduce gender inequalities through participation in identifying relevant interventions for achieving gender equity, encouraging gender-specific activities and increased participation by women. The increased participation of women and youths in the project will help increasing benefit among households leading to more investments in technologies being promoted. The strong use of research knowledge and technologies through backstopping by researchers will increase productivity of the production systems and reduce poverty. This will allow for further investments in agriculture and lead to sustainable livelihoods after the project phases out.

12. PROPOSED PROJECT TIMELINE

S.N.	Objective/Activity	Year 1				Year 2			
		1	2	3	4	1	2	3	4
1	**Pre-field activities**								
1.1	Project inception meetings – including selection of target communities and beneficiaries.	■							
1.2	Desk review and stocktaking on farmers knowledge of soil acidity and its associated problems.	■							
1.3	Awareness raising on soil acidity and its associated problems.	■							
1.4	Purchase of seeds, fertilizers, lime materials, soil survey and analysis tools, greenhouse materials, and other tools and equipment.	■							
1.5	Preparation of base maps and soil legends for field work.	■							
1	**Characterizing and mapping soil acidity and Al toxicity**								
2.1	Reconnaissance survey and preparation of base maps and soil legends.	■	■						
2.2	First set of soil sample collection, analysis, and interpretation of results.	■	■						
2.3	Preparation of soil acidity and Al toxicity atlases.			■					
2.4									
2	**Assessing soil fertility status, identifying major nutrient deficiencies and evaluating the impact of soil acidity on nutrient availability.**								
2.1	Second set of soil sample collection, analysis, and interpretation of results.				■				
2.2	Modelling the relationships between soil fertility and soil acidity				■				
2.3	Preparation of soil fertility atlases.				■				
3	**Identifying best-bet practices for managing soil acidity based on soil-test results.**								
3.1	Greenhouse pot experiment		■						
3.2	Field experiment		■	■					
3.3	Second set of soil sample collection, analysis, and interpretation of results.				■				
3.4	Agronomic data collection		■	■					
3.5	Post-field activities – data analysis and reporting		■	■					
4	**Capacity building programmes.**								
4.1	Training smallholder farmers and extension agents on appropriate climate smart crop production and nutrient management practices.		■		■		■		■
4.2	Creation of a Center of Excellence in soil health and fertility management.				■				
4.3	MSc. Student programme	■	■	■	■	■	■	■	■
5	**Monitoring, Evaluation & Learning (MEL) and Reporting**	■							