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Challenges of Soil Health Management by Small-Holder Farmers in Western Kenya: The C:N (Carbon: Nitrogen) Ratio Context in Composting

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Abstract: ***The project was conceived from the premise that there is a need to assist the Kenyan peasant farmers who at the moment do not use any soil fertility intervention measures, with the result that their soils are tired, and the yields cannot sustain them resulting in food insecurity. It is now known from the available literature that the composting cycle can be reduced from the current 3-6 months to a much shorter time. What makes this possible is an inoculant made up of some soil inhabiting microbes. What is also known is that for the microbes to reduce the compost maturity time, the Carbon: Nitrogen ratio is important, so the first investigation was to provide an answer to the question: By using a composting recipe with a set C: N ratio between 25—30:1, can the maturity time of the compost be reduced, even if an inoculant is not added, and if so what would the maturity time in days be, compared to where an inoculant is used? The project therefore started by carrying out substrate chemical analysis to determine their total dry matter content. From such results the project narrowed down to analysis of Carbon and Nitrogen contents, then calculate the C: N ratios of the substrates, and developed a composting recipe for each major substrate, including sugarcane bagasse which is abundant in the project area. From the efficacy tests it was found that by using the desired C:N ratio of between 25-30, the composting maturity time was considerably reduced.***

Keywords: Carbon Nitrogen Ratio (C:N Ratio), Soil Health, Agricultural Substrates, Composting recipes, compost maturity.

1. Introduction

1.1. Background

Western Kenya with mean household size of five (Kenya Economic Review 2008), has 210,000 households whose production of maize averages three 90kg bags per acre (De Groote et al. 2002).This low yield of staple food crop translates to food insecurity, undernourishment and predisposition to diseases for up to eight months in any one year. Many of these farmers also grow some cash crops; of which sugar cane is of greater significance as they grow it as out growers to one and sometimes more sugar cane factories, which normally provide them with not just technical backstopping, but also by providing inputs either directly or providing funds for the same. Despite the support they get, the cane yields are still low, and indeed has been on a downward trend without hope of reversing the trend.

The reason for such low yields is a combination between soil fertility and the striga (*striga hermontheca*) weed; a parasitic weed that attacks several cereal crops. Through the stewardship of the African Agricultural Technology

Foundation (AATF), some maize varieties that "kill" striga weed have been developed (Manyong et al. 2008).However, the yields still remain low because the soils are exhausted as the target farmers neither use inorganic fertilizers, principally on account of cost, nor other soil health intervention measures like composts, farm yard manures, green manures etc.

This trend therefore set the stage for an attempt to improve the yields through improved compost technology which would be cost effective for the farmers. Compost is the product of an aerobic process during which microorganisms decompose organic matter into a stable organic material. This can be used as a soil amendment or as a medium to grow plants. Mature compost is a stable material with humus, a dark brown or black substance with a soil-like, earthy smell (Peterson et al. 2007).

Although composting has been practiced for thousands of years, it was not until the end of the twentieth century that controlled scientific studies were published illustrating the benefits of compost in crop production. These studies helped to spur increased interest in composting and compost use, and led to the development of commercial composting facilities that supply finished compost products (Fitzpatrick et al. 2005).

1.1.1 The Carbon-to-Nitrogen Ratio (C:N Ratio)

All organic matter is made up of substantial amounts of carbon C, combined with lesser amounts of nitrogen N. The balance of these two elements in an organism is called the carbon-to-nitrogen ratio (C:N ratio). For best performance, the compost piles, or composting microorganisms, require the correct proportion of carbon for energy and nitrogen for protein synthesis. Scientists have determined that the fastest way to produce fertile sweet-smelling compost is to maintain a C:N ratio somewhere between 25 to 30. If the C:N ratio is too high, the decomposition slows down. If the C:N ratio is too low (excess nitrogen), the pile ends up stinking. Many ingredients for composting do not have the ideal ratio of 25-30:1.As a result, most must be mixed to create "the perfect compost recipe" (Richards *et al.* 2009).

1.2. Problem Statement

Composting has not been given the attention it deserves in Kenya, and more particularly in Western Kenya. Here there are plenty of agricultural wastes, such as sugar cane bagasse, maize stovers, grass clippings, rice husks, cattle manure and chicken manure, none of which has been utilized in an organized way to improve soil health.

There are no recorded interventions that can be employed to convert these wastes into composts which may be used as complimentary to, and/or a replacement to inorganic fertilizers. If some composting has been done, it has been done haphazardly and the duration of maturity has not been addressed. Equally, no record is available on the level of usage of composts and the rate of uptake of agricultural technologies by the farming community in the project area. The C:N Ratio is known to be critical in the composting process. For the project area, the C:N ratio of the various agricultural wastes have not been documented, and yet it is known that any C:N ratio outside 25-30:1, cannot allow rapid composting even if an inoculant is added to the composting feedstock.

1.3. Objectives of the study

1.3.1 Main Objective

The main objective of this study was to illustrate that application of the correct C:N Ratio (25-30:1) will shorten compost maturity time.

1.3.2 Specific Objectives

a. To identify and chose locally available agricultural wastes (substrates) suitable for composting
b. To determine C:N rations of each of the agricultural substrates based on their chemical composition
c. To formulate compost recipes (based on ideal C:N Ratios 25-30) from the agricultural wastes for use to test the efficacy of the EMI at enhancing compost maturity

2. Materials and Methods

2.1. Chemical Procedures used for Analyzing the Chemical Contents of the Substrates

Substrate samples are often contaminated by fungicides, nutrient sprays, soil, or dust. They were therefore first decontaminated by quickly rinsing in a dilute chlorine detergent solution (2%) followed by two distilled water rinses.

Following rinsing, the samples were blotted dry with absorbent paper, and first air-dried for six hours, and then oven-dried to bring the moisture down to 12% before shipment in a plant analysis mailing kit that was provided by the research station.

The samples were taken to Taichung Agricultural Research Station in Taiwan because Great Lakes University of Kisumu (GLUK) had a working relationships with the research station, and secondly and most relevant to this study, they have the equipment and the necessary technical capabilities to carry out this analysis.

2.2. Determination of Nitrogen

The SEAL analytical programmable Block Digestion System was used to determine the Total Kjeldahl Nitrogen (TKN). 2 grams of semi ground substrate material was put in a 250 ml tube inside individual ceramic heaters surrounded by 1" thick insulation board housed in chemically-etched aluminum casing with two fold-down handles. A heater element was encapsulated in each.

The digestion reagent was formulated to permit determination of Kjeldahl nitrogen. Mercury in this reagent catalyzes the breakdown of organic nitrogen compounds. Colorimetry completed the determination. 20ml of concentrated sulfuric acid [H2SO4, sp gr 1.84] was added to 70 ml of deionized water contained in a 1L volumetric flask with constant mixing. This solution was allowed to cool, then diluted to the mark with deionized water, and mixed well. This reagent was transferred to a plastic bottle at room temperature.

2.5 ml of 3.6 M sulfuric acid was added to 4.0 g of red mercury (II) oxide [HgO, FW 216.59] contained in a 100-ml Griffin beaker. The beaker was placed in an ultrasonic bath to speed dissolution. The resulting solution was then immediately used to prepare the digestion reagent.

Digestion

26.8 g of potassium sulfate [K2SO4, FW = 174.27] was added to 130 ml of deionized water contained in a 2-L volumetric flask. 400 ml of concentrated sulfuric acid [H2SO4, sp gr = 1.84] was added with constant mixing, and then added the mercury sulfate solution. The flask was placed in an ultrasonic bath to speed dissolution. This solution was then allowed to cool, diluted to the mark with deionized water, and mixed well. This reagent was transferred to a glass bottle or dispensing apparatus, and stored at or above 20^0C to prevent precipitation of potassium sulfate.

Colorimetry

A 200 ml aliquot of the above mixture was then subjected to colorimetric measurements cautiously adding 78 ml of concentrated sulfuric acid [H2SO4, sp gr 1.84] to 150 ml of deionized water contained in a 2-L volumetric flask with constant mixing. Added 54 g of potassium sulfate [K2SO4, FW = 174.27 g], and after it had dissolved, allowed the solution to cool. Then diluted to the mark with deionized water, and mixed well. This solution was transferred to plastic bottles at room temperature. Concentration of Nitrogen was thus determined by the SEAL BLOCK automated digestion system.

2.3. Determination of Carbon

For accuracy of determination, two independent methods were used and their results compared:

i. Dry combustion method (975ºC) was performed with a Vario EL *II* analyzer (Elementar Analysensysteme, Hanau, Germany) detecting carbon as CO_2. The detection limit for carbon was 0.4 μg. Tissue samples of about 30 mg were used.

ii. The Walkley-Black procedure of C analysis was based on the description of Nelson & Sommers (1996), with adaptation to the employment of external heat (Tedesco et al., 1995). The heating was provided by swirling the suspension over a Bunsen burner-flame after the addition of H_2SO_4 and was controlled so that the initial temperature of 120ºC could rise to 150ºC within one minute. Tissue samples of about 0.50 g were used.

The other elements (Ca %, Mg %, Na % Fe ppm, Mn ppm, Zn ppm, Cu ppm, B ppm.) were determined by the standard laboratory test methods

2.4 Determining C:N ratios of each of the agricultural substrates

2.4.1. Calculations of C:N ratios.

A desired C:N ratio was set, then using the formula of Richard *et al*. (1996); in a relationship given as:

$$R = \frac{Q_1 (C_1 x (100- M_1) + Q_2 (C_2 x (100-M_2) + Q_3 (C_3 x (100-M_3) + \ldots Q_n (C_n (100-M_n)}{Q_1 (N_1 x (100-M_1) + Q_2 (N_2 x (100- M_2) + Q_3 (N_3 x (100- M_3) + \ldots Q_n (N_n (100-M_n)}$$

where
R= Desired C:N ratio of the compost mixture
Q_n = Mass of material n
C_n = Carbon (%) of material n
N_n = Nitrogen (%) 0f material n
M_n = Moisture content (%) of material n

The above equation was used for a mixture of two or more materials, provided their; Carbon, Nitrogen, and C:N ratio set values are given or assumed, and specifying the mass of one ingredient. So the mass of the second and subsequent materials may be given by the following formula:-

$$Q_n = Q_1 \frac{x N_1 x (R- C_1) x (100 – M_1)}{(N_1)}$$

$$N_2 x \frac{(C_2 -- R) x (100—M_1)}{(N_2)}$$

Calculations were cross checked using Evans's formula (Evans 2009) as follows:

Calculate the pile's total carbon value by multiplying the % carbon of each ingredient by the number of parts by weight of that ingredient and then adding up all the carbon totals for all ingredients. Do the same for nitrogen then divide the carbon value (% or weight) by that of nitrogen. Adjust the proportions of ingredients to bring it to the required ratio. In this project, Evans formula has been used

2.5 Formulating compost recipes from the agricultural wastes based on the desired C:N Ratios

Desired C:N ratio is the basis of making compost recipes. Using Evans formula the following substrates; rice husk, maize stalk, sorghum stalk, sugar cane bagasse, saw dust, soya meal and grass clippings were first subjected to chemical analysis, and then their carbon and nitrogen values used to calculate the ratios. Using set C:N ratios, recipes were developed by balancing the carbon based substrates and the nitrogen based substrates.

2.6 Testing the efficacy of the C:N Ratio based recipes on composting feedstock

Six Treatments in a Randomized Complete Block Design (RCBD) replicated three times was the design shown in Table 1 below:

Table 1: Design Arrangement of the Compost Piles

Trt 1	Trt 4	Trt 3
Trt 2	Trt 6	Trt 1
Trt 3	Trt 1	Trt 4
Trt 4	Trt 5	Trt 6
Trt 5	Trt 3	Trt 2
Trt 6	Trt 2	Trt 5

Where:-
Trt 1 = Rice husk composting recipe C:N ratio 30:1
Trt 2 = Rice husk recipe + EMI (500gms)
Trt 3 = Grass clippings recipe + EMI (500 gms)
Trt 4 = Mixed agricultural wastes with no known C:N ratio + EMI (500gms)
Trt 5 = Mixed agricultural wastes with no known C:N ratio with no EMI (1000gms)
Trt 6 = Mixed wastes of no known C: N ratio.
The unit measure was days to compost maturity, and the data was analyzed by Analysis of Variance (ANOVA)

2.7. Maturity Indicators for the Compost

The parameters used in this study were the following:

i) No Temperature variations
ii) No odors
iii) pH of around 7.0
iv) Physical appearance
v) Size of heap reduced to around 70% of the starting **feedstock**
vi) Germination test

3. Results

3.1 The Chemical composition of various substrates

Table 2: Chemical Components of Local Agricultural Wastes

Organic Wastes	*C/N Ratio*	*C %*	*N %*	*P %*	*K %*	*Ca %*	*Mg %*	*Na %*	*Fe ppm*	*Mn ppm*	*Zn ppm*	*Cu ppm*	*B ppm*
Bagasse from Muhoroni	179.4	57.4	0.32	0.03	0.18	0.11	0.076	0.16	2438.6	117.7	43.7	32.4	0.0
Bagasse frm Chemelil	155.4	57.5	0.37	0.02	0.14	0.11	0.55	0.21	1158.5	55.4	14.5	8.9	0.0
Bagasse frm Kibos	230.8	57.7	0.21	0.02	o.11	0.069	0.039	0.089	787.7	45.3	11.2	7.4	0.0
Compost Day 1	91.5	42.1	0.46	0.01	0.36	0.27	0.19	0.16	1159.9	1344.5	49.4	6.1	0.0
Compost Day 4	85.7	51.4	0.60	0.01	0.47	1.13	0.23	0.15	1578.3	1469.8	70.9	6.9	0.0
Cattle Manure	33.8	40.2	1.19	0.02	0.64	1.49	0.36	0.18	1398.4	604.2	251.2	16.3	4.5
Chicken Manure	31.5	24.3	0.77	0.01	1.27	0.62	0.33	0.17	6228.6	4553.5	218.9	14.7	2.1
Rice Husk	220.8	55.2	0.25	0.01	0.36	0.086	0.065	0.012	371.1	390.9	19.3	2.6	0.0

3.2. Determining C:N ratios of each of the Agricultural Wastes

From the raw chemical components of the substrates shown in the above table, C:N ratios were calculated. A desired C:N ratio was then set using the formula of Richard *et al*. (1996). The various C:N ratios were calculated using a mixture of two or more materials. These calculations were cross checked using Evans's formula (Evans 2009), resulting in the following desired ratios: Sugar cane bagasse had a C:N ratio of 28.75, Rice husk 29.38, Maize stovers 25.06, Grass clippings 29.8, Soya bean meal 27.1, Rice straw 26.63 and Rice hull 29.1

3.3 Formulating Compost Recipes from the Agricultural Wastes

Evan's formula was used to develop the various recipes, one of which based on sugar cane bagasse is shown in Table 3 below. The same formula is used for other recipes based on rice hull, rice straw and saw dust.

Table 3: Recipe based on Sugar cane bagasse

Raw material	*C (%)*	*N (%)*	*Amount in a pile (KG)*	*C (KG)*	*N (KG)*	*C:N Ratio*
Bagasse	53	0.26	600	318	1.56	
Chicken manure	21.8	3.5	100	10	3.5	
Maize germ	52	1.76	90	26	1.76	
Cattle Manure	17.5	.8	200	11.4	1.3	
Urea	-	46	10	-	4.6	
Total amount			1000	365.4	12.72	28.73

Table 4: Results of compost maturity under natural conditions compared to project outputs:

Phase	*Time in Days Natural condition*	*Measured Time in Days S/Cane Bagase*	*Measured Time in Days Maize stovers*	*Measured Time in Days Grass clippings*
1	30			
2	300			
3	480			
4	720	108.7	103.8	73.5

3.3 Germination Test

Germination test was done using tomato seeds. Immature compost would not allow germination due to changing temperatures and pH

Plate 1: Testing compost maturity

The compost piles were set up to test:
1. The effectiveness of using the correct C: N ratios, alone and in comparison with the addition of EMI.
2. The efficacy of EMI in relation to compost maturity speed using some three commonly available substrates.
3. Over a period of two years, data was collected and the results obtained were analyzed using Analysis of Variance. A mean of three replicates is given in Table 5 below:

Table 5: Mean of 3 Replicates of days to maturity

		Compost maturity in days			
Trt	*Carrier*	*Maize stovers based pile*	*Sugar cane bagasse Based pile*	*Grass clippings Based pile*	
1.	Peat	63.0	71.3	41.7	Sum =175.6 SS=30835.36 MS=58.53
2.	Filter mud	71.7	77.3	48.7	Sum =197.7 SS=39085.29 MS=65.9
3.	Ant hill core soil	85.0	97.3	60.7	Sum =243.0 SS=59049.0 MS= 81
4.	Rice husk	104.7	109.0	69.0	Sum=282.7 SS=79919.29 MS=94.23
5.	Recipe pile without inoculants	138.3	139.7	94.0	Sum=372.0 SS= 138384 MS=124.0
6.	Inoculants on non recipe pile	160.0	158.0	120.3	Sum=438.0 SS=191844.0 MS= 146.0
		Sum = 622.7 SS = 387755.3 MS = 103.8	Sum = 651.9 SS = 424973.6 MS = 108.7	Sum = 440.7 SS = 194216.5 MS = 73.5	

3.4 Analysis of Variance

3.4.1. Analysis of Variance across the Substrates

These scores are then subjected to Analysis of Variance to test the significance of the differences between the different treatments (if any) in accordance with the following computational relationships:

i) $SS_{total} = \text{Sum } X^2 - \frac{G^2}{N}$

ii) $SS_{between} = [\text{ Sum } \frac{T^2}{n}] - \frac{G^2}{N}$

iii) $SS_{within} = \text{Sum } X^2 - \frac{(\text{Sum } X)^2}{N}$

iv) $SS_{total} = SS_{between} + SS_{within}$

and noting that, each df is associated with a specific SS,

Where;
X = Treatments
N = Total number of scores
G = Grad Mean
n = number of Treatments
T = Sum of b Treatments
SS = Sum of squares
Wherefore;

$$SS_{total} = (387755.3 + 424973.6 + 194216.5) - \frac{(622.7 + 651.9 + 440.7)^2}{21} = 1{,}254593.4$$

$$SS_{between} = [\frac{387755.3}{6} + \frac{424973.6}{6} + \frac{194216.5}{6} - 1{,}846.3 = 165977.9$$

SS_{within} = 1,254593.4 – 165977.9 = 1,088,615.5

So that:

Source	SS	df	MS	F
Between	165977.9	2	82988.95	2.0
Within	1,088,615.5	15	72574.4	

With df = (2, 15) F_O value of 2.0 and the corresponding F_C = 3.682 at P = ≤ 0.05, and is therefore statistically significant.
and

$$SS_{total} = [30835.4 + 39085.3 + 59049 + 79919.3 + 138384.0 + 191844] - [175.6 + 197.7 + 243 + 282.7 + 372 + 438] = 537605.7$$

$$SS_{between} = [\frac{30835.4}{3} + \frac{39085.3}{3} + \frac{59049}{3} + \frac{79919.3}{3} + \frac{138384}{3} + \frac{191844}{3}] - 162260.1 = 174440.8$$

SS_{within} = 537605.7-174440.8 = 363164.9
So that:

Source	SS	df	MS	F
Between	174440.8	2	87220.4	1.99998
Within	363164.9	15	24211	

With df =(2, 15), F_O value of 1.99998 against corresponding F_C = 3.682 at P $\leq$ 0.05, and therefore is statistically significant.

The results show that sterilized carriers significantly reduced the cfu (colony forming units) counts, and also significant reduction in maturity of the composts. Similar results were demonstrated by *Kuster et al*, 1966. Results also showed that better growth of soil microorganisms was found in sterilized carriers confirming results by *Hobben et al*, 1982; and *Rhoughley et al*, 1970.

4. Discussion on Challenges on Soil Health Management, Conclusions and Recommendations

4.1 Socio-cultural challenges on C:N ratio for Composting

In a related study, most of the smallholder farmers in the study area have land holdings under one hectare strewn about in scattered settlements. As it is now, these farmers are not able to generate sufficient compost feedstock to make more than two one-ton composting pile, which when matured will reduce to less than 700 kg of compost from each pile. Considering that the application dose for compost is some 15 mt per hectare or 6 mt per acre, composting as a means of maintaining or resuscitating soil health may not be an option for most of these farmers at this point in time. Considering that the population growth in this area is growing exponentially, the pressure on land is increasing at even a higher rate. Being able to feed the people in another 10 years will be such a challenge that the farmers will not be able to cope; and even the government will find it very difficult to feed people whose soil cannot produce any crop. Looked from that perspective, the concept of C:N ratio may be a useful technological tool, but will face serious constraints in its application.

4.2 Technological Challenges on C:N ratio for composting

The C:N ratios obtained from chemical analysis of various locally available substrates as shown in table 2 above; bagasse 203.8, maize stovers 68, sorghum stalks 73, rice straw 78, cattle manure 22, chicken manure 5.7, rice husks 87.5 and grass clippings 67.9 are way above the optimal 30 for carbonaceous source substrates and way below the 25 threshold for the nitrogenous source materials. Left on their own, they would not decompose and make composts. Organisms that decompose organic matter use carbon as a source of energy, and nitrogen for building cell structure.

When the energy source carbon is less than that required for converting available nitrogen into protein, organisms make full use of the available carbon and get rid of excess nitrogen as ammonia to the atmosphere. C: N ratio is a critical factor in composting to avoid nitrogen robbing from the soil, and conserving maximum nitrogen in the soil.

To ensure a compost feedstock will be useful for making rich compost and in the shortest time available, correct calculations have to be made to create the perfect compost recipes.

This is what was observed where the non-recipe treatment ranged from 120 to 160 days to mature compared with the best recipe treatment (peat on grass clippings) which ranged from 41 to 63 days to mature. This finding compares favorably with the experiments reported by other researchers; (Okalebo *et al*. 2005, Mucheru *et al*. 2003, and Lekani *et al*. 2003). Being ready to calculate the ratios every time one wishes to make a compost is a big challenge as the composting substrates are rarely obtained in any one predictable form.

This finding confirms report by Richard et al that “many ingredients for composting do not have the ideal ratio of 25-30:1.As a result, most must be mixed to create ‘the perfect compost recipe’” (Richards *et al*. 2009).

4.3 Conclusions

For successful composting, the selection of the most appropriate raw material is an important component (Fourti et al. 2011). Of the substrates tested, grass clippings, maize stovers and sugar cane bagasse were the most suitable material for large scale composting, but these are merely carbon sources and for proper composting nitrogen sources have to match the carbon sources in the prescribed ratios. However it is not easy to find matching cattle manure, chicken manure or leguminous plant remains, and considering that matured compost is dosed in tons per acre/hectare, composting under current circumstances is not a regular option for the smallholder farmers.

4.4 Recommendations

4.4.1 General

From the conclusion that composting is not viable in low potential areas because the quantity and quality of the biomass is limited, a design should be developed that would stimulate intensified agriculture. With intensified agriculture, it is then possible to generate high biomass within the small farm units, and composting to become a routine procedure because improvement of soil health is not a debatable intervention in the face of exponentially increasing population of the rural poor.

4.4.2 Socio-cultural considerations

The National and County governments should be persuaded to advice or even enforce cluster settlements for smallholder farmers so that agricultural land however small is lawfully protected. In the long run this option may need no debate if future livelihoods have to be self-supporting

4.4.3 Mixed farming

It is hereby highly recommended that the households in the project areas and their neighborhoods should be encouraged to practice mixed farming, so that whatever crop residues from their farms may be fed to livestock and the remainder used to produce composts.

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