Plant nutrient recovery following Palm Oil Mill Effluent Soil amendment in a maize (*Zea mays*) grown screen house experiment

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Abstract

We quantified effects of aerobically digested Palm Oil Mill Effluent (POME) on yield, nutrient use efficiency and soil residual chemical properties over a 2-year screen house experiment. The experiment was laid out in a completely randomized design in a loamy soil with four replications. The treatment consisted of 20-day fermented POME applied at rate of 10 ml kg^{-1} soil (equivalent of 3.7 m^3ha^{-1}). Synthetic fertilizer was applied at the mean rate of 2 mg NH_4NO_3-N kg^{-1} soil, 3.2 mg P_2O_5 kg^{-1}soil and 4.0 mg K_2O kg^{-1} soil as a standard check. Soil without treatment served as control. Data collected were statistically analyzed using ANOVA with Genstat Discovery 3 edition. Results showed that overall yield was modest. However, inorganic fertilizer gave the highest grain (69.6 g/pot) and dry matter yield (88.9 g/pot) and superior nutrient use efficiency (N: 2.82; P:23.0; K:66.0) in 2006 followed by POME (N: 2.0; P: 0.49; K: 1.86). There were considerable level of residual organic N and organic C in the POME and fertilizer pots. We conclude that fermented POME nutrients were available to maize plant and were efficiently utilized.

Keywords : Bioaugmentation; fermentation; organic–amendment; nutrient-recovery; waste-management

1.0 Introduction

The use of organic soil amendments (Olive Mill Effluent, sewage sludge, sludge compost, Palm Oil Mill Effluent) has received wide acceptance throughout Europe, America, Canada, Africa and other parts of the world. Many studies have demonstrated the positive effect of organic amendment; which include, higher plant available water holding capacity and cation exchange capacity (CEC) and lower bulk density, and foster beneficial microorganisms (Doran *et al*., 1996; Drinkwater *et al*., 1995; Pascual *et al*., 2007). pH stabilization and faster water infiltration rate due to enhanced soil aggregation (Stamatiadis *et al.,* 1999). Also, organic soil amendment could lead to increase in soil organic matter (SOM) and reduced nitrate runoff (Drinkwater et al., 1998). Food and environmental safety are often cited reasons for the use of alternative soil amendment, but increasingly economic considerations are becoming important with a rise in popularity of organically produced foods (Thompson, 1998).

Palm oil mill effluent (POME), a by product of palm oil processing is produced in large quantity in southern Nigeria. Immediate discharge to arable land has recorded undesirable effects such as death of fauna and flora within the vicinity (Perez *et al*., 2007). These effects are attributable to the presence of phenolic acids, heat and low pH nature of the effluent (Komilis *et al*., 2005). However, POME is amenable to biodegradation and could be used as soil organic amendment especially in areas where production is high. Palm oil mill effluent contains high concentration of carbohydrates, proteins, nitrogenous compounds, lipids and minerals (Habib *et al.,* 1997) making it possible for reuse in biotechnology and agriculture (Table 1.0). Onyia *et al*., (2001) reported that POME contains approximately 4-5 % solids (mainly organic), 0.5-1% residual oil and about 95 % water and high concentration of organic nitrogen. Palm oil mill effluent could be fermented for few days to enable resident heterotrophs oxidize the organic matter present, for plant nutrients release. Judicious soil application of POME is recommended to avoid unhealthy soil chemical reactions and to prevent nutrient leaching to underground waters. In the few instances where a nil or negative response to organic amendments have been observed, either a high C:N ratio, excess metals, high application rates were responsible for the reduced yields or negative effects to soils or crops.

The primary plant nutrients for effluent utilization in agriculture are N, P, and K though can significantly contribute to the amounts of other micro and macro nutrients (Shober *et al.,* 2003, Sims, 1990, Warman 1986, Zebarth *et al* 2000). Nitrogen availability from POME is reported to range from 0-26.4 % (Habib *et al.,* 1997; Cariton-Smith and Coker, 1985) (Table 1.0). The main factors that influence N availability from effluent are its inorganic N content (Hutching, 1984) digestion process (aerobic and anaerobic) (Amundson and Jarrel, 1983; Hutchings, 1984, Serna and Pomares, 1992), pH, the method and timing of application (Crips *et al*., 1992) and soil type and properties (Hutchings, 1984, Magdoff and Amadon, 1980).

Excessive application of POME beyond crop requirement and absorptive capacity of soil could be dangerous to the ecosystem and therefore, it is necessary to monitor nutrient release from POME vis-a-vis crop improvement. This important information would be valuable to assess the short and long term economic benefits to the farmer and to the ecosystem.

The objectives of the present study were to evaluate crop yields; nutrient content of crop and nutrient recovery efficiency of POME amended soil.

Table 1.0. The approximate composition (%) of major constituents, amino acids, fatty acids and minerals in raw POME (adapted from habib *et al*., 1997)

Major constituents	Composition (%)	Amino acids	Composition (%)	Fatty acids	Composition %	Minerals	Composition(µg/g dw)
Moisture	6.90	Aspartic acid	9.66	Caprylic acid	2.37	Fe	11.08
Crude protein	12.75	Glutamicacid	10.88	Capric acid	4.29	Zn	17.58
Crude lipid	10.21	Serine	6.86	Lauric acid	3.22	P	14377.38
Ash	14.88	Glycine	9.43	Myristic acid	12.66	Na	94.57
Carbohydrate	29.55	Histidine	1.43	Pentadecanoic acid	2.21	Mg	911.95
Nitrogen-free extract	26.39	Arginine	4.25	Palmitic acid	22.45	Mn	38.81
Total carotene	0.019	Threonine	2.58	Heptadecanoic acid	1.39	K	8951.55
Total	100.789	Alanine	7.70	10-heptadecanoic acid	1.12	Ca	1650.09
		Proline	4.57	Stearic acid	10.41	Co	2.40
		Tyrosine	3.16	Oleic acid	14.54	Cr	4.02
		Phenylalanine	3.20	Linoleic acid	9.53	Cu	10.76
		Valine	3.56	linolenic acid	4.72	Ni	1.31
		Methionine	6.88	T-linolenic	0	S	13.32
		Cystine	3.37	Arachidic acid	3.56	Se	12.32
		Isoleucine	4.53	Eicosatrienoic acid	2.04	Si	10.50
		Leucine	4.86	Eicosatetraenoic acid	1.12	Sn	2.30
		Lysine	2.66	Eicosapentaenoic acid	0.36	Pb	5.15
		Tryptophan	1.26	Total	95.99	Cd	0.44
		Total	90.84			B	7.60

2.0 Materials and Methods

2.1 Physicochemical and nutrient characteristics of POME

The experiment was conducted at the Institute of Erosion Studies (IES), Federal University of Technology, Owerri. in 2006 and was repeated 2007. A composite POME sample obtained from government owned palm oil mill plant ADAPAM Ltd Ohaji Owerri, Nigeria was fermented for 20 days. Fermentation was conducted using 60 litre bowl and diameter 0.5 m. The bowl was fed with raw POME + 0.8 g/L of urea to facilitate microbial activity and N mineralization. Temperature was maintained at 30 ºC, pH; 8.5 using 2 N NaOH. Onyia *et al.,* (2001) noted these conditions to be favourable for nitrification process to take place. The content was stirred at least once a day to provide aeration. Initial physicochemical properties of POME have been previously determined (Nwoko, 2010)

At the end of 20 d fermentation period, 20 ml sample was collected from the fermentation bowl and stored at 4 ºC for nutrient (NPK) determination. During analysis 20 ml samples was divided into four subsamples and used for all the determinations. Nutrient in POME before application was determined at the Central Analytical Laboratory, Department of Industrial Chemistry, Federal University of Technology Owerri. Total Kjeldahl N was determined following the method described by (Bremner and Mulvaney, 1982). Potassium and Phosphorus was determined using nitric acid digestion procedure and determined using inductively Coupled Plasma emission Spectrometry (ICP) Jarrel-Ash 9000 Plasma Spectrometer, Genesis lab. Systems Inc. Grand Junction, Co. 81505).

2.2 POME application, plant sampling and analyses

Pots (36 cm height and 38 cm surface diameter) were filled to make up 10 kg sand loamy soil. Composite soil classified as Ultisol was obtained, air-dried and ground to pass through a 2mm sieve. Measurements followed standard methods and included electrical conductivity, pH (1:1 soil: H_2O) (Table 2.0), organic carbon, total nitrogen, available P and exchangeable calcium (Ca), magnesium (Mg), Sodium (Na), Potassium (K) and total exchangeable acidity. pH (H_2O) (1:1) was determined using pH meter. Organic carbon was determined by dichromate oxidation method of Walkley and Black, (1945). Avail. P was measured using Bray no 1 solution of Murphy and Riley, (1972). Exchangeable bases were measured by extracting known quantities of the soils with neutral ammonium acetate (1N NH_4O-Ac: pH=7) solution (Bray and Kurtz, 1945). Exchangeable Potassium and sodium contents were estimated on the flame photometer while Calcium and Magnesium contents were determined by the Versnate (0.1 M EDTA) titration method. The exchangeable acidity was determined by 1N KCl extraction procedure as outlined by Mclean (1965). Effective cation exchange capacity (ECEC) was obtained by summation of exchangeable cations and acidity. Each pot received 2 maize seeds (*var.* Oba supper) and thinned to one after emergence. Application rate for POME amendment assumed that 50 % of the total N applied was available to the crop. Thus, 20 d fermented POME was applied at the rate of 10 ml/kg soil (equivalent of 3.7 m^3/ha,). NPK content of fermented POME is presented in Table 2.0. Synthetic fertilizer (NPK) was applied at the mean rate of 2 mg NH_4NO_3-N /kg soil, 3.2 mg P_2O_5/kg soil and 4.0 mg K_2O/ kg soil. Soil without treatment served as control. Each treatment was replicated four times in a completely randomized design.

Maize grain yield in both years were expressed at 5% moisture and analysed for nutrient NPK content after drying at 70 ºC and ground to >1 mm with a Wiley mill (A.H Thomas Co., Philadelphia, PA). Similarly, harvested plant (leave, stalk and root) were chopped, dried and weighed and ground with Wiley mill. Tissue N of both grain and plant part were determined by digestion in H_2SO_4-H_2O_2. Digests were distilled with 10 M NaOH into boric acid and quantitatively titrated with HCl. Tissue P and K were determined using a nitric acid digestion procedure and determined using inductively coupled plasma emission spectrometry (ICP). At the end of each growing season composite soil sample from the pots was subsampled and chemically analyzed for org. N content using the modified micro kjeldahls method. Mehlich-1 double acid procedure (0.05 N HCl – 0.025 N H_2SO_4) was used to extract P and K; extractable P and K were analysed by ICP.

From the data, efficiency of nutrient recovery was calculated according to Shober *et al.,* (2003) as follows

$$\% \text{ Recovery} = \frac{\text{treatment uptake - control uptake}}{\text{Total amount of nutrient applied}}$$

Data were analyzed using ANOVA with GenStat. Discovery 3.0 edition. Comparisons between means were done using Fischer least significant difference (LSD) at 5% significant level.

3.0 Results and Discussion

3.1 Effect on yields

The pre-planting soil physical and ch revealed an acidic nature of the soil (Table 2), low nitrogen and low organic carbon which implies low soil fertility. The fermentation procedure adopted on

POME enhanced plant nutrient release, N (126.4 ± 1.4-126.0 ±1.43mg/l, P (44.7± 3.2-45.2 ±2.9 mg/l) K(42.3± 2.2-44.5 ± 1.8mg/l) (Table 3.0). The average grain yield as influenced by POME and inorganic fertilizer for the two cropping seasons was 36.6 g/pot and 69.6 g/pot, respectively. Similarly, the average maize stover yield from POME and inorganic fertilizer pots was 73.5 g/pot and 88.9 g/pot, respectively (Table 4.0). The results obtained from fertilized pots were consistently higher than yields from control pots. Meanwhile there were minor but significant yield differences between inorganic fertilizer pots and POME amended pots. However, no significant yield differences occurred within treatment. This observation could be attributable to quick release of inorganic fertilizer on application compared to POME that undergoes mineralization before providing sufficient soil nutrient. These findings corroborate the results of Akanbi *et al.,* (2010) that obtained significant yield differences when 75 kg N ha^{-1} application rate gave highest fruit yield of okra against 11.4 kg ha^{-1} application rate of inorganic fertilizer.

Table 2.0 Physicochemical Characteristics soil (0-15cm)

Parameter(soil)	2006	2007
sand (%)	85	86
Silt(%)	64	63
Clay (%)	4	5
pH(H_2O)	5.7	5.6
Org. C (%)	1.68	1.63
Total N (%)	0.28	0.28
Avail. P(ppm)	7.6	7.4
ECEC	4.52	4.78

Values = mean of 4 determinations , org.C=organic carbon, N=nitrogen, Avail.P= phosphorus, ECEC = effective cation exchange capacity

3.2 Plant nitrogen

The stover and grain nitrogen content for the treatments are summarized in Table 5.0. The average nitrogen concentration in the grain component was higher than the concentration found in the stover irrespective of the type of fertilizer amendment (Table 5.0). In 2006, total tissue N concentration from POME pots did not significantly vary from that of inorganic fertilizer pots, but significantly varied in 2007 cropping season. Also, total tissue N concentration from amended pots significantly differed from that of the control pots (Table 5.0). Plant N

Table. 3.0. Nutrient NPK* content of 20-day fermented POME before soil application.

Year	N (mg/l)	P (mg/l)	K (mg/l)
2006	126.4±1.4	44.7±3.2	42.3±2.2
2007	126.5 ±1.43	45.2±2.9	44.5±1.8

POME= Palm oil mill effluent, *mean of 4 determinations ± std deviation.

Table 4.0. Maize dry matter (g/pot) and grain yield (g/pot) as influenced by POME and fertilizer application in 2006 and 2007 cropping seasons

Year	Component	POME	Fertilizer	Control	S.E	$LSD_{0.05}$
2006	Stover (g/pot)	78.3	98.1	66.9	2.12	13.5
	Grain (g/pot)	32.5	72.4	23.6	0.78	14.8
	Total	110.8	170.5	90.5	1.22	18.7
2007	Stover (g/pot)	68.8	79.8	65.8	2.09	15.6
	Grain (g/pot)	40.7	66.8	27.8	1.44	12.4
	Total	109.5	146.6	93.6	0.89	13.3

POME=palm oil mill effluent, SE= standard error, LSD= least significant different at 5%

accumulation was consistently higher in 2006 than in 2007 except in the control. And this translated to higher total dry matter and grain yields. We observed a trend where N nutrient accumulated in the plant had unrestricted access to the grain. Janssen et al., (1990) reported that factors such as climate, water stress at critical pollination stage, nutrients could prevent high grain yi accumulation. Except for the control experiment in

2006, however, the relationship between grain yield and N uptake by maize was remarkably consistent.

Table 5.0. Mean N (mg/g) content of maize grain and stover as influenced by POME and fertilizer application in the 2006 and 2007 cropping season.

Year	Component	POME	Fertilizer	Control	S.E	$LSD_{0.05}$
2006	Stover	11.6	18.7	10.2	1.65	2.1
	Grain	47.6	48.6	34.0	1.23	3.9
	Total	59.2	67.3	44.2	1.34	2.9
2007	Stover	11.30	13.3	9.6	0.96	1.5
	Grain	39.60	51.0	36.7	1.98	2.6
	Total	50.9	64.3	46.3	2.3	2.7

POME=palm oil mill effluent, SE= standard error, LSD= least significant different at 5%

From the data, POME did not supply N as effectively as the inorganic fertilizer. The lower maize tissue N from POME and similarity in yield with the control pot indicate this inefficiency. Using total N uptake (N concentration x yield), we calculated the % recovery of applied POME-N to be 2%, 0.98% in 2006 and 2007, respectively(Table 8.0) . Similarly, 37%, 25% from inorganic fertilizer for 2006 and 2007, respectively. These results compared well with an average N recovery of 4% from aerobically digested sludge (AES) and 6% from synthetic fertilizer applications to soil planted with feed corn and grass forage (Warman and Termer, 2005). The decrease in nitrogen recovery with POME application probably resulted from greater N losses from denitrification, volatilization and leaching. The screen house methodologies used in this study were not able to explain the fate of N applied as POME was not all recovered by the crop. Organic manuring could promote N losses by denitrification (Smith and Chambers, 1993) and ammonia volatilization (Holding, 1982) compared to pots receiving inorganic-N. Part of the N applied could also remain immobilized in the soil organic matter or fixed in clay minerals

Table 6.0. Mean P (mg/g) content of the maize plant as influenced by POME and fertilizer application in the 2006 and 2007 cropping seasons.

Year	Component	POME	Fertilizer	Control	S.E	$LSD_{0.05}$
2006	Stover	2.2	3.3	1.7	2.5	1.3
	Grain	3.0	3.1	2.2	1.9	0.2
	Total	5.2	6.4	3.9	1.7	2.4
2007	Stover	2.4	3.6	1.6	2.7	1.4
	Grain	3.3	4.6	2.4	2.1	1.6
	Total	5.7	8.2	4.0	2.1	2.5

POME=palm oil mill effluent, SE= standard error, LSD= least significant different at 5%

3.3 Plant Phosphorus.

Tissue P concentrations were higher in maize pots that received either inorganic fertilizer or POME than control pots. However, fertilizer pots gave higher P tissue content than POME. A portion of the higher tissue P in the POME and fertilizer amended pots could be attributed to a concentration effect which often appears with high yield ; for example the stover yield in 2006 and 2007 was high in the fertilizer compared with the control.

The percentage recovery of P applied to maize was (0.49%, 0.55%) from POME, and (23%, 25%) from fertilizer in 2006 and 2007, respectively. The low availability of P from POME amendment was due to surface application and limited P mobility in the imperfectly drained soil.

In addition, the organic amendment must be mineralized to release enough available P, which is often a slow process in newly amended soil. This finding agrees with Warman (1986) who obtained 27% recovery for fertilizer and 7% for aerobically digested sludge on timothy plant grown in two Quebec soils. Maize P requirement was met by POME as evidenced by almost similar P uptake from fertilizer pots.

Table 7.0. Mean K (mg/g) content of maize plant as influenced by POME and fertilizer application in the 2006 and 2007 cropping season.

Year	Component	POME	Fertilizer	Control	S.E	$LSD_{0.05}$
2006	Stover	22.6	24.2	19.8	2.2	3.00
	Grain	2.30	2.9	2.0	1.9	0.62
	Total	24.9	27.1	21.8	2.1	1.3
2007	Stover	22.4	24.0	19.7	2.3	2.6
	Grain	2.20	2.8	1.3	1.4	2.3
	Total	24.6	26.8	20.3	2.1	2.8

POME=palm oil mill effluent, SE= standard error, LSD= least significant different at 5%

3.
4 Plant Potassium

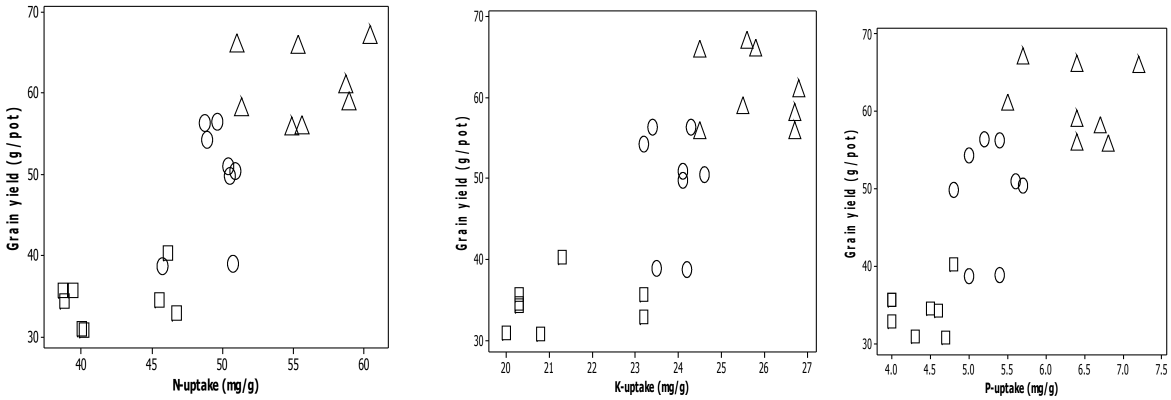
The POME contains relatively small amount of K because most of the K present in the amendment are readily leached beyond the reach of root of plants. In 2006, total K uptake was 24.9 mg/g , about 90.7% was in the stover (Table 7.0), while in 2007 total K uptake was 24.6 and 91.1% was stocked at the stover. Low K content recorded in the tissue grain that did not affect the grain yield could be that K is not a limiting nutrient (Saıdou *et al.,* 2003). There was significant difference between total K uptake in both fertilizer and POME pots as against K uptake in the control pot. The POME amendment provided a relatively high amount of K which caused a steady increase in tissue K. However, stover and grain K varied greatly in all the treatment pots and control. The % recovery of K from POME application was 1.86, 1.78, in 2006 and 2007, respectively. Fertilizer K was recovered at 66%, 50% in 2006 and 2007, respectively.

3.5 Yields and nutrient uptake.

In general, yields were modest (Table 4.0). Maize grain and stover yields and uptakes of N, P and K were significantly ($P < 0.05$) higher in the NPK pots than in POME and control. Unfertilized maize had small and poorly filled cobs, pointing to P deficiency (Gaise *et al.,* 1997). The relationships between the maize grain yields and the uptakes of N, P and K (internal utilization efficiency) as measured in the pot according to treatments in 2006 and 2006 are presented in Fig 1 and Fig 2. Fertilizer treatments had the highest internal utilization efficiencies among the treatments followed by POME as evidenced in the yield results. The differences among treatments were more marked than between the years experiment was conducted.

Table 8.0. Percentage Recovery efficiency of POME and inorganic fertilizer in 2006 and 2007 experiments

Year	POME (%)			Inorganic Fertilizer (%)		
	N	P	K	N	P	K
2006	2.0	0.49	1.86	2.82	23.0	66.0
2007	0.98	0.55	1.78	2.54	25.0	50.0



(a) (b) (c)

Fig.2.0 (a-c). Relationship between grain yield and uptakes of N, P and K according to treatments in 2007. Legend: □ control, O POME, Δ fertilizer

3.6 Residual soil properties.

Post harvest soil analysis implicitly evaluates nutrient (NPK) management. However, Schroder et al.,1993 concluded that the post harvest soil mineral nutrient supply is not just determined by the balance of nutrient losses during the growing season that can be related to cumulative precipitation. There was poor variation in percentage N as influenced by POME in the pot experiment. NPK pots recorded the highest residual percentage N and org. C. while the control gave the least (Table.8.0). The org. C and N contents provide a measure of organic matter status of soil, which is the net function of crop management practices in any agro ecosystem (Gregorich et al.,1994; Kanchikerimath and Singh, 2001). Amongst the treatments applied, NPK pots recorded higher soil organic C and N, followed by POME amended pots, consequently moderate C: N ratio recorded in POME pot indicates build up of N pool in the soil. POME amendment may have provided the needed microbes and NO_3-N that stimulated soil organic matter (SOM) degradation. Longer days of POME fermentation provided quality time for microbial build up which ultimately increased residual org.C and N. The differences in the rates of residual org. carbon and N are indicative of the variable amounts of labile org. C accumulated in different treatments. Adegbidi and Briggs, (2003) reported that N mineralization rate composts are specific to the materials utilized and to the experimental conditions.

Conclusions.

Palm Oil mill Effluent (POME) could be effective source of N, P and K for crop production, although the nutrient availability of organic amendment was considerably lower than the inorganic fertilizer. The inorganic fertilizer provided the highest nutrient availability among other treatments followed by POME and it therefore produced significantly ($p<0.05$) higher grain yield. The amendment equally left considerably level of organic residues with potential to prolong the health of the soil.

Table 9.0. Mean residual soil chemical properties as affected by POME application in 2006 and 2007

POME=palm oil mill effluent, SE= standard error, LSD= least significant different at 5%

Year	Component	POME	Fertilizer	Control	S.E	$LSD_{0.05}$
2006	% org. N	0.04	0.02	0.03	0.5	0.01
	% org.C	1.81	1.91	0.83	1.2	0.6
	P (ppm)	4.63	5.13	4.24	2.3	2.1
	K (ppm)	20.4	24.36	18.3	2.4	2.6
	pH	6.0	5.7	5.6	1.3	0.2
2007	% org.N	0.04	0.02	0.03	0.3	0.02
	% org.C	1.78	1.93	1.02	1.4	0.5
	P(ppm)	4.21	4.67	3.97	2.4	0.2
	K (ppm)	22.2	29.5	20.5	1.9	1.3
	pH	5.9	5.8	5.4	1.4	

Org.C=organic carbon, org.N=organic Nitrogen, P= phosphorus, K=potassium,

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