COMPARATIVE STUDY IN LAB INCUBATIONS OF FIVE ORGANIC SOIL AMENDMENTS AT TWO DIFFERENT TEMPERATURES

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ABSTRACT:

An experiment was conducted to analyze the difference that two temperatures (22˚C and 37˚C) have on nutrient content, nitrogen mineralization and carbon release in some common organic products used for organic growers in the Pacific Northwest. The products used for the current study were coffee grounds, feather meal, fish emulsion, shrimp shells and horse manure. These amendments were tested for pH, EC, N mineralization, CO_2 lost through decomposition, and plant available nutrients through ion flux with PRS probes in a 7 day period. Temperatures affected the amendments with C: N ratios lower than 10 (fish, feather, shrimp), more than the amendments with C: N ratios more than 20 (horse, coffee). The different temperatures did not affect micronutrient availability. All of the amendments did follow the trend of decomposing more quickly at higher temperatures.

INTRODUCTION:

A preliminary group experiment has been designed to make a rough characterization of the availability of plant nutrient potentials on a variety of fresh (not composted) materials over a period of two weeks at two different temperatures; one at 22˚ and another at 37˚ C. Amendments included in this experiment consist of feather meal, coffee grounds, fish emulsion, horse manure, and shrimp shells. The objective is to obtain an understanding on which treatments will be most useful for different agricultural applications. This lab experiment will answer the following questions: (i) does the incorporation of the amendments results in an increase of plant available nitrogen and other important plant nutrients in the soil, (ii) does temperature effect the release rate of plant available nitrogen and other important plant nutrients from the amendments (iii) what is the stability of these amendments in the soil over time at different temperatures? Each amendment and the control soil used will be tested for pH, electrical conductivity, C:N ratio, decomposition rates, total and available nitrogen, phosphorous, potassium, various secondary elements and nitrogen mineralization.

METHODS & MATERIALS:

C:N ratio

The carbon to nitrogen ratio is one of the first and most important pieces of information that you can have about any amendment and your soil in all types of growing conditions. The CNS-2000 (LECO) located in the central analytical laboratory of the crop and soil science department was used to measure the C:N of all five amendments used in our experiment. Approximately one gram, precisely measured and recorded by the LECO, was added to ceramic boats. These boats are then put into the machine and combusted in the pure oxygen environment of the furnace. Combustion gases are collected after being pulled through anhydrone, which scrubs out any water in the samples. Carbon and nitrogen contents are then detected by IR cells within the machine and nitrogen by thermal conductivity cells. This information is used to give you a carbon nitrogen ratio which then allows one to make analytical decisions about how the material will act in a growing environment and at what amount it should be applied.

pH

To measure pH of the amendments and soil used, the Saturated Paste Extract Method was used as obtained from The U.S. Composting Council; some parts of the exact procedure had to be amended to fit the parameters of the experiment. A measured quantity of each amendment and soil was weighed, a known amount of deionized water was added, and a thorough mixing and squeezing of each sample was performed as they were allowed to soak for one hour. The desired sample solutions were to be of semi-liquid/paste compositions; great care was taken to ensure that none of the samples dried out or were so watery that they ran when tilted. Once soaking was completed each sample was subjected to a pH reading obtained by a pH probe; the pH probe was calibrated at pH 4 and 10 prior to sample testing.

ELECTRICAL CONDUCTIVITY (mmhos/cm):

For Electrical Conductivity measurements all amendments and soil were subjected to the Mass Ratio Method as described by The U.S. Composting Council. Based on Total Solid percentages each sample was combined with deionized water, five to one. To obtain the amount of each solid used I divided 5g by the total solid as a decimal. The samples were then mixed and allowed to soak for three hours. Once soaking was complete each sample was filtered through a Watman No. 41 filter, the supernatant was collected and stored in the fridge for two days until analysis could be performed. Once the Electrical Conductivity probe was calibrated each sample was tested.

TOTAL SOLIDS (%):

Total solid calculations were performed for each of the five amendments and the soil used in each of the experiments. All amendments were weighed wet, dried for twenty-four hours (aside for the fish liquid that had to be dried for several days due to its composition) at 105°C, then re-weighted dry. The metal boats used during the drying process were also measured pre-sample addition and their weights recorded. After the samples were allowed to cool the combined soil and boat weights were measured. Once all measurements were completed the dry weight, minus the boat, was divided by the wet weight; this gave us total solid measurements in percentages.

DECOMPOSITION (Loss of carbon as a measure of decomposition):

100g of moist soil was added to each jar along with a base trap of NaOH to collect the CO_2 released from decomposition. For the base traps, 20 mL of 1.0 M NaOH was used, which can trap approximately 120 mg C. A known weight of each amendment, calculated by total solid data and N content, was placed in two separate glass jars; 2.8 g coffee grounds, 0.22 g feather meal, 1.0 g fish emulsion, 4.1 g horse manure, and 3.1 g shrimp shells. Lids were placed on each jar and separated into two groups, each group containing one of each amendment. One group of jars was kept at 22˚ C, and the other at 37˚ C. After three days of incubation each jar was opened, the base trap was collected and a new base trap was added for the following four days.
The CO_2 was trapped as bicarbonate (HCO_3^-). The more decomposition occured, the more bicarbonate was formed, and the less NaOH remained. Before titration, the HCO_3^- present in the NaOH was removed from solution as a $BaCO_3$ precipitate. The titration measured the unreacted NaOH remaining. The greater the volume of acid needed to neutralize the remaining NaOH, the less decomposition occurred during the incubation of the amendment with the soil. At the conclusion of the seven day incubation period all base traps were collected for titration. The results for the titration illustrate the cumulative measure of decomposition. The following equations were used to obtain usable values of decomposition for each amendment.

Calculations for titrations

- Estimated C added in amendment = wet amendment added * (amendment dry/100wet) * (% C/100 dry) * (1000 mg/1g)
- net treatment respiration = Gross respiration - Soil only gross respiration
- % treatment C lost = net treatment respiration/ Estimated C added in amendment
- % cumulative treatment C lost = % treatment C lost jar A 5/14+ % treatment C lost jar A 5/17
- % cumulative treatment C lost = % treatment C lost jar B 5/14+ % treatment C lost jar B 5/17

PRS PROBES (primary and secondary nutrients):

Five soil amendments plus one control (soil) were incubated in two temperature treatments, 22° and 37° C. There were a total of 12 - 1 gallon polyethylene bags with 3kg of soil including the soil amendment. In each bag 2 PRS probe pairs (2 anion, 2 cation) were inserted and incubated for 7 days; giving a total of 12 bags with 24 pairs of PRS core probes. After the 7 day incubation the PRS probes were removed and cleaned with DI H_2O (deionized water). The probes were completely clean before analysis in order to obtain accurate nutrient supply rate data. After washing the PRS probes were placed in clean polyethylene bags separated by treatments. The sampled core probes were used to determine the soil nutrient supply dynamics in the lab analyzing: NO_3-N, NH_4-N, H_2PO_4-P, K, Ca, Mn, Cu, Zn, B(OH)-B, Na, and Mg.

In order to extract these soil nutrients two solutions were prepared 0.5M KCl and 0.5 HCl. For each treatment one PRS probe pair was eluted for 1 hour in 300 ml of 0.5M KCl, and the other pair was eluted for 1 hour in 300 ml using 0.5M HCl. The 0.5M KCl extract was analyzed for levels of NH4-N and NO3-N with the automated colourimetry, and also analyzed using ICP (Inductively Coupled Plasma) for the other nutrients (PRS™ Operations Manual, Western Ag). Both, the eluent and analysis were done at the Central Analytical Lab at Oregon State University.

RESULTS AND DISCUSSION:

C:N

As a general rule materials with a C:N above 15 will imobilize within the soil before being available to plants; nitrogen within the material will be unavailable to plants as microbes will need it for energy to break down the material until a lower C:N is reached, which will then allow the nitrogen to be available for plant uptake. With the amendments shown in Table 1-1, horse manure and coffee will act similar; nitrogen will be immobilized an unavailable to plants until a C:N of 15 or less is reached. From calculations requiring C:N content its known that it would take approximately 5-6 weeks of decomposition within the soil at 22° for nitrogen to be mineralized per four grams of wet coffee or horse manure. Feather meal, Shrimp shells and fish emulsion have a low enough C:N for nitrogen to be mineralized and made available upon application.

pH

All measured values and pH readings are given in table 1-3, each sample was completed with two replicates so that an average could be obtained.

The desired pH of most amendments ranges from 6.1 to 8.9; high pHs are undesirable for soils with a pH above 7.2. As a general rule amendments should not be added to any soil in a growing situation above 9, unless the amendment is being added to an acid soil to specifically help raise the pH. pH values obtained from the amendments and soil were consistent with previous knowledge, however, both the horse manure and fish were not predicted. Possible explanations for the horse manure pertains to its freshness; while there is a large quantity of urine (acidic) properties, the presence of large amounts of wood sawdust would act as a buffer until the composition of the amendment is changed through decomposition. The fish is a dissolved solid (slurry) and has properties closer to that of a liquid rather than a solid. For the fish to play a direct role in nutrient availability in the state that its applied it would make sense that its pH should be acidic to be of a greater availability to both the crops that its being added to and the biological community that is altering the form of nutrients being supplied.

ELECTRICAL CONDUCTIVITY (mmhos/cm):

All measurements and parameters of this procedure are shown in Table 1-4. Crop tolerance to soluble salts varies greatly, the most appropriate action to take when using different products is to know your crop and its characteristics. Generally amendments with an EC of less than 6 mmhos/cm will not cause crop damage. When your dealing with a situation where your EC is toward the higher end you must pay close attention to your soil EC, soil cation concentrations and sodium, also what is in the amendment that may be giving rise to the high EC. A great contributor to EC is cation nutrients, especially sodium. Ammonia often contributes to a higher EC, but when added to soil in proper application rates little effect is seen.

The shrimp shells and fish emulsion in our experimental study both have EC's well and above the suggested 6.0. The shrimp is expected to have a higher EC based on its composition, carbonate shells, this should not be a problem in most crops as long as the overall EC is watched and a suitable application rate is used. The fish also exhibits properties of carbonates, based on the solution consisting of ground fish, this should find some type of equilibrium within the soil but close attention should be taken during application to ensure that the soil doesn't show a large increase after application.

TOTAL SOLIDS (%):

Total solid information is used or many calculations pertaining to percentages and amounts of various nutrients. For this experiment all obtained values were within expected values, aside from the fish emulsion, and shown in Table 2-1. An explanation for the extremely high total solid percent shown for the fish emulsion is its liquid slurry composition; there may be additives within this amendment to retain moisture and prevent easy drying.

DECOMPOSITON (Loss of carbon as a measure of decomposition):

Coffee grounds and horse manure decomposed more slowly than the other amendments due to their high C:N ratio; coffee grounds behaved much like a composted material. Horse Manure is a fresh material, but the high amount of sawdust and bedding in the material added C which slowed the rate of decomposition. Fish emulsion had the largest % C lost at both temperatures. Fish emulsion, feather Meal and shrimp shells have a low C:N ratio which resulted in a much more rapid decomposition rate. (Figure 2-2)

All amendments followed the trend of decomposing more quickly at the higher temperature. Temperature greatly affected the decomposition rate of feather meal. Shrimp waste had the smallest difference of % C loss between incubation temperatures.

When applying these amendments in the field it is important to be aware of how quickly the nutrients are becoming available to the plants. Fish emulsion, feather meal, and shrimp shells are going to supply nutrients the most rapidly to plants. Horse manure may require composting before field application to get the C:N ratios down, caution should also be taken due to the salt content. Coffee grounds do not supply many nutrients to the plant, especially short term. The largest benefit of coffee grounds is to build soil structure and provide a long term slow release and retention of nutrients.(Table 2-3) Overall, the amendments with C:N ratios between 4-8 had very high cumulative decomposition as expected for raw amendments. (Figure 2-4)

When the 7 day decomposition data from this experiment are compared with the amendments used in Gale et al, a correlation can be made between several of the amendments used. The amount of CO_2 respired by feather meal at 7 days is similar to broiler litter compost, and rabbit manure. Another example is the amount of CO_2 respired by coffee grounds after 7 days, which shows similarities to yard trimmings, compost and rabbit manure compost.

PRS PROBES (primary and secondary nutrients):

Table 4.1 shows the concentration of nutrients in the probe extracts in ppm (parts per million) from the automated colourimetry and ICP. The volume of 300 ml for the extraction solution used for PRS probe extraction was not the recommended volume; the volume of 300 ml diluted the nutrients by 8 times more than recommended. Therefore, the nutrient concentration were low, near or below detection limit for H_2PO_4-P, Cu, Zn, and B(OH)-B thereby, the data of these nutrients are not included in further calculations for the supply rate.

Sodium (Na^+) cannot be included in the results because the PRS probes are not suitable for measuring Na^+ supply rates since the ion exchanged by the PRS probes was Na^+, and the probes were treated with $NaHCO_3$.

Table 4.2 elucidate the supply rate of nutrient/ion absorbed per amount of absorbed surface area of the PRS probe membrane per entire time of burial in the soil at the given temperature and moisture conditions. The PRS probe nutrient supply rate units are reported as: µg ion/10cm^2/length of burial (7 days). The surface area of one PRS-probe is 17.5 cm^2, accounting for both sides, consequently the conversion equation of the nutrient supply rate is: ppm in extract x 300ml divided by the surface area (2 x 17.5 cm^2) x 10 (to express per 10 cm^2 surface area)

Example calculation: K = 5.1 ppm in extract x 300ml / (2 x 17.5 cm^2) x 10 = 437 µg K sorted/ 10cm^2

These calculations confirm that most nutrient sorption rate increased or had the equal nutrient supply rate at 37° C compared to 22° C. Also, the nutrient supply rates decreased at 37° C compared to the 22° C in NH_4-N µg/10cm^2/7days for horse manure; K, Ca, and Mn µg/10cm^2/7days for Coffee grounds; and Ca, Mg, and Mn µg/10cm^2/7days for feather meal. NH4-N release is faster in feather meal, fish emulsion and shrimp shells, and shrimp tends to increase its mineralization with 37°C. The supply rate of NO_3-N in the control soil is surprisingly high compared to the soil amendments and even among control temperatures. This could be a normal variation in the source of the soil sample or as in most of the amendments, could be due to the differences in C:N ratios of the amendments. The N03-N increase at 37°C is more noticeable in feather, fish and shrimp when compared with the 22°C treatment. Horse manure has almost the same ratio at both temperatures, and coffee ground doesn't show much activity Fig 4.1.

Due to the high dilution of PRS nutrient supply rate many nutrients could not be analyzed, however, given some of the amendments it is surprising that P supply rates were below minimum detection limits, especially the horse manure amendments under warm, moist soil conditions. A possible explanation could be that the ICP equipment had a high minimum detection limit. Other possible reasons for low nutrient supply rates could be the lack of amendment added to the soil, or the soil had enough buffer capacity and was not yet in equilibrium.

With the analysis of the micronutrients that we could still analyze and compare, we can see that just in Ca there is a remarkable difference between both temperatures, and mostly in the shrimp shells, which doubles the ratio when analyzed at 37°C. Fish emulsion has high concentrations of this element as well. Further than these analytical differences, none of the amendments seem to have dramatic changes from one temperature to another, as shown in Figure 4.2.

For future analysis, elute the PRS probes by adding 17.5 ml (corresponds to 17.5 cm2 surface area of the PRS probe membrane) 0.5 M HCl or KCl solution for each PRS probe in the bag. If two PRS probes, anion and cation are being bulked for analysis then add 2 x 17.5 ml = 35 ml. Ensure that the PRS probes are completely immersed in the solution and seal the bag properly to eliminate solution leakage. Cation and anion PRS probes can be combined in the same bag. A bank PRS probe pair should be included in the eluting process in a separated bag in order to adjust for possible PRS probe contamination.

CONCLUSIONS:

It is important to know what your management goal is before applying any soil amendments, as well as the major limitations of the amendment. Fish emulsion, feather meal, shrimp shells and horse manure are all minimally processed amendments, with high biological activity and the ability to supply nutrients. Coffee grounds are better used for building soil organic matter, because it is a much more stable material which behaves much like compost.

Each amendment has limitations for its use depending upon the management goals and what crop it is being applied to. Fish emulsion, feather meal and shrimp shells all have rapid N mineralization, whereas horse manure and coffee grounds mineralize much slower due to the higher C content. Shrimp, feather and fish tend to increase PAN as C:N ratio decrease to less than 10 , while coffee grounds and horse manure have a higher C:N ratio and less PAN without the influence of temperature differences.

Fish emulsion has a low pH and a high EC, so should be diluted or applied sparingly to crops that are salt sensitive or that require a higher pH. Feather meal is a source of N and doesn't provide any other nutrients. Shrimp shells have a high EC due its $CaCO_3$, so it should be applied sparingly to salt sensitive crops. Horse manure also has a high EC and fresh horse manure isn't approved by OMRI for use in organic production. Coffee grounds have a very slow rate of mineralization, and are not a good nutrient source.

From Figure 5.1 a slight correlation can be seen from each amendments C:N and its corresponding PAN. The feather meal, shrimp meal and fish emulsion all contain C:N ratios below the 15:1 mineralization mark; all these amendments also hold PAN values above 10%. The horse manure and coffee grounds both have much higher C:N ratios but very different PAN values; the horse manures unpredicted high amount of PAN can be contributed to the large amount of ammonia within the material. The PAN related to the coffee grounds, a negative number, is closer to what you would expect to see from a material with such a low total nitrogen amount, as shown in table 3-1, and a high C:N.

There are definite correlations shown in Figure 5-2 between each amendments C:N value and its corresponding % carbon lost. Both the feather meal and fish emulsion have C:N ratios of similar values, as shown their decomposition rates are also closely related. As the C:N value rises to 5.4, shrimp meal, the average decomposition rate decreases by 20%. The final amendments, horse manure and coffee grounds, would show closer values to one another if the horse manure didn't contain such a high amount of wood products. In this case the horse manure has a higher C:N value than the coffee grounds but also contains a material, sawdust, which has a much faster decomposition rate.

APPENDIX

Table 1-1 C:N Ratios of Experimental Amendendments

Feather Meal	3.5
Horse Manure	35.1
Shrimp Meal	5.4
Fish Liquid	4.6
Coffee	27.1
Soil	

Table 1-2 Total Solids (%) of Experimental Amendments

Amendment	Boat (g)	Wet Sample (g)	Dry Sample and Boat (g)	Total Solids
Feather Meal	15.67	61.35	73.5	94.26
Shrimp	15.71	119.64	43.36	23.11
Fish	1.34	10.98	6.87	50.36
Horse Manure	16.26	105.38	50.93	32.9
Coffee	10.57	129.31	55.41	34.68
Soil	1.77	20.15	18.2	81.54

Table 1-3 Electrical Conductivity of Experimental Amendments

Amendment	Weight (g)	H_2O Added (mL)	EC (mmhos/cm)	Average EC (mmhos/cm)
Horse Manure 1	15.19	50.00	3.23	3.11
Horse Manure 2	15.52	50.00	2.99	
Coffee 1	14.42	50.00	0.49	0.45
Coffee 2	14.40	50.00	0.40	
Shrimp	21.63	50.00	1.99	8.55
Feather Meal 1	5.30	50.00	1.59	1.66
Feather Meal 2	5.30	50.00	1.73	
Fish 1	50.05	50.00	19.06	20.43
Fish 2	50.18	50.00	21.80	
Soil 1	6.09	50.00	0.04	0.04
Soil 2	6.10	50.00	0.03	

Table 1-4 pH of Experimental Amendments

Amendment	Weight (g)	H_2O Added (mL)	pH	Average pH
Horse Manure 1	19.96	33.97	8.83	8.85
Horse Manure 2	20.13	31.36	8.87	
Coffee 1	20.19	9.92	5.8	5.83
Coffee 2	20.09	8.87	5.85	
Shrimp	20.1	27	8.55	8.55
Feather Meal 1	20.14	30.3	5.68	5.69
Feather Meal 2	20.1	31.26	5.7	
Fish 1	21.86	5.66	3.67	3.68
Fish 2	19.71	4.17	3.68	
Soil 1	19.93	6.51	6.24	6.19
Soil 2	19.98	6.65	6.13	

Table 2-1 % Cumulative Treatment C Loss

Project ID	% Cumulative Treatment C Loss
Coffee grounds 22	2.1
Coffee grounds 37	5.08
Feather meal 22	31.06
Feather meal 37	62.56
Fish emulsion 22	60.93
Fish emulsion 37	65.84
Horse manure 22	7.94
Horse manure 37	13.55
Shrimp waste 22	43.55
Shrimp waste 37	44.37

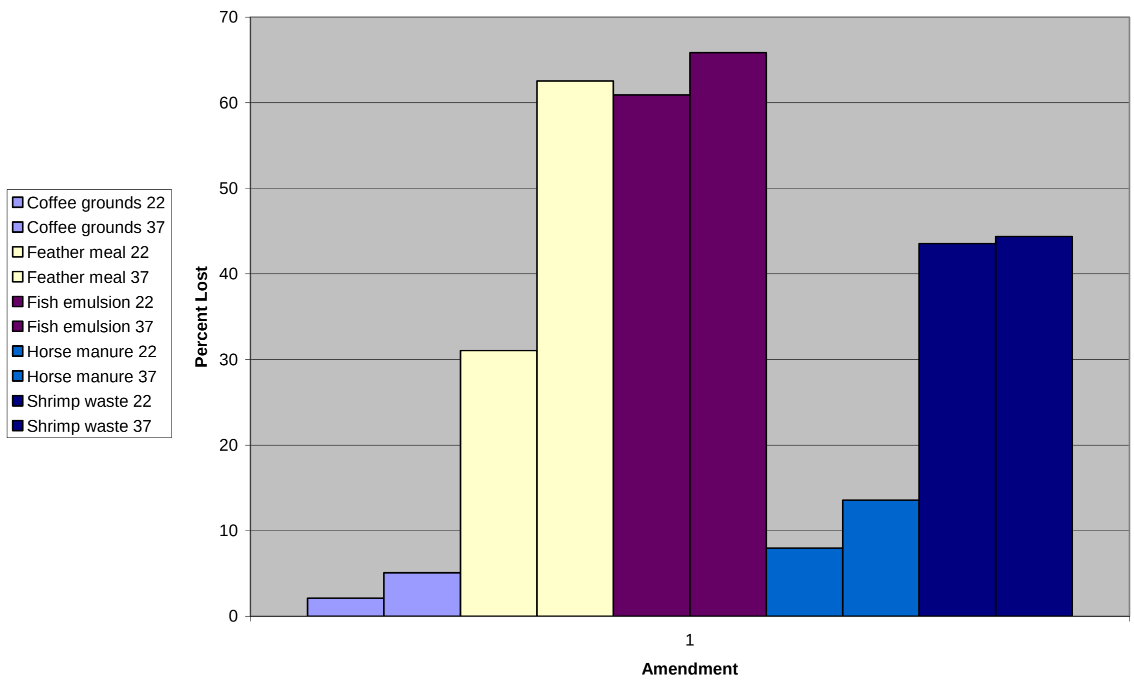


Figure 2-2 % cumulative treatment C lost

Table 2-3 Properties and Charectoristics of Amendments

Decomposition	C:N	Examples of Amendments	Impact of Amendment	Time to Equilibrium
Fast	> 15	Paper, Sucrose	N Immobilization, Rapid immobilization	~ 1 month
Fast	< 15	Fish Meal, Feather Meal, Shrimp Meal	N Mineralization, Rapid Mineralization	~ 1 month
Slow	> 15	Horse Manure, Coffee	N immobilization, Slow immobilization	~ 3-6 months
Slow	< 15	Compost	N mineralization, medium mineralization	~ 3-6 months

Figure 2-4 C:N Ratio of Amendment vs. Decompostion (% amendment lost as CO_2)

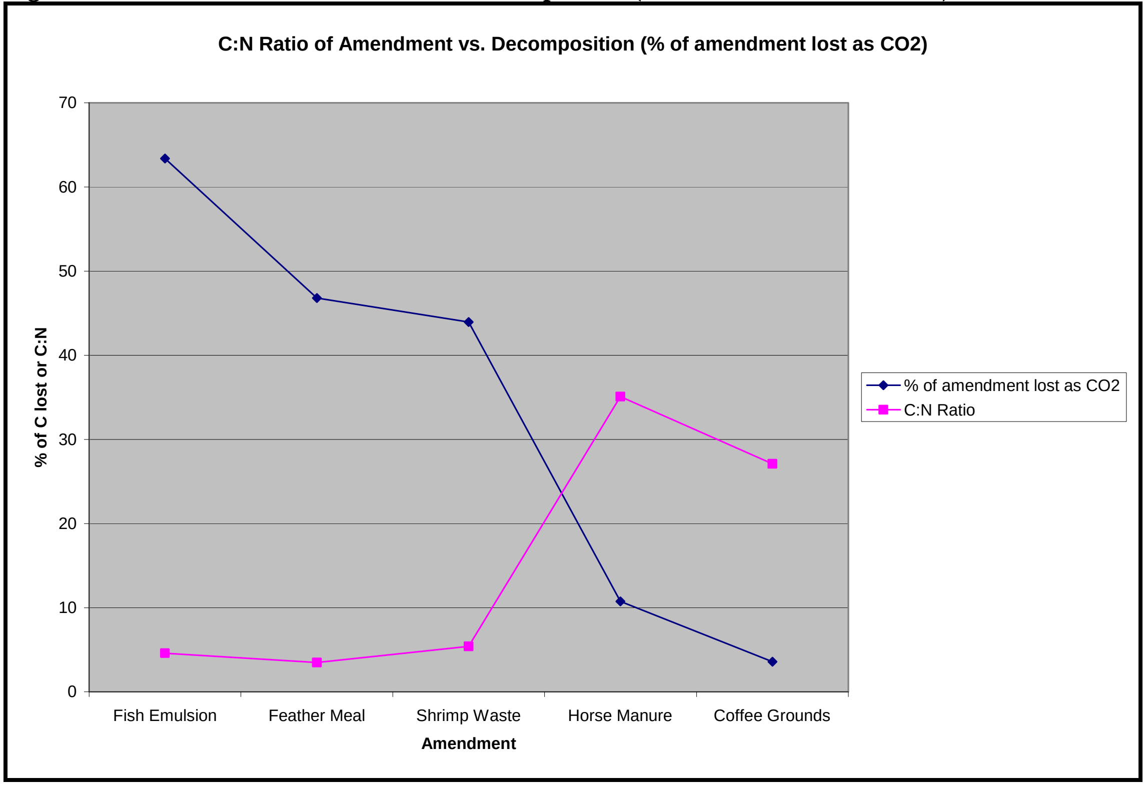


Table 3-1 Nitrogen Mineralization in Amended Soil

Amendment	Temperature C	Total N %	NH4-N	Net PAN NO3-N	Total	PAN mineralized of total N %	Carbon to Nitrogen ratio
			mg N kg-1dry wt soil				
Coffee grounds	22		-0.1	-1.9	-2.0	-1	27
	37		0.0	-3.0	-3.0	-2	
Feather meal	22	11.9	54.2	3.2	57.5	24	3
	37	11.9	78.2	5.4	83.5	35	
Fish liquid	22	7.4	53.9	-1.9	52.1	9	5
	37	7.4	71.8	-0.1	71.7	12	
Horse manure	22	1.3	22.2	8.9	31.1	18	35
	37	1.3	12.3	16.1	28.4	16	
Shrimp meal	22	5.0	97.0	1.2	98.1	29	5
	37	5.0	143.8	8.5	152.3	45	
				Gross PAN			
			NH4-N	NO3-N	Total		
			mg N kg-1dry wt soil				
Control	22		0.34	1.92	2.3		
	37		0.43	3.08	3.5		

Figure 3-1 Percent of PAN of the total N added to soil during incubation vs. amendment C:N

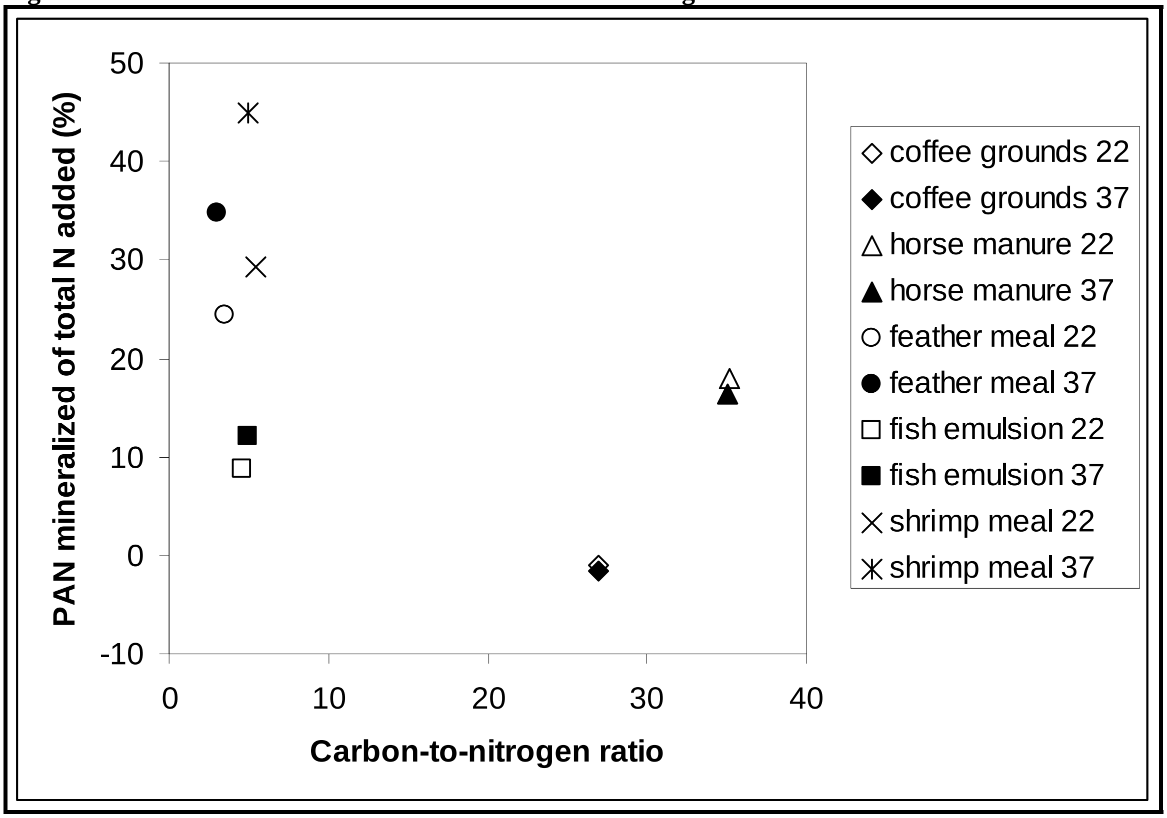


Table 4-1 1Analytical analysis of PRS probe nutrient concentrations

Amendment	Temp C°	NH_4-N	NO_3-N	K	Ca	Mg	Mn	Na	B	Cu	Zn	P
		ppm	Ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	Ppm
Coffee ground	22	0.3	0.01	5.1	9	2	0.4	10	< 0.05	< 0.05	< 0.05	< 0.1
Feather meal	22	0.6	0.5	3	12	2	0.07	6	< 0.05	< 0.05	< 0.05	< 0.1
Fish emulsion	22	0.6	0.2	3	14	2	0.37	1.8	< 0.05	< 0.05	< 0.05	< 0.1
Horse manure	22	0.4	0.5	2	10	2	0.13	10	< 0.05	< 0.05	< 0.05	< 0.1
Shrimp waste	22	0.7	0.01	2	6	0.5	0.1	18	< 0.05	< 0.05	< 0.05	< 0.1
Control (soil)	22	0.2	0.4	2	7	1	< 0.05	21	< 0.05	< 0.05	< 0.05	< 0.1
Coffee ground	37	0.3	0.01	5	8	2	0.06	13	< 0.05	< 0.05	< 0.05	< 0.1
Feather meal	37	0.6	0.7	4	10	1	0.05	9	< 0.05	< 0.05	< 0.05	< 0.1
Fish emulsion	37	0.7	0.4	3	14	3	0.42	4	< 0.05	< 0.05	< 0.05	< 0.1
Horse manure	37	0.3	0.5	3	13	2	0.11	6	< 0.05	< 0.05	< 0.05	< 0.1
Shrimp waste	37	0.9	0.1	7	14	2	0.14	5	< 0.05	< 0.05	< 0.05	< 0.1
Control (soil)	37	0.3	0.9	3	10	2	0.05	7	< 0.05	< 0.05	< 0.05	< 0.1

Table 4-2 Nutrient supply rate: µg/10cm²/7days. Amount nutrient/ion absorbed per amount of absorbing surface area of the PRS probe membrane per entire time of burial in the soil.

Amendment	Temp. C°	NH_4-N µg/10cm² /7days	NO_3-N µg/10cm² /7days	K µg/10cm² /7days	Ca µg/10cm² /7days	Mg µg/10cm² /7days	Mn µg/10cm² /7days
Coffee ground	22	26	1	437	771	171	34
Feather meal	22	51	43	257	1029	171	6
Fish emulsion	22	51	17	257	1200	171	32
Horse manure	22	34	43	171	857	171	11
Shrimp waste	22	60	1	171	514	43	9
Control (soil)	22	17	34	171	600	86	4
Coffee ground	37	26	1	429	686	171	5
Feather meal	37	51	60	343	857	86	4
Fish emulsion	37	60	34	257	1200	257	36
Horse manure	37	26	43	257	1114	171	9
Shrimp waste	37	77	9	600	1200	171	12
Control (soil)	37	26	77	257	857	171	4

Figure 4-1 N with PRS probes 1

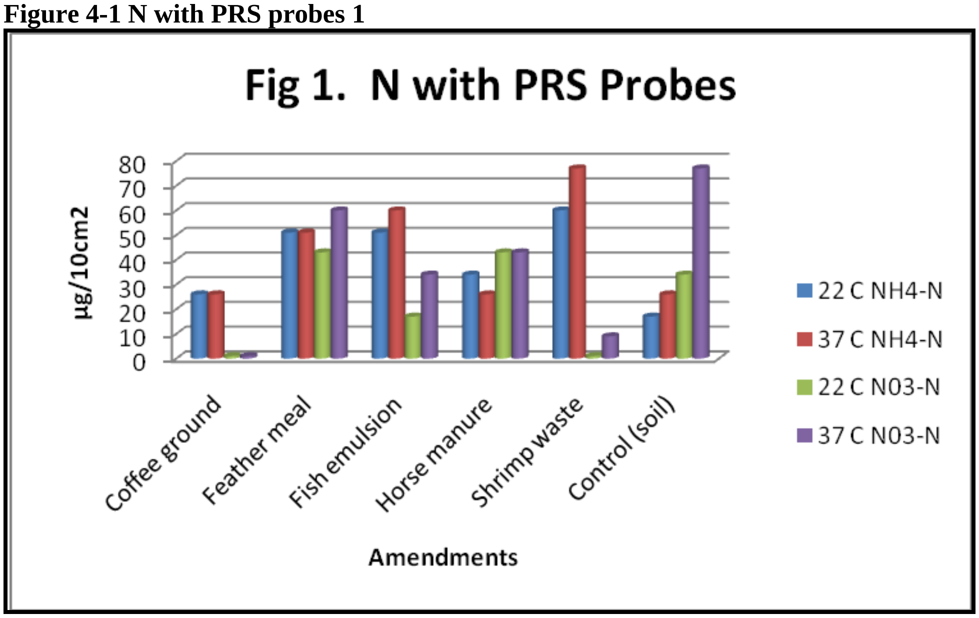


Figure 4-2 K, Ca, Mg, Mn with PRS probes 1

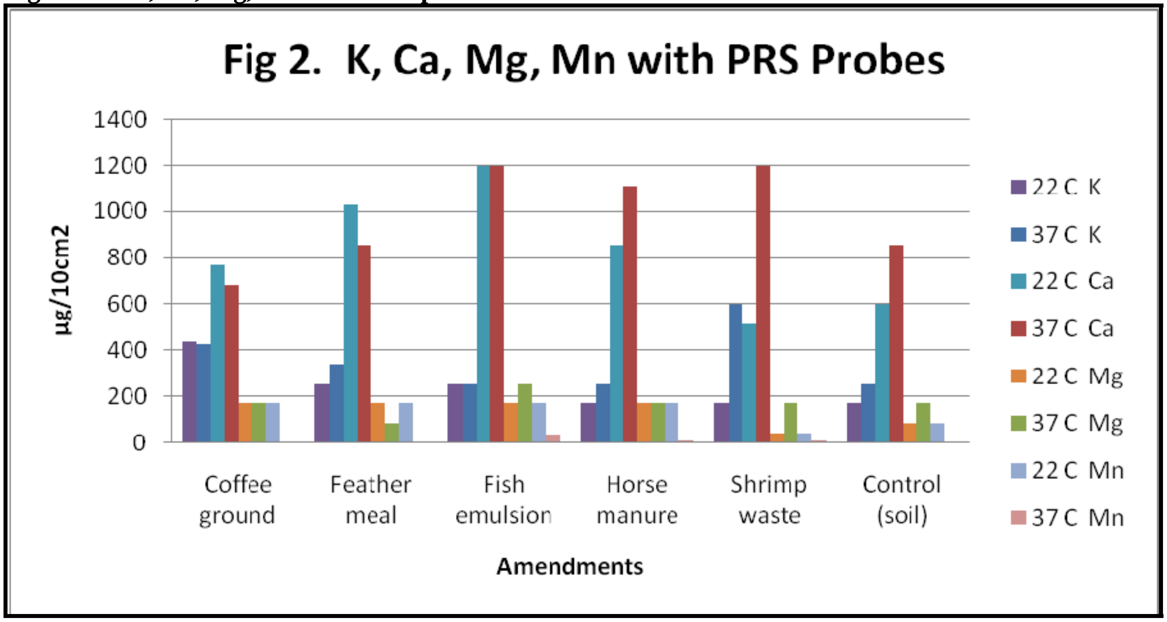


Figure 5-1 C:N vs. % PAN for experimenta1 amendments

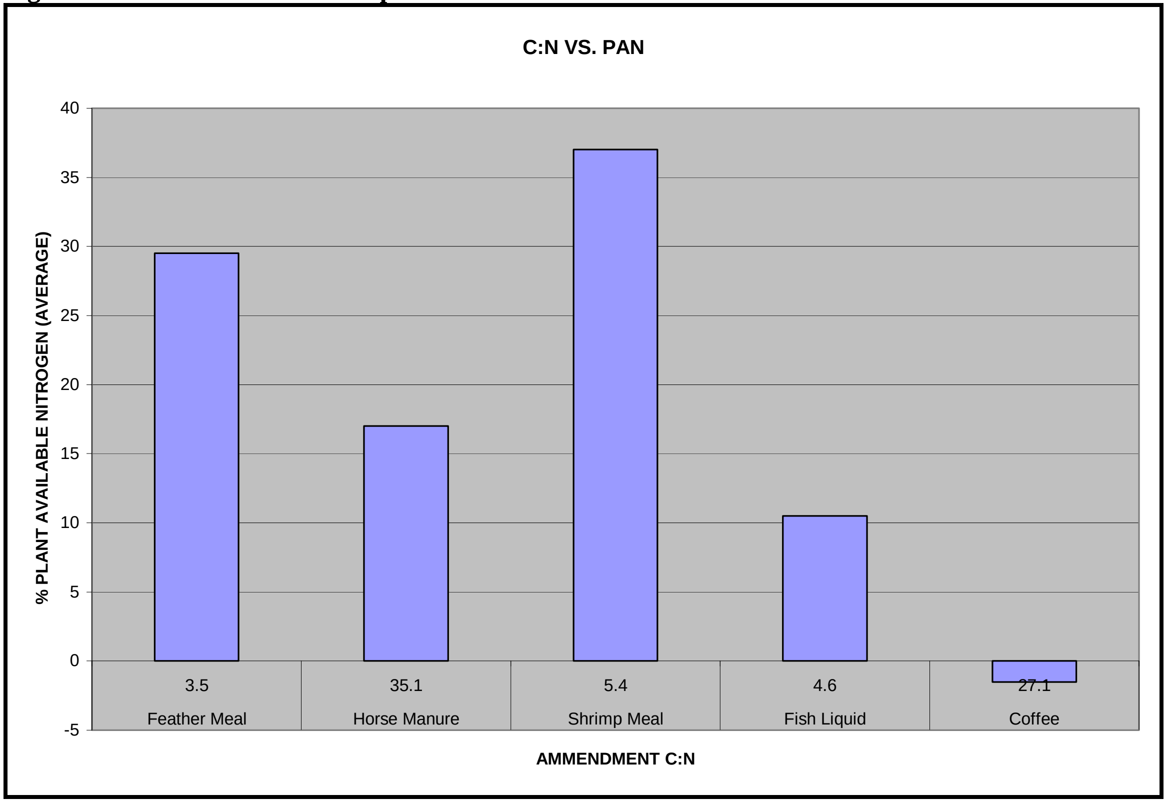
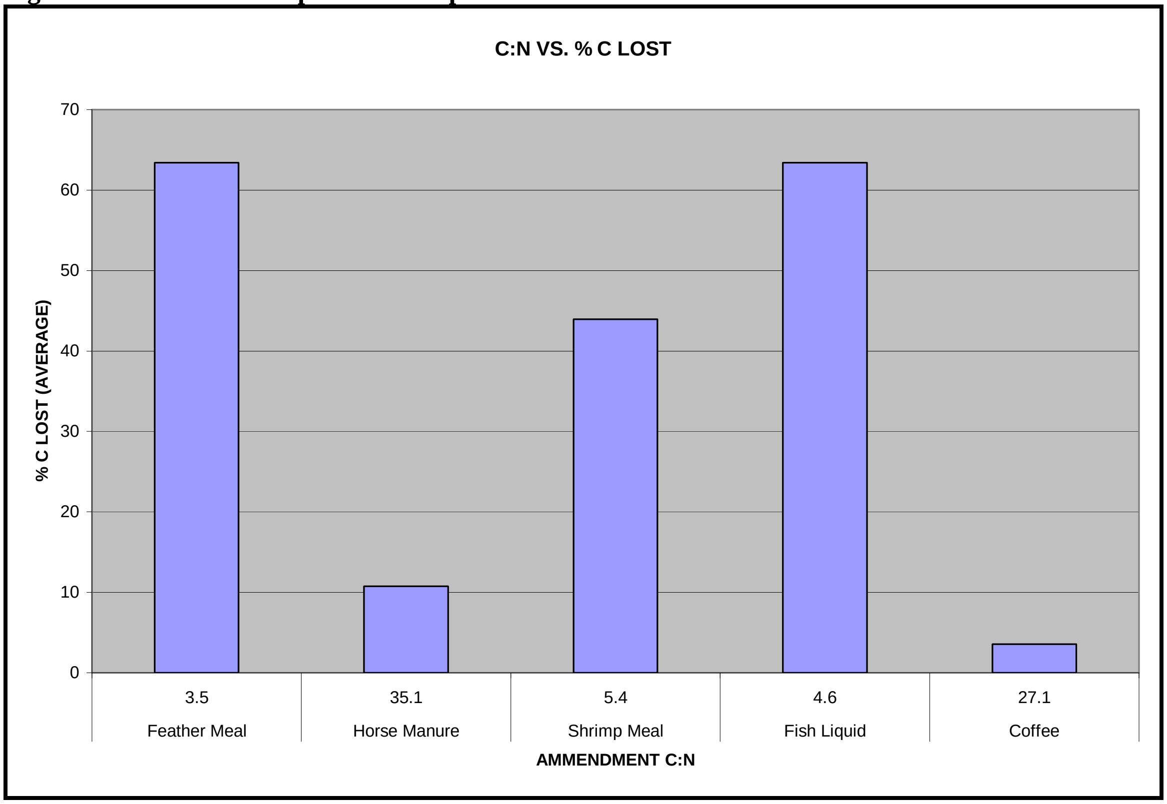


Figure 5-2 C:N vs. Decomposition of experimental amendments



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