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An Efficacious Supplementary Fertilizer Formulation from Agricultural Farm Biomass

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Authors' contributions

This work was carried out in collaboration among all authors. Author EACP designed the study, carried out the methodology, performed the statistical analysis, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Authors NH and CE guided the study. All authors read and approved the final manuscript.

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ABSTRACT

Though composting is a practical method of recycling plant macronutrients in organic matter, it is impractical with biomass like sisal leaf wastes, horns, hooves and feathers that take long to decompose. This biomass is therefore ignored; causing waste disposal hitches and yet are rich in plant macronutrients (nitrogen, phosphorous, potassium and calcium). This study set out to use them to formulate a supplementary fertilizer (SF). Samples of maize cobs and stalks, sugarcane bagasse, cattle hooves/horns and sisal leaf biomass were, taken through wet digestion before laboratory analysis for levels of nitrogen, phosphorous, potassium and calcium using standard procedures. Different formulations were obtained by mixing solvent digested hooves/horns (HD) with lye pre-treated sisal leaf biomass (CASD) giving ratios HD:CASD 0:1 (SF_0), 1:1 (SF_1), 2:1 (SF_2), 3:1 (SF_3), 1:2 (SF_4) and 1:0 (SF_5) that had varying pH values. Formulation SF_1 (ratio 1:1 and pH 8.0) was used during fieldwork to evaluate the formulation's efficacy on the rate of growth, pest control and crop (maize) yield. Four sets of maize plots under varying fertilizer treatments or schedules (SF_1/SF_1, SF_1/CAN, NIL/CAN and DAP/CAN) were replicated three times within the study area (Lugari Kakamega county, Kenya). There was no significant difference (p = 0.273) noted in the

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yields between the use of the formulation, SF_1 and the commercial fertilizers DAP/CAN schedule. The stalk borer attack on the stems, fruits and tassels of the maize in plots that had nil fertilizer schedule (control) was in the range 60-75% compared to 10-15% and 4-7% in those where the supplementary fertilizer (SF_1) and DAP/CAN were respectively applied. The findings of this study showed that the agricultural biomass can be blend into an effective and efficient supplementary fertilizer with sufficient levels of plant macronutrients (N, P, K and Ca). The approaches used in material pretreatment shorten the period of decomposition compared to the traditional composting methods.

Keywords: Biomass; macronutrients; formulation; supplementary; fertilizer; efficacy.

1. BACKGROUND INFORMATION

The Post-2015 goals for sustainable agriculture and food production on food security, nutrition and health goals, FAO, stipulates the need for increasing the world's real food supply by 70-100% by 2050 through increasing agricultural productivity on existing land [1]. 30-50% of crop yields are attributed to natural or synthetic commercial fertilizers [2]. Since fertilizer access in most developing countries is limited, frantic efforts have to be made to supplement the present and future demand using natural sources for sustainable crop production. Fertilizers typically provide in varying proportions six macronutrients: nitrogen, phosphorous, potassium, calcium, magnesium and sulphur and eight micronutrients iron, boron, chlorine, manganese, zinc, copper, nickel and molybdenum [3]. Macronutrients play an important role in the entire plant life. They perform various beneficial activities in plant metabolism as well as protection from biotic and abiotic stresses that include stresses of heavy metals, drought, heat, UV, radiations and from diseases and insect attack [4]. The macronutrients also help increase yield, growth and quality of crops [5].

Farming households in rural communities in developing countries generate enormous solid organic biomass such as manure, tree trimmings, grass clippings, animal and crop residues. The organic biomass amount up to 80% of the total biomass generated in a farm household [6]. Farmers and gardeners are often encouraged to utilize the organic biomass as a resource that can help bridge the gap between the need and access to fertilizers through composting. Utilization of agricultural plant and animal biomass in composting is a useful process of recycling nutrients and maintaining or restoring levels of organic matter in the soil [7]. Agricultural composting (anaerobic method of decomposing organic solid biomass) is highly encouraged to reduce threats to the environment. Apart from composting being slow, it is impractical with farm biomass such as feathers from poultry, horns, hooves and fur from the livestock which though richer in nitrogen would not easily decompose based on the current approaches.

Large scale agricultural activities in most countries such as the growing of sisal, maize, sugar cane and livestock keeping generate enormous biomass including sisal leaf biomass, maize cobs/stalks, sugarcane bagasse and livestock hooves, horns, fur and feathers. Improving composting (shortening the period of biomass degradation) and therefore utilization of the biomass as a source of readily available plant macronutrients in supplementing the commercial fertilizers would be a significant value addition venture. This study determined and compared levels of macronutrients (calcium, potassium, phosphorus and nitrogen) in the agricultural biomass, formulated a supplementary fertilizer (SF) with readily available macronutrients whose efficacy in promoting growth and yield in maize was evaluated.

2. MATERIALS AND METHODS

2.1 Materials, Chemicals and Instruments

The study design involved laboratory and field works. The laboratory work entailed determination of levels of macronutrients in agricultural farm wastes (maize cobs and stalks, sisal (*Agave sisalana*) leaf biomass, sugar cane bagasse and in livestock hooves and horns). The data was used to define the role of the biomass in the formulation of a supplementary fertilizer (SF). The fieldwork targeted assessing the efficacy of SF compared to DAP/CAN on growth and yield of maize. Field trials were done in Lugari sub-county - Kenya.

Sisal leaf samples (young and old) were collected from sisal plants on hedges of farms in

Lugari, stripped and sundried for two days before extrusion of the sisal fibre to obtain the biomass. The sisal leaf biomass was then spread in the sun daily to dry for one week until constant weight. The dry sisal biomass samples were mixed mass for mass and stored in stoppered plastic containers awaiting analysis and use. Sets of cattle horns and hooves were collected from different slaughterhouses in Lugari, Kakamega County, washed with distilled water and dried at 140ºC in an oven to drive off moisture and traces of humus. They were labelled horn or hoof. Maize cobs of varieties (H6213, DK, H614 Pioneer) commonly grown in lugari were sampled from homes after shelling, spread out in the sun to dry. They were milled separately before mixing in equal mass ratios. The sugar cane bagasse was obtained from Butali Sugar company, Kakamega County. The fresh samples were sun-dried six hours daily for five days and stored in stoppered containers.

All the chemical reagents used were of annular grade purchased and used as obtained from Kobian-Kenya. Instruments used in the study included the UV-Vis spectrophotometer (Cecil-CE 2041-2000 series) for phosphorous (660 nm) and a flame photometer (Sherwood classic model 410) for calcium (422.7 nm) and potassium (766.5 nm) and pH meter (Benchtop pH/mv meter model 210) calibrated at standard solutions pH 4.2, 7.0 and 10.0.

2.2 Methods

2.2.1 Levels of macronutrients in biomass

The [8] procedures as outlined in the laboratory manual [9] were followed in the determination of total nitrogen, potassium, calcium and phosphorous.

Total mass of nitrogen (mg/100g),

$$DM = \frac{140{,}000x\ V_a x T}{M_O\ x\ M_S}$$

Where Va =volume of the acid used,
M_s = mass of the sample used
T_a = molarity of the acid used,
M_o = % moisture.

Levels of K, P and Ca in the samples were obtained from calibration curves of standard solutions made from their salts. The procedures were repeated with 0.5 g of supplementary fertilizer formulated. The pH of soil sampled from study site farms in Lugari, were determined using standard procedures in the same laboratory manual.

2.2.2 Formulation of the supplementary fertilizer

This involved lye preparation from the ash of maize cobs. Dry maize cobs were weighed (50 kg) onto steel metallic sheet and burned to obtain the ash. The ash was transferred into a plastic container, mixed with 8 litres of distilled water and stirred thoroughly before filtering to obtain the lye. The procedure was repeated twice using 8 litres of water, stirring and filtering off the residue respectively. Lye (10 l) was added to dry sisal biomass (1.5 kg) and boiled until frothing subsided. The mixture was put on a black polythene paper in the sun to dry. Sisal strands were physically removed to obtain the residue cobs ash sisal digests (CASD). The mixture was oven-dried at the temperature of 120ºC before weighing. The drying and weighing at intervals (10 minutes) was done repeatedly until a constant weight was obtained. The dry CASD was stored in clean airtight plastic containers. This was done before the Horns/Hoof Digest (HD) mixture was prepared.

Dry horn and hoof (2 kg) were weighed and soaked in peracetic acid solution (3 l) in an open container for 14 days with periodic stirring. At the end of the period, the liquid in the mixture was decanted off and the residue rinsed three times with distilled water and sun-dried to allow agglutinating properties to develop through exposure to the atmosphere. The resultant horn and hoofs digest (HD) was kept in the plastic container. The formulation involved mixing CASD (alkaline) with HD in designate ratios. Since CASD was to provide alkaline to react with the horn digest to generate ammonia, the amount of alkalinity available in CASD was determined. CASD (0.6 g) was put in a beaker with 100 cm^3 of standardized 2 M HCl. The mixture was heated until total volume remained 30-40 cm^3 original content. Standard 2M NaOH was then used to establish a concentration of unreacted HCl. The moles of HCl that had reacted with alkalinity in the CASD was given by:

$$\text{Moles of HCl} = \frac{V^2{}_a M_a - 100 V_b M_b}{1000 V_a} \text{ moles,}$$

Where V_b =volume of base used in the titration,
V_a = volume of acid used in the back titration
M_b =molarity of base used in the back titration,
M_a = molarity of acid used in titration

The amount of alkalinity required to generate maximum ammonia from HD was also determined. Horn plus Hoof Digest – HD (0.6 g) was weighed into 100 cm^3 of standardized 2 M NaOH in a beaker and heated to boiling until the level of the mixture remained 30-40 cm^3 and the vapour above the boiling mixture had no effect on wet red litmus paper. The mixture was cooled and topped up to 100 cm^3 with distilled water. 25 cm^3 of the mixture (in triplicate) was pipetted and titrated with standardized 2 M HCl to establish the unreacted NaOH. This enabled establishing the amount NaOH (alkalinity) required by Horn/Hoof Digest (HD) to give the maximum ammonia from given amounts. The moles of NaOH that reacted with 0.6 g HD was given by

Moles of NaOH that reacted with 0.6 g HD = $V^2_bM_b$-$100V_aM_a$ moles/ 10000 V_b

where, Vb = volume of base used in the titration,
V_a = volume of acid used in the back titration
M_b = molarity of base used in the back titration,
M_a = molarity of acid used in titration

The amounts of alkalinity required for maximum production of ammonia from given HD was used to determine how much of CASD (alkalinity provider in the formulation) to be used. Formulations SF_1 obtained by mixing HD: CASD in the ratio 1:1 based on the ratio of moles of NaOH used on HD to moles of HCl used on CASD, SF_2 (2:1) and SF_3 (3:1) were made. The formulations' pH and levels of macronutrients were determined.

2.2.3 Field trials

The land was prepared by ploughing to an average depth of 15-20 cm just before the long rains and then subdivided into three blocks. Four plots measuring 2×2 m^2 were demarcated in each of the three blocks. Each of the plots, labelled A, B, C and D in each block, was under separate fertilizer schedule treatments.

Though more than one formulation was established by the study, SF_1 (1:1), more alkaline, was found the ideal for the acidic soils of the study site. The supplementary fertiliser (SF_1) was used for both planting and top dressing in all plots labelled A across all the three blocks. Those labelled B in each block had nil fertilizer at planting but side dressed with a spoonful of calcium ammonium nitrate (CAN). The plots labelled C were planted with the supplementary fertilizer sample (SF_1) and side dressed with CAN. The plots labelled D were planted with Diammonium phosphate (DAP) and side dressed with calcium ammonium nitrate (CAN).

The fertiliser treatments were applied at designate intervals of 25 cm apart in harrows. Two seeds of maize variety DK were immediately added at the spots where fertilizer had been put. The seeds were covered with soil. Weeding was done 23 days after germination to control weeds and improve soil tilts. Side dressing (2^{nd} fertilizer application) was done immediately after 24 days of planting. The second and last cultivation was done after 40 days of planting.

Efficacy Measurements were done. The rate of growth of maize was determined by measuring the heights of each plant using ruler/tape measure weekly. Deficiency symptoms, pest and insect (stalk borer) infestations were observed and recorded fortnightly until harvest time. The maize from each plant in designate plots under given treatments was harvested, shelled and dried in the sun with weighing for five days until a constant weight was attained. The produce per plot, on the whole, was weighed before 100 seeds were randomly withdrawn and rotten seeds physically counted to evaluate percentage (%) impact of pests and insects (stalk borer) during the growing of maize.

The data generated were analysed by SPSS version 21.0. The mean levels of potassium, nitrogen, phosphorus and calcium in the samples were determined with the intention of aiding in selecting and apportioning roles of different biomass in the formulation of SF. Analysis of variance (ANOVA) was used to compare pH values of site soil samples as well as mean heights and yields of maize plants from plots under different fertilizer schedules. This was intending to establish if any variations existed between treatments. Post hoc analysis assuming Duncun's equal variances was done to help separate and identify the causes of variation.

3. RESULTS AND DISCUSSION

3.1 Macronutrients Levels in Biomass

The average levels of macronutrients (nitrogen, phosphorous, potassium and calcium) in different agricultural farm biomass summarized as in Table 1.

Maize cobs are notably higher in potassium (429.57±111.210 mg/100 g) than sugar cane Bagasse and horns/hoofs that had

157.045±3.658 and 13.081 mg/100 g respectively. The cobs had lower nitrogen levels compared with the maize stalks (258.17±136.32 and 587.17±211.89 mg/100 g). Cattle horns/hoofs showed the highest levels of nitrogen of the farm biomass studied (4145.60 ±763.34 mg/100 g). They, however, had lower quantities of phosphorous, potassium and calcium. The sisal biomass is key in providing on average the highest of each the of macro elements. Horns and hoofs, as well as sisal leaf biomass, showed higher levels of nitrogen than were in other farm wastes. Sisal leaf biomass, however, had higher amounts (mg/100 g) of phosphorous (274.900±127.585), potassium (2194.68±420.51) and calcium (3419.023± 1309.171 g) compared to other farm biomass. Fig. 1 shows a comparison of the macronutrients in the biomass assessed.

The horn/hoof digest had the highest of nitrogen while maize cobs had the least. Since sisal leaf wastes had also high levels of nitrogen it was therefore important that both sisal leaf waste and horn/hoof digest be considered as the main sources for nitrogen in the formulation. The levels of phosphorus and potassium were highest in the sisal wastes suggesting their use in the formulation. Maize cobs, maize stalks and sugar cane bagasse had relatively less potassium than sisal leave biomass and either of them could be burnt to produce ash needed for lye production to decompose sisal and derive ammonia from the HD. For this study maize cobs were preferred due the convenience of transporting as the weight for weight are less bulky moreover since lower in nitrogen and phosphorous than stalks was found ideal to test the viability of corn stover in formulating a supplementary fertilizer.

Agricultural farm biomass can supplement each other in the provision of plant macronutrients in the formulation of supplementary fertilizer (SF). Involvement of sisal wastes, hoof/horn, with either maize cobs or sugar cane bagasse or maize stalks would give a satisfactory supplementary fertilizer.

Table 1. The levels (mean ± SD mg/100 g, DM) of macronutrient in agricultural biomass, N=30

Farm biomass	Levels of macronutrients (mg/100 g), DM in farm wastes			
	Total Nitrogen	Phosphorous	Potassium	Calcium
Maize cobs	258.17 ±136.32	36.67± 11.927	429.57 ±111.210	142.104±34.459
Maize stalks	587.17±211.89	45.41±15.77	525.221±138.622	345.730±103.337
Horns / hoofs	4145.60±763.34	70.083±21.247	13.081±2.841	101.85±17.69
Sisal leaf	1772.93±469.57	274.900±127.585	2194.68±420.51	3719.023±1309.171
Sugarcane bagasse	371.32±14.43	45.127±14.419	157.045±3.658	73.088±11.567

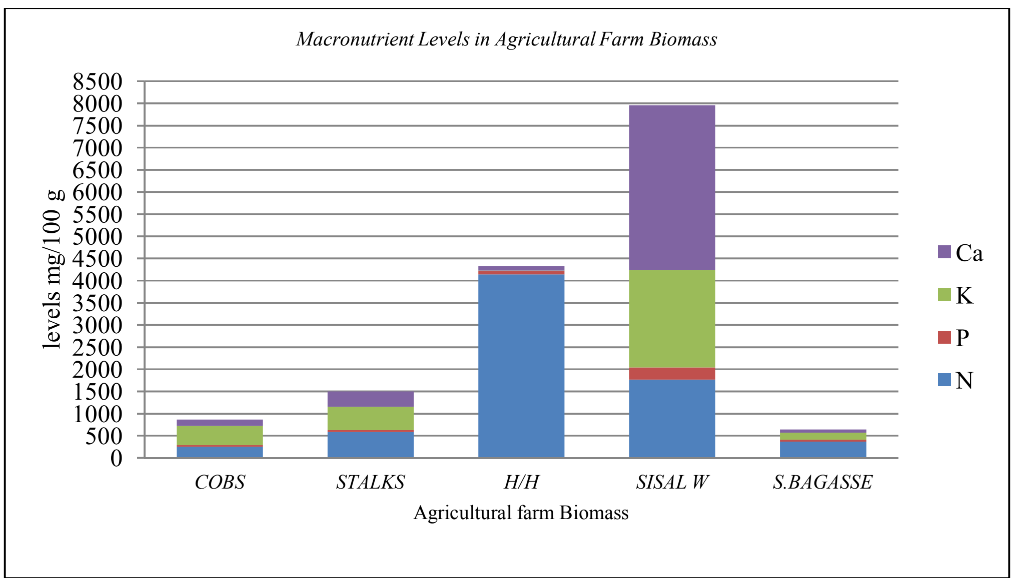

Fig. 1. A stack column diagram comparing levels of macronutrients in agricultural biomass

3.2 Supplementary Fertilizer (SF) Formulation

The formulation process sought to shorten the composting period of agricultural farm biomass containing high levels of macronutrients. It entailed determining the study site soil pH to guide on the nature of the supplementary fertilizer (SF) to be formulated, selecting agricultural biomass rich in plant macronutrients, investigating of pH changes in pretreated sisal leaves and establishing formulation ratios in which the biomass could be the blend for an effective and appropriate SF. A supplementary fertilizer investigated for its effectiveness depended on the pH of the soils.

3.3 Soil pH

Preliminary soil pH tests in the plots within the study area were carried out to guide on the choice of appropriate SF and crop to be used. This was necessary since formulations ideal for acidic, neutral or alkaline soils were possible and that growth of crops like maize is sensitive to the soil pH (Table 2).

Table 2. The mean soil pH values (± SD) of field study site soils

Plot label	pH (Mean ± SD)
A1	6.377±0.154
A2	6.330±0.180
A3	6.423±0.237
B1	6.413±0.226
B2	6.323±0.180
B3	6.437±0.152
C1	6.753±0.133
C2	6.63±0.880
C3	6.600±0.257
Mean pH value	6.476±0.367
P-value	0.111

N = 5

The pH of soils ranged 6.323±0.180 to 6.753±0.133 giving a mean of 6.476±0.367. This implied that soils were moderately acidic [10,11]. The soil pH in the study area (Lugari) is affected by the nearby Rai Paper Factory that releases SO_2 and Cl_2 waste gases into its environs. The soil acidity is also caused by long term use of nitrogen fertilizers especially ammonium-based ones that increase soil acidity by the conversion of ammonium to nitrates (nitrification) and H^+ ions are released to the soils. Legumes (beans and soya) grown as intercrops with maize in this area too increase acidity since these plants take up more cations in proportion to the anions [12]. This causes H^+ to be released from plant roots to maintain electrochemical balance within their tissues.

Soil pH ranging from 4.5 to 5.5 is classified as strongly acidic while that from 5.6-6.5 is moderately acidic [13]. Different plants require different soil pH levels, though optimum pH range for most plants is between 5.5 and 7.5 [14]. Low pH levels in soils are increased by applying lime or use of organic matter. The amount of time needed to change pH is determined by the mesh size of the lime and the buffering capacity of the soil [15]. Since the buffering capacity depends on the clay content, soils with higher buffering capacity require a greater amount of time and this can be an extra expense to farmers. A self pH regulating organic cum inorganic supplementary fertilizer would, therefore, be ideal. Moderately acidic soils require fertilizers of pH values above seven that are basic to counter and reduce acidity. The study site soils being acidic the formulation chosen for fieldwork was basic.

3.4 Formulation Ratios of the Supplementary Fertilizer

Lye (pH 8.5±0.67) was extracted from maize cobs ash. It was boiled with sisal leaf wastes to obtain cobs ash sisal digest (CASD). This was with a view that when used in the formulation it would provide both macronutrients readily and also an alkaline environment for the liberation of ammonia from the horn/hoof digests (HD). The alkalinity required by HD for maximum production of ammonia was determined by back titration. In this regard, HD was reacted with 2M NaOH. The amount of NaOH used was determined by titrating what remained with a standard 2 M HCl. The moles of the standard NaOH that reacted with HD was considered the moles of alkalinity needed for maximum production of ammonia from HD.

Moles of alkalinity available from the CASD was similarly determined by back titration. CASD was boiled with 2M HCl. The resulting solution was decanted and titrated with 2 M NaOH. The amount of 2 M HCl used against the decanted solution was equivalent to the alkalinity available in CASD. It was found that 2.40 ±0.15 moles alkalinity was available per 100 g CASD while 1.33±0.09 moles of alkalinity would be required to derive maximum ammonia from 100 g HD. To obtain a near-neutral supplementary fertilizer HD was mixed with CASD in the ratio 2:1. The supplementary formulation would be ideal for neutral soils. Other mixing ratios culminating into separate formulations became apparent and were made. For each formulation, the pH and % macronutrient levels were determined as well as the proximate nature of target soils (Table 3).

The cobs ash sisal digest (CASD), SF_0 provides relatively higher levels of each macronutrient phosphorus (0.17%), potassium (6.30%) and calcium (9.20%) except nitrogen (2.68%) compared to other formulations. It, however, would not be ideal for it is a strongly basic mixture (pH = 8.41±0.27) limiting its use to strongly acidic soils. Though macronutrients would be readily available when SF_0 is used, the pH range for proper growth of most plants 6.5-7.0 [16] limits its use. Addition of HD to obtain other formulations lowers the percentage concentration of macronutrients more so calcium from 9.20% to 3.46% as in SF_1. This is likely because the HD becomes a 'bulking material' as it has very little calcium. High calcium levels are associated with high pH values above 7.0 [17]. Typical calcium concentrations for plant growth are in the range 0.1-0.5% [18, 19]. Use of calcium increases the pore space in the soil. This is a desirable result until the pore space reaches 50% of the total soil volume but when too much of it is applied so much more pore space can result that the soil dries up much easier than before [20]. Thus availing a lower percentage of calcium per plant would minimize these effects in the long run.

Phosphate is pH sensitive and its availability in the soil increases with the rising in pH but if unduly increased phosphates tie up elements such as boron, iron, manganese, copper, potassium, magnesium and zinc. This makes them unavailable to plants and deficiencies occur [20]. Typical concentrations of other macronutrients sufficient for plant growth are 15000 mg/kg (1.5%) nitrogen, 2,000 mg/kg (0.2%) phosphorous, 10,000 mg/kg (1.0%) potassium [18]. Use of horn/hoof digests (HD) as in the formulation SF_5 provides highest levels of nitrogen (3.96%) but little of other macronutrients. Moreover, it is acidic for had pH value lower than seven. An increase in the amounts of HD used in the formulation while holding the amounts of CASD constant led to a lowering of pH of the resulting SF. This was indicative that the reaction of HD in the presence of moisture with the alkalinity in CASD is rapid and removal of OH^- was rapid. Both CASD and HD must be kept dry.

Acidic, neutral or basic soils require different ratios (HD: CASD) for optimum growth of plants. Mixing HD and CASD in equal mass ratios give an alkaline formulation (SF_1) source of macronutrients. Alkaline fertilizers such as SF_1 are ideal for acidic soils pH range 5.5-6.5 for maximum crop production. Apart from CASD contributing macronutrients, it avails alkaline conditions that not only activate decomposition of HD in the formulation but also be useful in acidic soils. Acidic soils limit the availability of some essential plant nutrients and promote toxic elements such as aluminium and manganese causing poor crop performance and failure [21]. Soils with pH below 5.5 make aluminium to be concentrated limiting or stopping root development. As a result, plants cannot absorb water and nutrients, get stunted and exhibit nutrient deficiency symptoms, especially those for phosphorus. Toxic levels of manganese interfere with normal growth process in the aerial plant parts that stunts the plant discolouring and causing poor yields. Use of SF_1 provides a less expensive approach in countering soil acidity compared with current approaches that include the addition of basic materials like calcium carbonate, or calcium oxide or calcium hydroxide to neutralize the acid present [22].

The SF_2 has only sufficient alkaline conditions to activate the HD and is ideal for soils pH range 6.8-7.2 while SF_3 with excess HD would need a basic environment to assist activating it. SF_3 works well in soils pH range 7.5-8.5 that may arise due to over liming acidic soils or use of alkaline irrigation waters [13]. Acidic soils arise due to acid rain; continued use of ammonium (NH_4^+) based fertilizers and organic matter decomposition which acidifies the soil by producing H^+ [23]. In modifying soil pH the addition of amendments and fertilizers, tillage practices, levels of soil organic matter and drainage practices have been proposed [23]. Common soil pH amendments used to acidify alkaline soils include sulphur, iron (II) sulphate and aluminium sulphate [22, 24]. Due to the technicality that surrounds the use of aluminium sulphate, utilization of organic matter has been recommended [25]. This study proposes the use of the formulation SF_3 derived by mixing HD: CASD in the ratio of 3:1 for basic soils. It will not only maximize NH_3 production but utilize the alkaline conditions in the plant environment thereby lowering the pH.

Table 3. pH and percentage macronutrient levels available in SF formulation mixtures

Formulation	Mixing ratio HD: CASD	pH	Target Soils	% Macronutrients in formulations (100 g)			
				N	P	K	Ca
SF_0	0:1	8.41±0.27	Acidic	2.68	0.17	6.30	9.20
SF_1	1:1	8.06±0.21	Acidic	3.11	0.08	2.50	3.46
SF_2	2:1	7.15±0.18	Neutral	3.49	0.04	1.34	1.97
SF_3	3:1	6.71±0.20	Basic	3.54	0.03	0.94	1.37
SF_4	1:2	8.23±0.25	Acidic	2.85	0.07	3.13	4.57
SF_5	1:0	6.82±0.15	Basic	3.96	0.002	0.001	0.08

N=15

3.5 The Efficacy of the Supplementary Fertilizer (SF)

The ability of the Supplementary Fertilizer (SF) to produce desired results (effectiveness) in terms of healthy plants and improving yield was evaluated. The growth characteristics of maize (DK variety) under different fertilizer schedules, pest infestation and yield were monitored.

In normal practice, maize is planted in Kenya with DAP or NPK and side dressed with CAN. This raises DAP/CAN or NPK/CAN fertilizer schedule. To evaluate the SF effectiveness varying schedules including SF/SF, SF/CAN, NIL/CAN and DAP/CAN were considered and used in designate plots during planting and side dressing of maize (variety DK). Since field soils in Lugari were of pH of 6.476±0.367 (Table 2), the supplementary fertilizer chosen was SF_1 of pH of 8.06. The growth characteristics evaluated for efficacy of SF_1 were plant height measurement, leaf properties and insect attack.

The height of each plant was measured weekly to establish differences caused by the use of different fertilizer schedules. The mean ± SD height attainments of maize plants under the test schedules were found (Table 4).

Maize seeds planted under designate fertilizer schedules significantly varied (p = 0.000) in the period (days) taken before sprouting out of the soil. Plots under NIL/CAN and DAP/CAN schedules took 9 and 10 days respectively to germinate out of the soil while those under SF/SF and SF/CAN took at least 13 days. Seed germination depends on the fertilizer used [26]. Terence [27] reported that high fertilizer levels and low moisture results in reduced seedlings emergence. One characteristic feature of any fertilizer is being hygroscopic [28]. The extent of hygroscopy differs from fertilizer to fertilizer [28]. There is a likelihood of SF being more hygroscopic than DAP and that it, therefore, absorbs more moisture dehydrating the seed environment thus causing a delay in germination. Seed germination and emergence as affected by osmotic potential (stress) in its environment [29].

The maize seedlings under SF_1/SF_1 treatment had a mean height of 6.700±3.001 cm. They were not significantly different from those under SF_1/CAN (5.250±2.350) after two weeks of planting. The mean heights of plants under SF_1/CAN schedule were significantly different from NIL/CAN and DAP/CAN. This meant the maize seeds planted with SF delayed in germinating compared to those controls of nil fertilizer at planting as well the ones in which DAP was used. The seedlings under NIL/CAN and DAP/CAN attained greater heights of 8.759±2.868 and 7.923±2.837 respectively.

Crops of different species respond differently to pH reflecting the genetic diversity among the species [30]. The study site soils were acidic with pH range 5.923-6.437 and SF_1 used in this case provided an alkaline environment that not only neutralized the soil but also left it alkaline and may have caused the difference. In the assessment of the effectiveness of cultivating and treatment of maize cultivars and the use of organic and inorganic fertilizers as options for management of soil acidity the best soils for maize are those moderately acidic to neutral in the pH ranges 5.5-7.5. Alkaline soil conditions due to the use of SF_1 could have caused the delay in week one. In the study of effects of the long application of organic and inorganic fertilizers on soil organic and physical properties in maize-wheat rotation [31] found that balanced fertilization had improved soil physical properties including pH.

A comparison of mean heights attained by each schedule per week across the entire period showed a significant difference ($p \leq 0.05$). Initially, SF/SF and SF/CAN maize plants lagged as NIL/CAN and DAP/CAN took lead in mean

Table 4. Heights (cm) of maize plants under different fertilizer schedules

Fertilizer schedule	Sprout period (Days)	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
SF/SF	13	6.7003.001[ab]	27.750±4.503[a]	39.850±6.469[b]	73.525±12.391[b]	102.800±16.732[b]	135.413±22.917[b]
NIL/CAN	9	8.759±2.868[a]	27.164±6.424[ab]	36.977±9.941[b]	62.600±12.243[b]	90.641±14.809[b]	121.250±17.179[b]
DAP/CAN	10	7.923±2.837[a]	33.023±7.191[a]	52.509±8.783[a]	96.764±13.754[a]	137.741±12.423[a]	163.377±22.604[a]
SF/CAN	13	7.662±2.993	28.812±7.079	42.109±11.615	72.986 ±21.508	105.055±28.232	133.024±31.363
Mean±SD		7.662±2.993	28.812±7.079	42.109±11.615	72.986±21.508	105.055±28.232	133.024±31.363
P –Value		0.030	0.001	0.000	0.000	0.000	0.000

N = 50. ANOVA, those with same suffixes had no significant difference heights attained especially after week one. The height of maize planted with the formulation SF1 was 6.700±3.001 cm, a week after germination. The height increased to 27.750±4.503 cm in week 3, an increase of 20.050 cm. The increase in height in week 4 was only 12.10 cm while in succeeding weeks 33.675, 27.275 and 32.614 cm reaching a height 135.413±22.917 cm 7^{th} week. Monocots like maize show linear growth [32]. The height was significantly lower than DAP/CAN schedule maize plants that attained 163.377±22.604 cm but significantly higher than those SF_1/CAN schedule 95.867.

Differences within SF_1/SF_1 plants reflect variations in age of organic material, rate of decomposition, application method, timing and incorporation time as earlier observed [32]. The closeness to DAP/CAN schedule means height deviations signify resemblance in the availability of the necessary plant macronutrients during the period. This high height attainment in DAP/CAN schedule compared to SF_1/SF_1 can be attributed to the definite levels of phosphorous in the commercial fertilizer DAP used. As reported in earlier studies plants need phosphorous for strong root growth, fruit, stem and seed development, disease resistance and general plant vigour [33].

Leaf properties indicate deficiencies in plants. Leaf colourations of the maize plants under different treatments were periodically checked. The purple colouration of the leaves was observed during 2^{nd} and 3^{rd} weeks in plots A (SF/SF), B (NIL/CAN) and C (SF/CAN) compared to those in plot D under DAP/CAN (Plate 1).

Purple colouration in the maize leaves implied phosphorous deficiencies. Phosphorous has an essential part in the process of photosynthesis, helps in changing light energy into chemical energy, assists in rapid growth as well as plant and root growth [34]. When side dressing with SF_1 was done on the affected maize, the purple colouration on the new leaves had been eliminated a week later. The maize plants under the schedule under DAP did not show phosphorous deficiency within the same period. This is attributed to a sufficient amount of phosphorus in commercial fertilizer. Applying SF_1 (50 g of the formulation of 500 ml water) provided sufficient phosphorous for the growth of maize and deficiency earlier observed was cleared.

Pests like stalk borer attack maize stem, fruit cobs or the tassel aerials with varying effects on the yield. Attacked maize is characterized by wilting or dying of the upper leaves or by ragged irregular holes chewed in the newly unrolled leaves. Many approaches have been proposed to control this damage including planting early, maintaining soil fertility or practices that increase nitrogen availability, powdered neem tree leaves and use of wood ash mixed with pepper among others [35]. The study sought to establish if the use of supplementary fertilizer (SF_1) had any control effect on growth and yield of maize (Plate 2).

The percentage attack (visible) by the stalk borer on maize in plots under different fertilizer schedules were assessed across all the sets as in Table 5.

Table 5. The plants (%) attacked with stock borer

Plot No.	Treatment schedule: Planting and side dressing	% of plants attacked
A	SF_1/SF_1	14.3
B	NIL/CAN	77.8
C	SF_1/CAN	33.2
D	DAP/CAN	4.2

Maize plants in plots labeled D that had treatment schedule of planting with diammonium phosphate (DAP) followed by calcium ammonium nitrate (CAN) side-dressing was the least attacked (4.2%) by the stalk borer. This observation could be attributed to the level of nitrogen in the doses of DAP and CAN used were sufficient amounts of nitrogen limits the attack [36, 37]. In separate studies on the effect of nitrogen levels on the infestation by stalk borers established that high nitrogen levels equal to or greater than 200 kg/ha minimizes the attack. The same studies affirmed that the use of doses lower than 200 kg/ha nitrogen made the maize susceptible to attack. Limiting levels of nitrogen by restricting fertilizer application at top dressing with CAN as in the plots labeled B that had 77.8% of the plants attacked. The attack was independent of the position of the plot.

Right levels of nitrogen (≥ 200 kg/Ha) minimize stalk borer attack. Plots A that was on SF_1/ SF_1 had 14.3% of maize attacked which was much lower than in plots B. Substituting SF with CAN during top dressing in plots labeled C that had 33.2% of the plants attacked implying that use of SF was better than CAN. The low attack on the plants using formulations schedule could also be explained based on insecticidal characteristics of the materials used in the formulation.

The role of chemicals in controlling the stalk borer attack on maize has been explained in separate studies [36]. while investigating the effect of different nitrogen fertilizer levels reported that treatment of the soil in the crop environment with diazinon in addition to right quantities of nitrogen fertilizer significantly reduced the damage by the stalk borers. Thus apart from providing sufficient levels of nitrogen the formulation's effectiveness in lowering the stalk borer attack can also be attributed to insecticidal properties from sisal (*Agave sisalana*) and maize cobs ash [38]. While testing a leaf extract of *Agave sisalana* as a larvicide established that the extract had significant activity against Anopheles *stephensi*, culex *guinquefasciatus* and *Aedes aegypti* larvae. Both Singh, et al. [39,40] reported sisal waste to have insecticidal properties. The study on the phytochemical and anti-microbial screening of *Agave Sisalana* perrine juice (waste) reported the presence of Saponins, glycosides, phlobatannins, terpenoids and flavonoids all of which are pathogenic against insects [41]. The effectiveness of maize cob powder in controlling weevils in stored maize grain [42] has also been reported indicating its importance in the formulation.

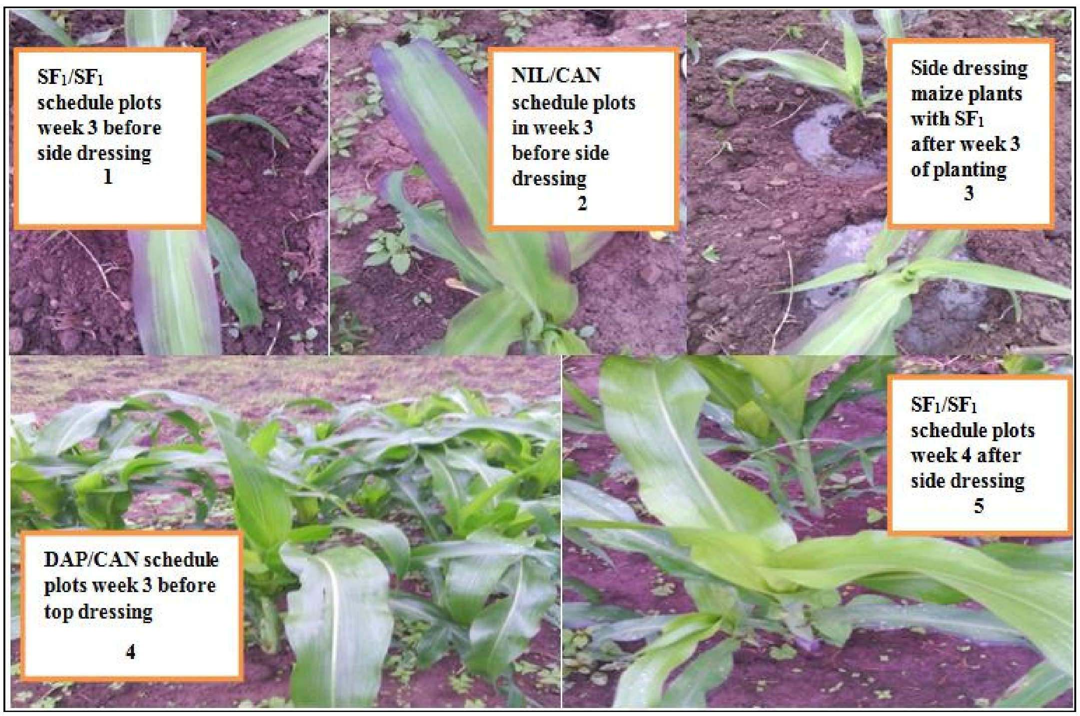

Plate 1. Leaf properties in maize under different fertilizer schedules

Plate 2. Stalk borer attack on maize fruits stems and tassels

3.6 Maize Yield

Maize from designate plots was harvested, labeled, shelled and dried separately per plot. The dried maize was weighed per plot to establish if any significant impacts were made on the yield by the varying fertilizer schedules. Table 6 shows the results.

The mean yield of maize (kg) in plots under different treatments significantly differed (p=0.002). Plots labeled A under SF_1/SF_1 produced 1.794±0.68 Kg per plot. This was near plots D under DAP/CAN (1.954±0.72 Kg). The yield was significantly higher than in plots B and C. The closeness of yields in plots A and D signify similarity in the inputs. Though the mass of maize is influenced by many factors presence of available and sufficient levels of phosphorous and potassium is important for maize yield. Maize seeds are significantly higher in phosphorous (299.6 mg/100 g) and potassium (324.8 mg/100g) compared to calcium that is only 48.3 mg/100 g [43]. Phosphorous and potassium levels influence the mass of maize seeds. The yields in plots B were lower than the control because they not only relied on soils phosphorous and potassium but also attack from the stock borer. On the other hand yields in plots, C was low for available phosphorus from SF_1 must have been precipitated and made unavailable for the growth and yield of maize by calcium from CAN used for topdressing. It is recommended that the formulation should not be used in combination with CAN.

The impact of stalk borer (*Papaipema nebris*) on the maize yield from the plots under varied fertilizer schedules was investigated. Yields from designate plots were sampled and percentage rote determined using standard procedures. It was observed that yields from SF_1 /SF_1 schedules exhibited an average of 12% rote. This was high compared to DAP/CAN fertilizer schedule (6.5%) but lower than the damage of the schedules SF/CAN (28.5%) and NIL/CAN (72.5%) had. The stalk borer causes injury to maize either by feeding on the leaves or stalk tunneling. The stalk tunneling destroys the growing point causing the whorl to die [44]. The plants that survive the attack do not produce normal-sized ears. [45] reported a maize grain reduction range 49-89% of the yield when plants are attacked by the stalk borer.

Many methods of controlling stalk borer infestation including use of biological and environmental influence [46], cultural practices like planting date or weed control [47], use of herbicides [44] and use mixtures of herbicides and insecticides [48] have been reported. Mixed herbicides and insecticides not only destroy weeds that act as pre-host but also suppress the development of the larval stage. SF/SF schedule's impact in minimizing the yield rote arises from insecticidal properties of materials sisal leaf wastes [38] and maize cobs powder [42]. The results imply that the formulation can minimize stalk borer attack.

The yield per plot (2x2 m^2) under the same treatment in different sets was weighed and used to calculate projected yield (90 kg bags) per acre (Table 7).

The use of DAP-CAN schedule in plots labelled D would produce the highest number of 90 kg bags (22) per acre, followed by the formulation schedule (SF_1/ SF_1) that indicated an average of 20.3 (90 kg bags) of maize per acre. The yield range of 16-22 bags per acre is in the range of maize production per acre in the study area. According to a household survey data collected by Tegemeo Institute most farmers in the high potential maize zones including Lugari in Kenya produce 15-30 bags per acre while those in agro-ecologically less favourable zones typically obtain less than 5 bags per acre [49]. Activities in the high maize production potential areas by the Kenya maize development Programme (KMDP) in the period 2002-2010 tripled smallholder farmer maize yields from a baseline output of 8 bags an acre to an average of 26 bags an acre [50]. This affirms the Tegemeo survey. The results of this study indicate that the formulation (SF) is as good as commercial fertilizers in the growing of maize.

Table 6. Mean yield ± SD and % rote of maize per plot under different fertilizer schedules

Plot label	Fertilizer schedule (Treatment)	Mean yield± SD (Kg/ plot)	% Rote
A	SF_1/SF_1	1.794±0.68	12.0
B	NIL/CAN	1.040±0.22	72.0
C	SF_1/CAN	1.509±0.45	28.5
D	DAP/CAN	1.954±0.72	6.5
P - value		0.002	0.000

Table 7. The projected yield (maize) per acre under different fertilizer schedules

Plot label	Treatment		No. of 90 kg bags per Acre
	Planting	Side dressing	
A	SF	SF	20.3
B	Nil	CAN	12.0
C	SF	CAN	17.0
D	DAP	CAN	22.0
P-value			0.003

4. CONCLUSION

Agricultural farm biomasses are rich in plant macronutrients and can supplement each other in formulations that can be used as supplementary fertilizers. Sisal leaf wastes, horn/hooves, maize cobs with varying levels of macronutrients were blended giving rise to SF_1. Other formulations involving horns/ hooves digests (HD) and Cobs Ash Sisal Digest (CASD) in ratios 0:1, 1:2, 2:1, 3:1, 1:2 and 1:0 as SF_0, SF_2, SF_3, SF_4 and SF_5 respectively were realized. These would be for soils of pH other than acidic. The supplementary fertilizer SF_1 used during fieldwork showed effectiveness in promoting growth, minimized macronutrient deficiency symptoms, improved pest (stalk borer) resistance and maximized the yield of maize. Trials with other formulations raised during the study on either maize or other crops within basic soils or under greenhouses are recommended.

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The Author has dedicate this to his mother, Agnes who without knowing, years ago, taught me effect of lye on cellulose (softening vegetables then!).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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