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ORIGINAL RESEARCH

Laboratory study of the nutrient release rate for vinasse on sandy soil and three coastal clay soils of Guyana

Clairmont Clementson[1*], Lalita Gopaul[2]

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Abstract

Purpose Vinasse is produced in large quantities as a by-product from bioethanol production. To ensure environmental sustainability, a beneficial use was sought. Previous study showed that short-term crops grown with vinasse-amended soil provided higher yield than crops treated with chemical NPK (15:15:15) fertilizer. To understand this phenomenon, this study sought to establish the nutrient release rates of vinasse in the agricultural soils of Guyana.

Methods Soils representative of the three most common and one futuristic agricultural land in Guyana were fertilized with vinasse, then watered as with normal course of plant growth of cash-crops for twelve weeks. The soil was sampled periodically, and the soil nutrients were determined.

Results The nutrient availability from the application of vinasse as a soil amendment was greater for the clay soils than the sandy soil. EC was high while there was high availability of N,Ca, Mg, Fe and Mn during the 6-12th week. There was no discernable trend for tiwiwid sand.

Conclusion In this laboratory study, high nutrient availability was observed in weeks 6-12 for the three clay soils studied. This period is the fruit and foliage growth phase for most short-term crops; hence, this suggests that vinasse is a good soil amendment for short-term crops in these soils. Vinasse did not improve the fertility of sandy soils; hence, it would be unsuitable as a fertilizer source in the Intermediate Savannahs of Guyana. Further studies should be done to fully determine the soil nutrient dynamics and the nutrient uptake.

Keywords Vinasse, Organic fertilizer, Nutrient release, Cash-crops, Plant nutrients

Introduction

Global agricultural demands have drastically increased to meet the world's population growth over the last few decades. The extravagant use of inorganic fertilizers within the agricultural sector to meet this demand has triggered environmental concerns. As such researchers are exploring various avenues of alternative organic fertilizers (Abrahim et al. 2016; Chan et al. 2008). In response to the need for viable alternative sources of renewable energy, Guyana has begun producing ethanol from "blackstrap" molasses at a rate of 1000 liters per day. Each day, the plant produces 10,000 litres of the waste by-product (vinasse) which has been identified as an alternative to synthetic fertilizers (Clementson et al. 2016). Clementson et al. (2016) found that vinasse contains high quantities of the primary plant nutrients (nitrogen (N), phosphorus (P), potassium (K), iron (Fe), copper (Cu), magnesium (Mg) and manganese (Mn)). Clementson et al. (2016) also showed that short-term crops (cash- crops) grown on vinasse-amended soil provided higher yield than crops treated with chemical fertilizer NPK (15:15:15). These findings formed the basis of this study to investigate the rate at which nutrients are released from vinasse when used as a soil amendment and the effect of electrical conductivity (EC) (measure of a material's ability to conduct an electrical charge) on nutrient availability. Do Carmo et al. (2016) posited that EC has a direct and critical correlation with plant growth performance such that increased EC values correlate with an increase in nutrient availability and organic matter in soils.

✉ Clairmont Clementson
kemba.cc@gmail.com

1 Agricultural and Biological Engineering Department, Purdue University, West Lafayete, United States
2 National Agricultural Research and Extension Institute, Mon Repos, East Coast Demerara, Guyana

The nutrient release rate of fertilizers for plant uptake depends on the physical and biological properties within the soil (Haby et al. 2009; Moran-Salazar et al. 2016). Sandy soils are characterized by their weak structure, poor water retention capacity, high permeability and low fertility (Bruand et al. 2005). On the contrary, clay soils have a high water-holding capacity and a high organic matter content which makes them high in nutrients (FAO 1965a). In Guyana, agricultural activities are predominantly in the coastal area which is composed mostly of clay soils. This experiment utilizes four soil types: white sand labelled as tiwiwid series and the three most prevalent coastal clay soils types labelled as the Whittaker Series, Onverwagt Series and Weldaad Series. According to the FAO (1966), Whittaker Series are classified as members of the Aquic Haplorthents clayey, non-acid, soft or moderately firm family and as Low Humic Gley soils that are poorly drained. These soils are known for their dark grey surface, mottled with brownish yellow and dark reddish-brown subsoil, and a substratum of clay or silty clay loam. The upper horizons (0-37 cm) are mostly neutral while the middle horizons (38-117 cm) are mildly alkaline and the lower horizons (117-137cm) moderately alkaline. FAO (1965a) classified soils of the Weldaad series as members of a clayey, acid, soft or moderately firm family of Aquic Haplorthents; also, as Humic Gley soils, very poorly drained. They have a darker grey surface with subsoil that is soft and contains acid sulphates (FAO 1965b) as such all horizons are extremely acidic. Soils of the Onverwagt series are classified as members of the Typic Ochraquults clayey family, poorly drained and Low Humic Gley soils. They have a thin dark grey surface soil and a grey mottled subsoil with strong brown. The upper horizons are strongly acid, but the soil below a depth of 24 to 30 inches is neutral or slightly alkaline (FAO 1965a). Tiwiwid soil is utilized in the experiment since agriculture is currently being developed in the Intermediate Savannah of Guyana which comprises of this type of soil. This soil type is composed of almost pure quartz with a shiny white appearance and a dry, gritty texture. All horizons are moderately acidic. It is a very porous well drained soil with an average water holding capacity of 0.75 inch per foot of soil (FAO 1965c).

The high nutrient content of vinasse makes it a sustainable, environmentally acceptable soil amendment, since it is known for stimulating growth of microorganisms, thereby facilitating nutrient uptake by plants (Moran-Salazar et al. 2016). Vadivel et al. (2014) utilized vinasse in India on poor, well drained soils and this successfully improved the physical soil properties. They found that application of vinasse on these reclaimed soils increased hydraulic conductivity and eventually increased the water-holding capacity of the sandy type soil. They also determined that high organic content and carbon, nitrogen ratio of vinasse facilitate microbial activity within the first 45 days of vinasse application followed by nutrient release. Campiteli et al. (2018) suggested that in addition to improved soil microbiological and fertility conditions, vinasse-amended soil retained higher moisture content than those treated with chemical fertilizer.

Suitable physical and chemical properties of soils provide the environment and supply adequate nutrients conducive for optimal activities of soil microorganisms. The fungi and bacteria present in vinasse assist in the decomposition of organic matter in the soil (Yang et al. 2013). Yang et al. (2013) determined that there was a slow rate of nutrient release of soil treated with vinasse. They attributed this to a higher population of actinomycetes in vinasse and the complexity of its compounds. Chen et al. (2018) posited that environmentally friendly fertilizers can increase soil organic matter and improve water-holding capacity of soils. Arafat and Yassen (2002) highlighted that while chemical fertilizers release most of its available nutrients to the plant within two to four weeks, common organic fertilizers continuously release nutrients within four to eight weeks. The latter time is most suitable for cash crop cultivation since it is during this period that nutrients will be mostly required for healthy plant growth and development.

This study was conducted during a twelve-week period (the time frame to produce most cash crops) and seeks to investigate the rate at which the essential plant nutrients present in vinasse are being released in a sandy type soil and three common coastal type soils in Guyana. Additionally, the effect of EC on the rate at which these nutrients are being made available to plants is investigated.

Materials and methods

Location and Treatments

This study was carried out at the National Agricultural Research and Extension Institute (NAREI), Mon Repos, Guyana under a shaded facility with free air flow. The release rates of the nutrients were tested on four different soil types: white sandy soil (series tiwiwid 700) and the three mostly prevalent coastal soil types in Guyana. The coastal soils are Soil Series #37, Soil Series #41 and Soil Series #44 referred to locally as the Whittaker Series, Onverwagt Series and Weldaad Series, respectively.

Tiwiwid soil was sourced from the Soesdyke-Linden Highway (Upper Demerara Region) while the other soil types were collected from the Agriculture Research Reserve within NAREI area which contain most of the soils used in Guyana for agriculture purposes.

Experimental Set up

Three replicates of each soil were collected and placed in five-gallon containers of 9.5 inches diameter and 13 inches depth (Fig. 1). The pH of the vinasse (3.94) was neutralized by the approach utilized by Clementson et al. (2016) to increase the pH to 6.50 after 24 hours by applying 10g of $CaCO_3$ (calcium carbonate-limestone) per 25 ml of vinasse. The vinasse application rate was based on Arafat and Yassen's (2002) method. Further, using the rate similar to Clementson et al. (2016), where 500 ml was used for a bed of eight (8) plants and assuming each container can accommodate one plant, 62.5 ml of vinasse was measured and poured evenly onto the surface of the soil in each container. All containers were watered normally with amounts determined by the net irrigation requirement (NIR). The net irrigation requirement of the Mon Repos area was determined to be 15mm.

The daily water requirement for each replicate was determined using equation (1): The area of the containers utilized in the experiment was 0.049m^2, therefore, 735ml of water was required.

$$A \times NIR = Tw \qquad (1)$$

Where A – Area (m^2) to be watered, NIR – net irrigation requirement of the location, Tw - Total Volume of Water (L)

Data Collection

Soil samples were taken prior to the application of vinasse to establish a baseline of the nutrient content present in each type of soil. The five-point star shaped soil sampling technique was used where soil was extracted at each point of the star (circular red points in Fig. 2) by inserting a hand core to depths of up to 6 inches. Ten extractions from each container formed a composite and was placed in a labeled sample bag. These samples were taken fortnightly for twelve weeks commencing two weeks after the addition of vinasse. The nutrient content of these soil samples was analyzed at the Guyana Sugar Corporation's soil laboratory. The nutrients analyzed were nitrogen (N), phosphorous (P), potassium (K), magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn) and copper (Cu). Samples were taken at one-week intervals for EC test. The initial and final pH of the soils were also determined. All soil samples were air dried for 48 hours grounded, weighed and solutions were added followed by using the UV-VIS Spectrophotometer filtration for respective analyses. EC was measured using a conductivity meter and a pH meter was used to measure pH. The Cu, Fe, Ca and Mg were measured using an Atomic Absorption Spectrophotometer. N was measured using the UV-VIS Spectrophotometer while K was measured using a flame photometer. These tests were performed according to methods specified in FAO 2008.

Fig. 1 Potted soil samples

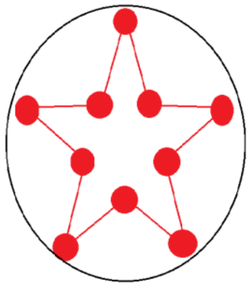

Fig. 2 Illustration of soil sampling strategy

Data Analysis

Descriptive statistics in Microsoft Excel were used to graphically display the results of all soil analyses. Microsoft Excel Data Analysis Toolpak and Statistix 8 were used to analyze the data collected. Regression analyses were done to establish trends within the data set, ANOVA and LSD pairwise tests were used to determine if there are differences in nutrient concentration and EC over the weeks, while Pearson Product Moment Correlation was used to test for relationships between nutrient concentration and EC.

Results and Discussion

There are five major processes that occur to fertilizers after application to the soil. It is first taken up by the crop, it reacts with the soil minerals and organic matter, it can leach from the root zone with water, it can be removed through erosion and run-off and it can be lost to the atmosphere as gas (Shaviv and Mikkelsen 1993). The one process that is of interest in this experiment is its reaction with soil minerals and organic matter to become part of the soil reserve, hence the release of nutrients over a period of 12 weeks is shown in Table 1.

Table 1 Mean concentrations of nutrients in the vinasse and four soil types over the twelve (12) weeks period

Substrate	Week	pH	Nutrients Analyzed (mg/kg)$^{\&}$								
			N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
Vinasse (mg/L)	Initial	4.05	3470	1.00	650	700	108	0.56	1.03	5.52	1.03
Treated Tiwiwid Series	Initial	6.26	1675.00^{b}±83.52	3.13^{a} ± 0.90	13.90^{b} ± 1.01	6.81^{b} ± 0.19	1.52^{d} ± 0.02	0.17 ± 0.01	0.92^{b} ± 0.01	0.14^{a} ± 0.02	0.83^{bc} ± 0.01
	2	-	1483.33^{b} ± 1200.35	0.69^{d} ± 0.05	14.67^{b} ± 2.08	39.82^{b} ± 66.24	8.53^{bc} ± 1.30	0.00	0.86^{b} ± 0.11	0.21^{a} ± 0.03	2.25^{a} ± 0.17
	4	-	575.00^{c} ± 259.81	1.45^{c} ± 0.15	21.67^{a} ± 1.15	13.20^{a} ± 00	8.23^{bc} ± 0.88	0.00	1.13^{b} ± 0.12	0.49^{a} ± 0.06	2.33^{a} ± 0.27
	6	-	3566.67^{a} ± 554.71	2.37^{b} ± 0.57	4.80^{c} ± 0.82	8.11^{c} ± 1.86	8.88^{b} ± 1.32	0.00	0.86^{b} ± 0.52	0.27^{a} ± 0.11	0.25^{d} ± 0.22
	8	-	1625.00^{b} ± 66.14	1.94^{bc} ± 0.18	5.10^{c} ± 0.75	29.43^{c} ± 4.19	11.70^{a} ± 0.90	0.00	1.01^{b} ± 0.19	4.30^{a} ± 6.41	0.54^{cd} ±0.16
	10	-	1533.33^{b} ± 52.04	1.37^{c} ± 0.29	5.20^{c} ± 1.65	23.03^{c} ± 10.17	11.97^{a} ± 1.97	0.11	1.00^{b} ± 0.43	0.39^{a} ± 0.26	1.07^{b} ±0.36
	12	6.54	1633.33^{b} ± 57.74	1.67^{c} ± 0.81	4.47^{c} ± 0.21	11.43^{c} ± 1.01	7.24^{c} ± 0.33	0.00	2.18^{a} ± 0.53	0.42^{a} ± 0.08	1.09^{b} ±0.48
Treated Whittaker Series	Initial	5.03	4125.00^{ab} ± 109.78	20.00^{d} ± 0.87	172.00^{c} ± 8.89	323.40^{c} ± 4.51	366.90^{cd} ± 2.01	0.14 ± 0.01	17.40^{c} ± 0.01	31.60^{ab} ± 0.02	12.80^{c} ±1.25
	2	-	2241.67^{cd} ± 777.15	32.40^{bc} ± 6.75	624.33^{a} ± 58.02	178.00^{c} ± 39.28	263.33^{d} ± 68.98	0.00	42.63^{bc} ± 9.35	23.43^{c} ± 2.63	17.00^{ab} ±2.42
	4	-	1433.33^{d} ± 747.64	33.83^{b} ± 5.77	632.33^{a} ± 114.15	155.00^{c} ± 9.54	258.67^{d} ± 118.13	0.00	58.00^{c} ± 20.66	24.30^{c} ± 5.34	19.03^{a} ±2.82
	6	-	5333.33^{a} ± 361.71	43.44^{a} ± 6.12	371.67^{b} ± 48.23	1099.00^{b} ± 79.79	627.33^{b} ± 55.75	0.00	41.17^{a} ± 8.83	20.17^{c} ± 4.83	19.17^{a} ±3.27
	8	-	3666.67^{bc} ± 1216.12	20.30^{d} ± 6.10	379.00^{b} ± 57.00	498.00^{c} ± 119.38	1106.33^{a} ± 73.53	0.00	42.73^{bc} ± 10.02	25.93^{bc} ± 2.83	16.33^{b} ±3.65
	10	-	4533.33^{ab} ± 972.22	26.63^{c} ± 7.39	370.67^{b} ± 58.77	467.00^{c} ± 167.31	988.33^{a} ± 64.39	0.00	45.47^{bc} ± 11.05	34.07^{a} ± 7.21	17.40^{ab} ±3.44
	12	5.30	3483.33^{bc} ± 1187.00	26.73^{c} ± 7.93	348.67^{b} ± 56.57	3897.67^{a} ± 823.34	432.33^{c} ± 1200.35	0.04	61.57^{ab} ± 22.81	33.60^{a} ± 7.92	15.33^{b} ±3.18
Treated Onverwagt Series	Initial	3.95	4550.00^{abc} ± 599.40	20.10^{abc} ± 0.17	175.00^{e} ± 6.56	295.70^{cd} ± 3.04	557.70^{e} ± 1.61	0.21 ± 0.03	15.70^{d} ± 2.31	18.20^{a} ± 1.11	12.60^{ab} ±3.70
	2	-	1858.33^{e} ± 946.48	22.23^{ab} ± 3.08	616.33^{b} ± 28.54	188.33^{d} ± 35.57	733.67^{d} ± 26.73	0.00	16.57^{d} ± 0.59	12.29^{d} ± 2.25	12.67^{ab} ±0.67
	4	-	2466.67^{de} ± 512.55	24.53^{a} ± 6.74	652.67^{a} ± 46.54	181.00^{d} ± 50.09	767.33^{d} ± 71.02	0.00	18.77^{c} ± 0.51	12.57^{cd} ± 2.45	13.23^{a} ±1.31
	6	-	5150.00^{ab} ± 336.34	19.95^{abc} ± 4.25	329.67^{d} ± 25.15	1099.00^{b} ± 79.27	1107.33^{b} ± 69.82	0.00	16.20^{d} ± 0.89	8.28^{e} ± 2.53	12.00^{bc} ±1.48
	8	-	3841.67^{bcd} ± 487.55	15.63^{c}± 3.76	389.67^{c} ± 20.98	522.33^{c} ± 107.36	1645.00^{a} ± 9.17	0.07	20.97^{b} ± 0.51	12.30^{cd} ± 2.42	11.87^{bc} ±0.87
	10	-	5591.67^{a} ± 1484.36	18.17^{bc} ± 4.74	375.33^{c} ± 32.19	372.67^{cd} ± 70.87	1716.67^{a} ± 44.00	0.05 ± 0.02	19.63^{bc} ± 2.19	14.77^{bc} ± 2.98	11.93^{bc} ±1.36
	12	4.17	2975.00^{cde} ± 1128.33	23.77^{a} ± 3.72	335.67^{d} ± 16.44	3094.67^{a} ± 423.18	954.67^{c} ± 135.18	0.00	25.80^{a} ± 1.61	16.20^{ab} ± 0.89	11.20^{c} ±0.87
Treated Weldaad Series	Initial	5.05	4800.00^{bc} ± 127.94	6.58^{b} ± 0.56	168.00^{e} ± 0.69	168.80^{b} ± 0.89	194.10^{c}± 7.81	0.05 ± 0.01	46.70^{c} ± 0.64	46.60^{a} ± 0.23	12.90^{ab} ± 0.10
	2	-	3675.00^{cd} ± 50.00	6.48^{bc} ± 0.40	605.00^{b} ± 35.37	152.33^{b} ± 21.13	177.33^{c} ± 1.15	0.00	50.87^{c} ± 3.41	30.53^{c} ± 1.88	13.07^{ab} ±0.57
	4	-	2450.00^{d} ± 1740.87	6.92^{b} ± 0.94	492.33^{b} ± 19.14	187.33^{b} ± 94.16	177.00^{c} ± 1.00	0.00	71.53^{b} ± 18.42	30.87^{bc} ± 2.86	13.60a ±0.26
	6	-	6016.67^{ab} ± 641.45	10.22^{a} ± 2.26	234.67^{d} ± 20.84	486.00^{a} ± 4.36	204.67^{c} ± 19.22	0.00	47.70^{c} ± 1.28	31.20^{bc} ± 0.96	12.80^{ab} ±0.66
	8	-	5050.00^{abc} ± 390.51	3.57^{d} ± 0.68	271.00^{c} ± 9.54	469.00^{a} ± 38.12	449.00^{a} ± 17.35	0.00	55.00^{bc} ± 0.00	31.40^{bc} ± 0.20	12.17^{b} ±0.46
	10	-	6975.00^{a} ± 2602.40	4.13^{cd} ± 0.47	257.67^{cd} ± 11.93	269.00^{b} ± 48.57	447.67^{a} ± 19.22	0.00	53.03^{c} ± 1.50	31.53^{bc}± 1.40	12.10^{b} ± 0.95
	12	5.30	4058.33^{bcd} ± 166.46	6.58^{b} ± 2.13	248.00^{cd} ± 15.72	402.00^{a} ± 140.57	355.00^{b} ± 73.51	0.00	90.00^{a} ± 3.46	34.97^{12}± 4.57	10.87^{c} ± 1.17

& - letters indicate significant difference of nutrient means for the soil type over the duration of the test ($p < 0.05$); ±= Standard Deviation; all other values are expressed as means; replicates n=3

Fig. 3 shows pattern of the EC monitored on a weekly basis for the soils tested. Fourth order polynomial provided the high R^2 values and there were significant differences in the mean weekly readings (Table 2).

Tiwiwid had the lowest values after vinasse application being highest of 185.84 S/cm in week ten and lowest of 86.48 S/cm in week twelve. Whittaker series showed an increase in EC to around 600 S/cm about week seven then decreased to 370 S/cm at week twelve. The polynomial for the Onverwagt Series showed steady increase until week ten peaking at about 490 S/cm, then decreasing to about 370 S/cm at week twelve. Weldaad series showed the least variation of the coastal soils with most values between 300-400 S/cm. The variations of Pearson's coefficient (Table 3) between the EC and nutrients measured indicate that there's no clear relationship regarding any of the tested soils. There was strong correlation for (negative) P and (positive) Mg of the sand; (negative) Cu and Mn, (positive) Zn of Whittaker Series; (positive) Mg of Onverwagt Series; (negative) Cu and Mn, (positive) Fe of Weldaad Series. Mg for the sand, Whittaker Series and Weldaad showed positive correlation with EC which correspond with the findings of Do Carmo et al. (2016).

Table 2 Mean Electrical conductivity in the four soil types over the twelve weeks' period

Weeks	EC (S/cm)#			
	Tiwiwid Series	Whitaker Series	Onverwagt Series	Weldaad Series
0	34.09^{f}±4.88	152.49^{k}±6.30	116.78^{j}±6.33	175.41^{j}±3.78
1	94.00^{de}±6.91	208.85^{j}±5.37	184.78^{i}±5.82	327.44^{h}±6.73
2	144.03^{bc}±6.37	431.12^{g}±13.46	194.80^{i}±4.85	338.00^{gh}±5.85
3	153.01^{b}±10.07	459.60^{f}±6.76	243.30^{h}±6.75	358.89^{f}±6.29
4	191.82^{a}±7.04	480.54^{e}±4.65	287.04^{g}±6.63	388.65^{d}±3.47
5	97.28^{de}±7.47	519.12^{d}±7.97	304.88^{f}±4.09	407.55^{bc}±7.98
6	137.37^{c}±8.38	559.19^{c}±5.55	334.61^{e}±6.76	372.69^{e}±6.44
7	133.85^{c}±7.04	595.07^{b}±6.98	366.58^{d}±7.02	400.59^{c}±7.38
8	98.16^{de}±8.13	658.72^{a}±11.21	415.68^{c}±5.68	413.95^{b}±5.71
9	107.71^{d}±9.14	597.93^{b}±5.65	469.61^{b}±5.45	432.38^{a}±5.92
10	185.84^{a}±13.45	425.10^{gh}±10.33	534.34^{a}±7.09	282.91i±5.95
11	138.29^{c}±9.77	415.29^{h}±6.17	418.20^{c}±3.81	348.82^{fg}±8.99
12	86.48^{e}±6.20	370.08^{i}±6.24	356.77^{d}±6.77	431.32^{a}±9.68

- letters indicate significant difference of means (p< 0.05), values are expressed as means ±: Standard Deviation; Replicates: n=3

Table 3 Pearson's coefficient showing the correlation between EC and nutrients released

Soil Types (EC)	Nutrients								
	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
Tiwiwid Sand	-0.20	-0.69	0.22	0.39	0.68	-0.37	-0.22	-0.16	0.48
Whittaker Series	-0.01	0.35	0.44	-0.10	0.53	-0.86	0.47	-0.58	0.72
Onverwagt Series	0.44	-0.43	0.01	0.20	0.92	0.44	0.52	-0.22	-0.55
Weldaad Series	-0.30	0.05	0.27	0.59	0.24	-0.83	0.61	-0.73	-0.33

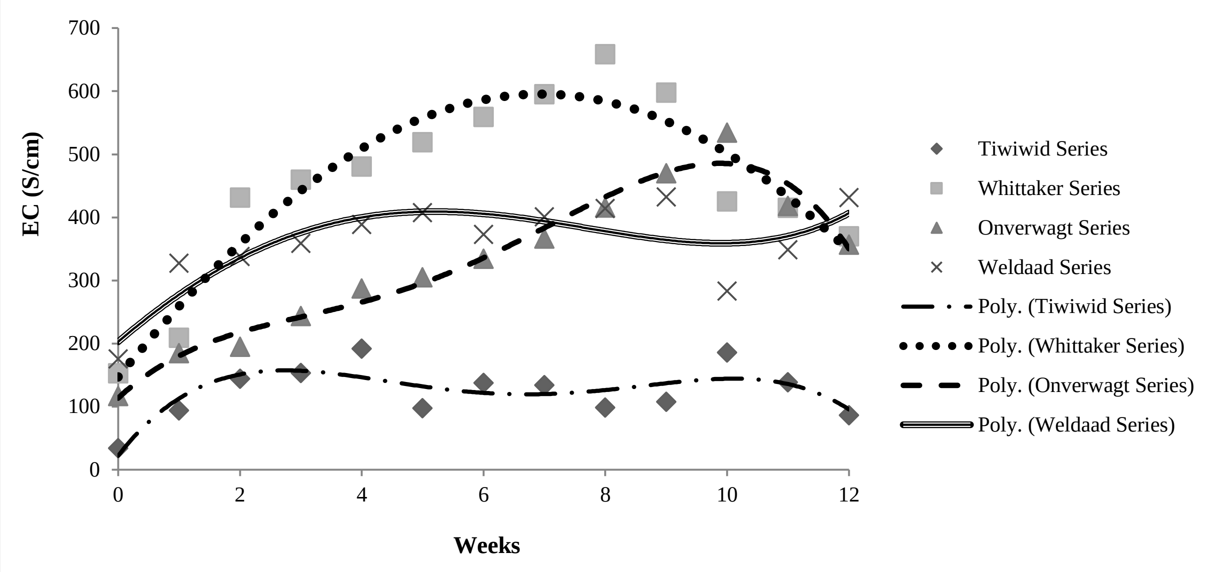

Fig. 3 Electrical conductivity of the various soil types after vinasse application(n=3)

Upon adding vinasse to the various soils, there was a general decrease in N concentration for all the soils after two weeks, then generally increasing to an optimal value (week six for sand, about week eight for Whittaker Series and Onverwagt series, and week ten for Weldaad Series), then decreased again (Fig. 4). There was low weak correlation between nitrogen and EC in the soils. It is suggested that when nitrogen is added to the soil, it is firstly taken up by microorganisms before it is made available to the plants, then the microbes begin to release the N, hence the concentration went up for all the soils (Simanjuntak and Lengkong 2017).

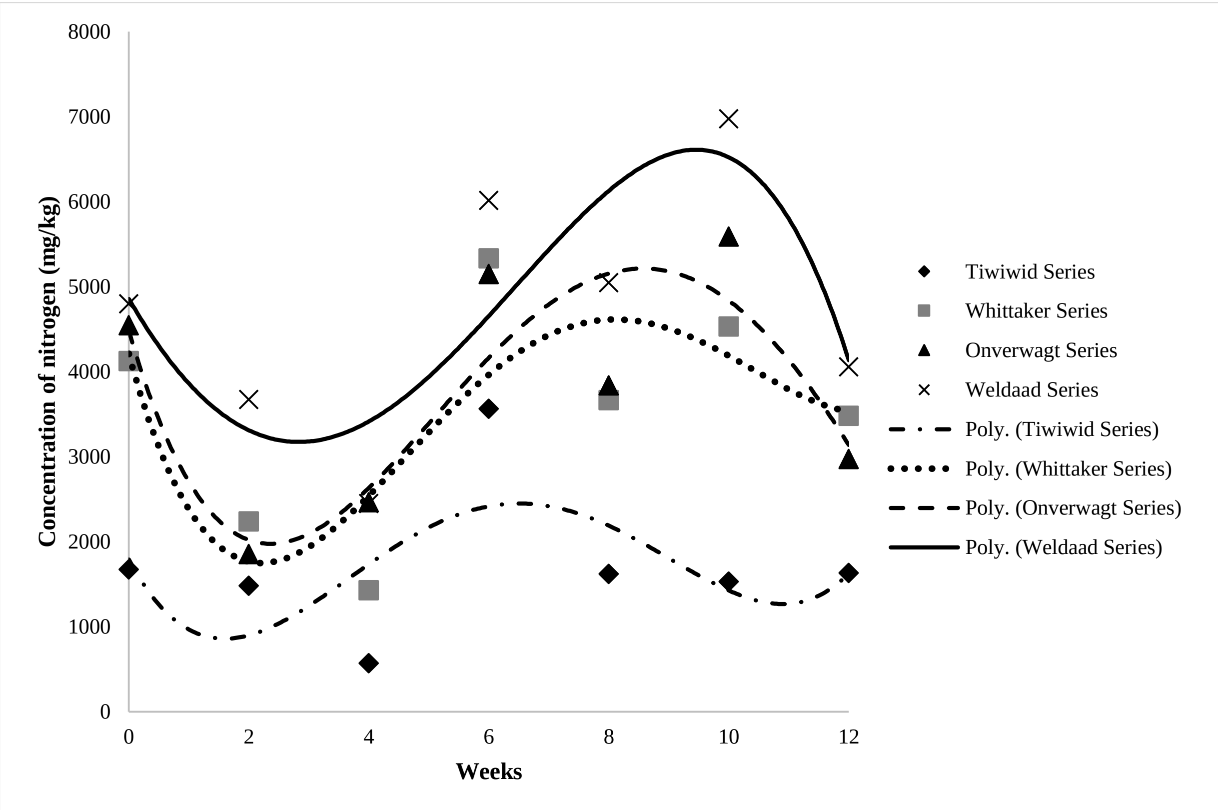

Fig. 4 Nitrogen concentration over twelve weeks after vinasse application(n=3)

The P concentration of the Whittaker series was generally high with variation while peaking at about week four. The coastal soils showed the distinct pattern with their lowest value about week 10 before increasing thereafter (Fig. 5). However, sand showed a near perfect trend in the availability of P with its polynomial having the highest R^2 value of 0.98. P movement in soil is limited due to its reaction with clay and other elements to become less available. These newly formed phosphorus compounds dissolve slowly, releasing P over many months or years (Mikkelsen 2012).

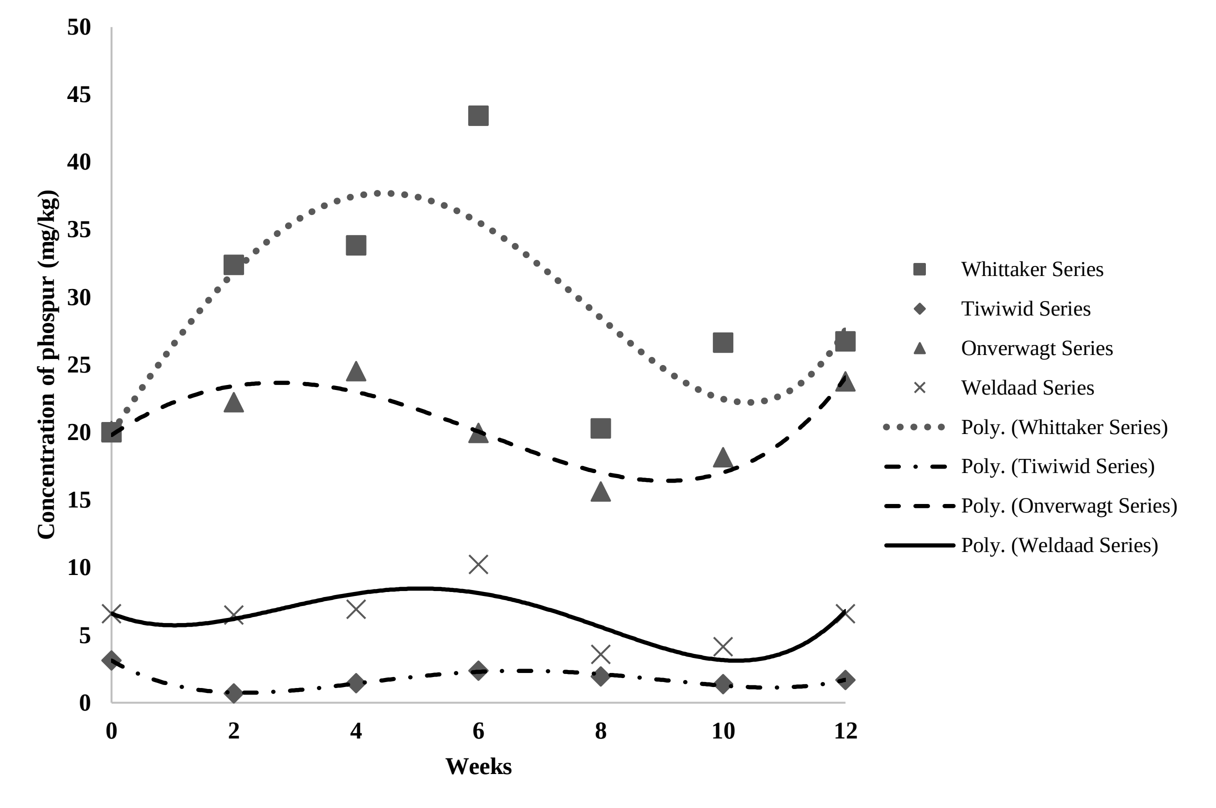

Fig. 5 Phosphorous concentration over twelve weeks after vinasse application(n=3)

K concentration increased for all the coastal soils at week two, then decreased to the minimum after vinasse application about week seven before increasing about week ten, then decreased. Sand, on the other hand, experienced minimal variability in its release of K (Fig. 6). K dissolves quickly in soil and would either displace a cation on the clay surface or move with water until it displaces a cation (Mikkelsen 2012).

The polynomial equation for the Ca concentration of the Whittaker and Onverwagt Soil series followed the same pattern, decreasing at about week two before increasing to about 1100 mg/kg at week six, then decreasing with an inflexion point about week nine and increasing to optimal values at week twelve (Fig. 7). This can be attributed to the increase in pH for both of these soils (Table 1). The line for the Weldaad Series showed a maximum value about week six while the values for the sand was the lowest of all the soils with a maximum value of 39.82 mg/kg at week two (Table 1). Ca is found in many primary and secondary soil minerals making it relatively insoluble when it reacts with phosphate ions, hence it is not considered a leachable nutrient (Mikkensen 2012).

The line for the magnesium concentration of the coastal clay soils generally followed an S-shaped curve with optimal values about week nine (Fig. 8). Mg is a component of several primary and secondary plant nutrients making them insoluble, for agricultural considerations. Upon addition of vinasse to the soil, there was a gradual increase in the concentration of Mg for the three clay type soils with a sharp decline as the experiment was coming to an end while the Mg concentration of the sand was relatively constant with values below 12 mg/kg. This might be attributed to the fact that as Ca becomes more available for uptake, Mg becomes less available; in a phenomenon referred to as cation competition (Gransee and Führs 2012). Particles of sand have no charge in their structure, therefore upon addition of vinasse, the Mg concentration remained stable throughout the twelve weeks since the added Mg may have just leached out (Gransee and Führs 2012).

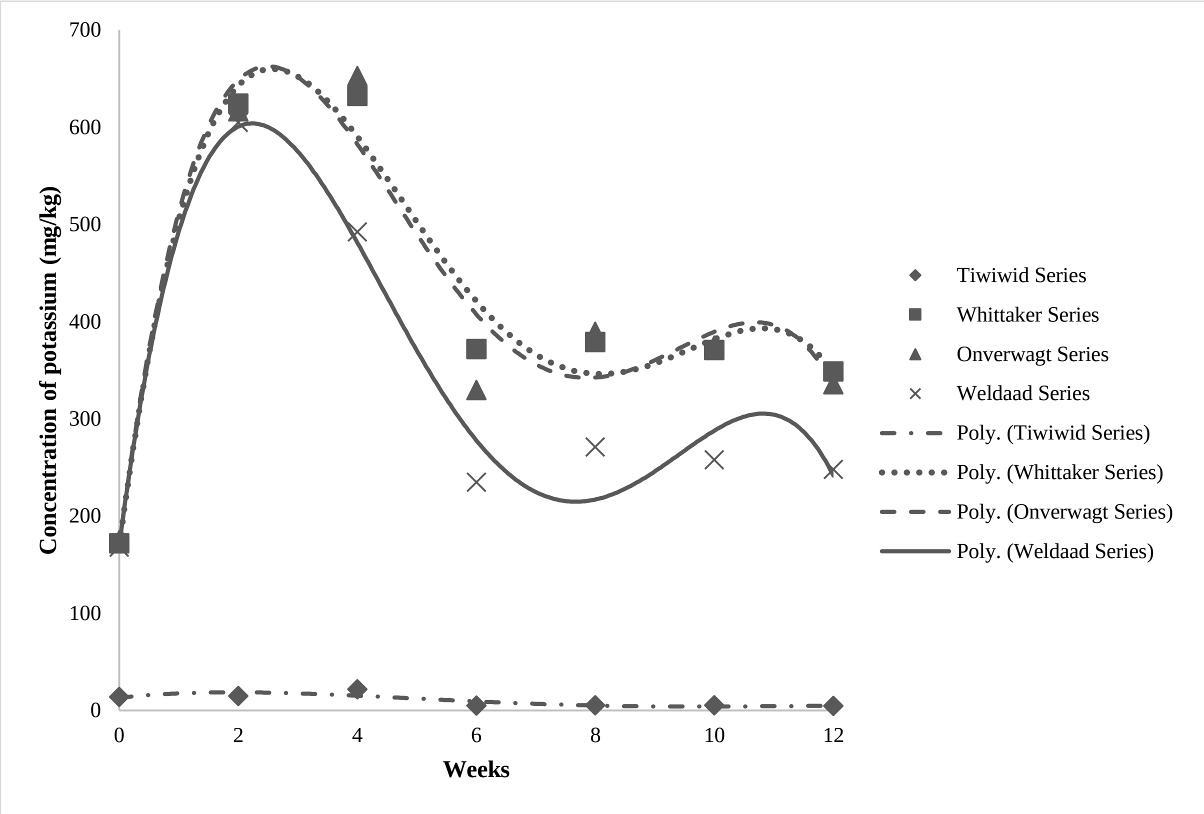

Fig. 6 Potassium concentration over twelve weeks after vinasse application(n=3)

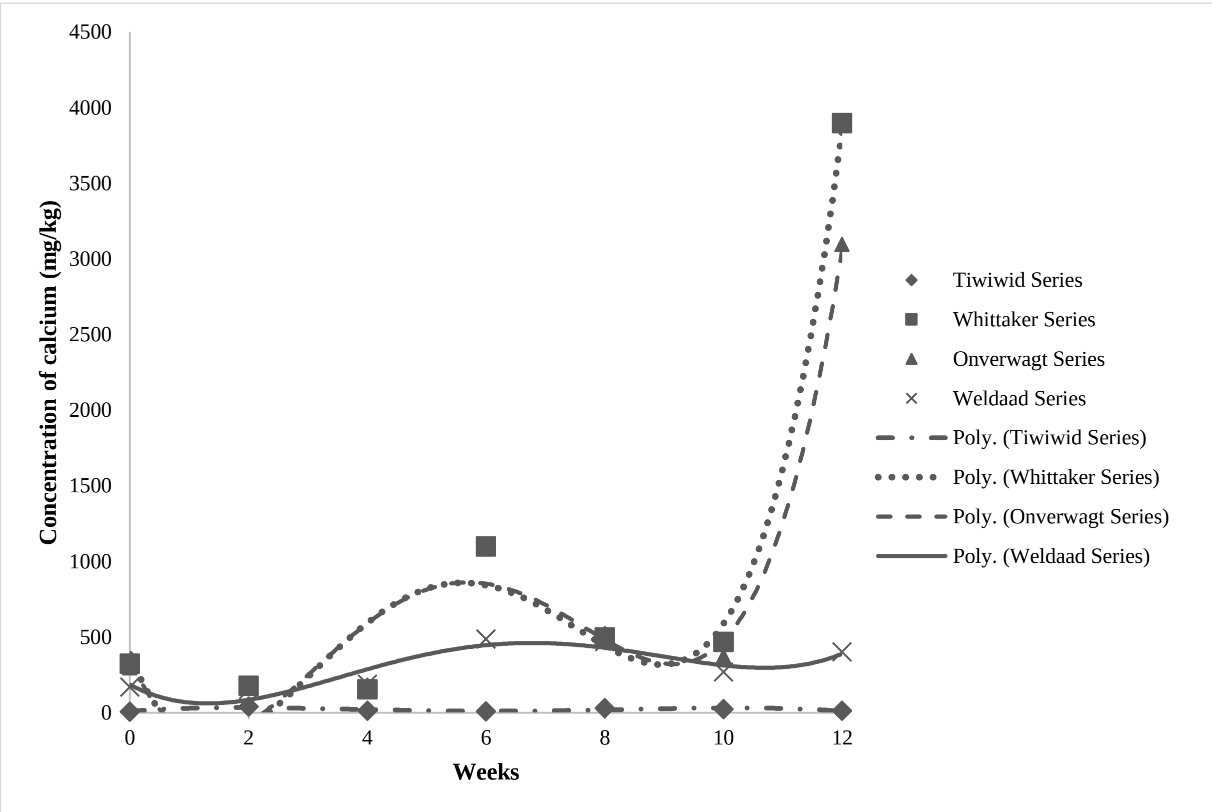

Fig. 7 Calcium concentration over twelve weeks after vinasse application(n=3)

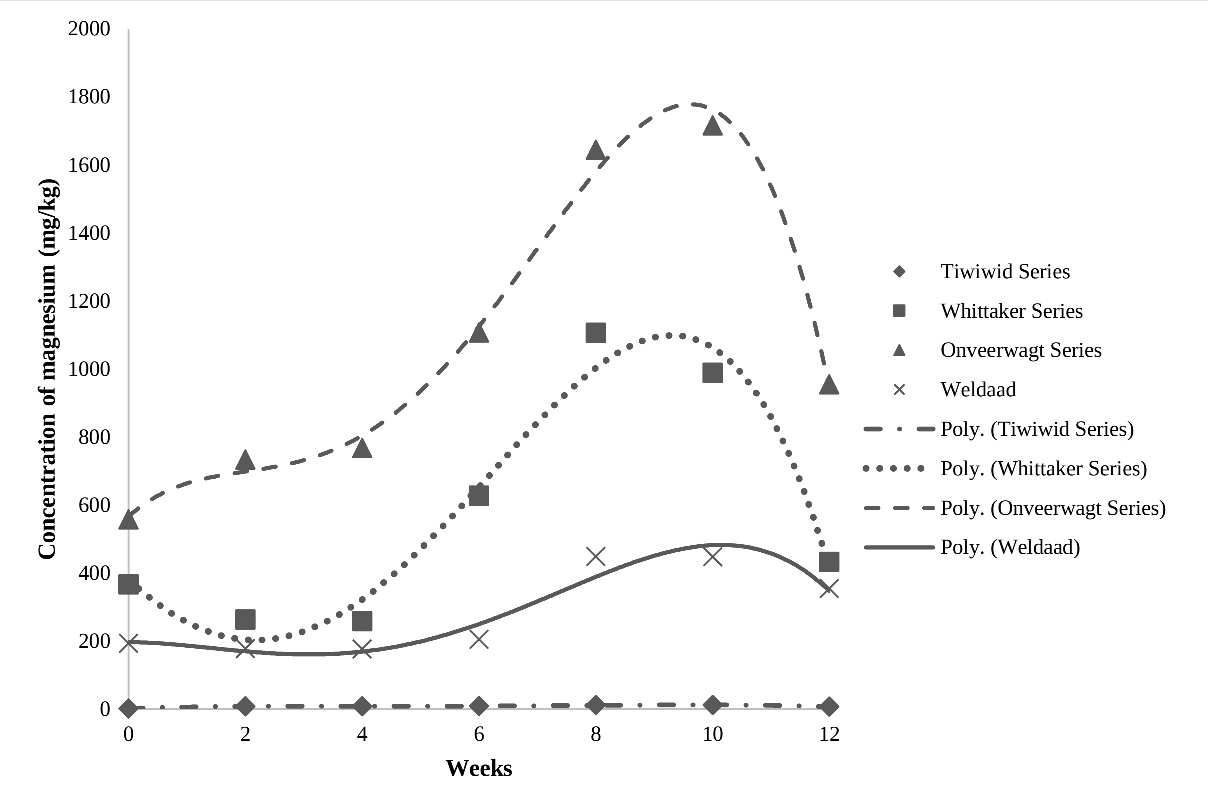

Fig. 8 Magnesium concentration over twelve weeks after vinasse application(n=3)

Fe concentration for all the soils increased after two weeks (Table 1). The increase for Onverwagt series and sand showed small gradient of their curve with the low values for sand (Fig. 9). For Whittaker series and Weldaad series, the curve showed an increase of iron concentration at week two, then decreasing with an inflexion point about week nine before attaining optimal values. The Onverwagt Series is more readily drained than the Whittaker and Weldaad series. This could be the reason for the Onverwagt having a lower concentration of Fe throughout the experiment since the Fe may have leached out during watering. This phenomenon also holds true for sand owing to its high porosity which causes nutrients to be readily leached. Fe ions react very quickly with the soil hence, most of the Fe present in soil is unavailable for uptake by plants (Mikkelsen 2012).

The concentration of Mn decreased for all the soils after the application of vinasse in two weeks. Whittaker series and Onverwagt series continued to decrease until week four then showed steady increase with a plateau at week ten. Weldaad Series curve showed small variation after week two (Fig. 10). High available Fe is associated with low available Mn. However, they share similar characteristics, hence, the high availability of one would result in the low availability of the other in a phenomenon referred to as the Fe-Mn balance (Heenan and Campbel 1982).

For Zn, there was a general increase in concentration for all the soils after the addition of vinase in week two (Fig. 11) up to week four then gradually decreases. The reason being that Zn adsorbed to soil particles are less soluble than Zn compounds that are usually found in chemical fertilizers (Zn(OH)2, ZnO and ZnCO3), hence slowing its release after application (Alloway 2008). The initial increase for tiwiwid sand and Whittaker Series were greater than the other soils while Onverwagt Series and Weldaad Series values and patterns were almost identical.

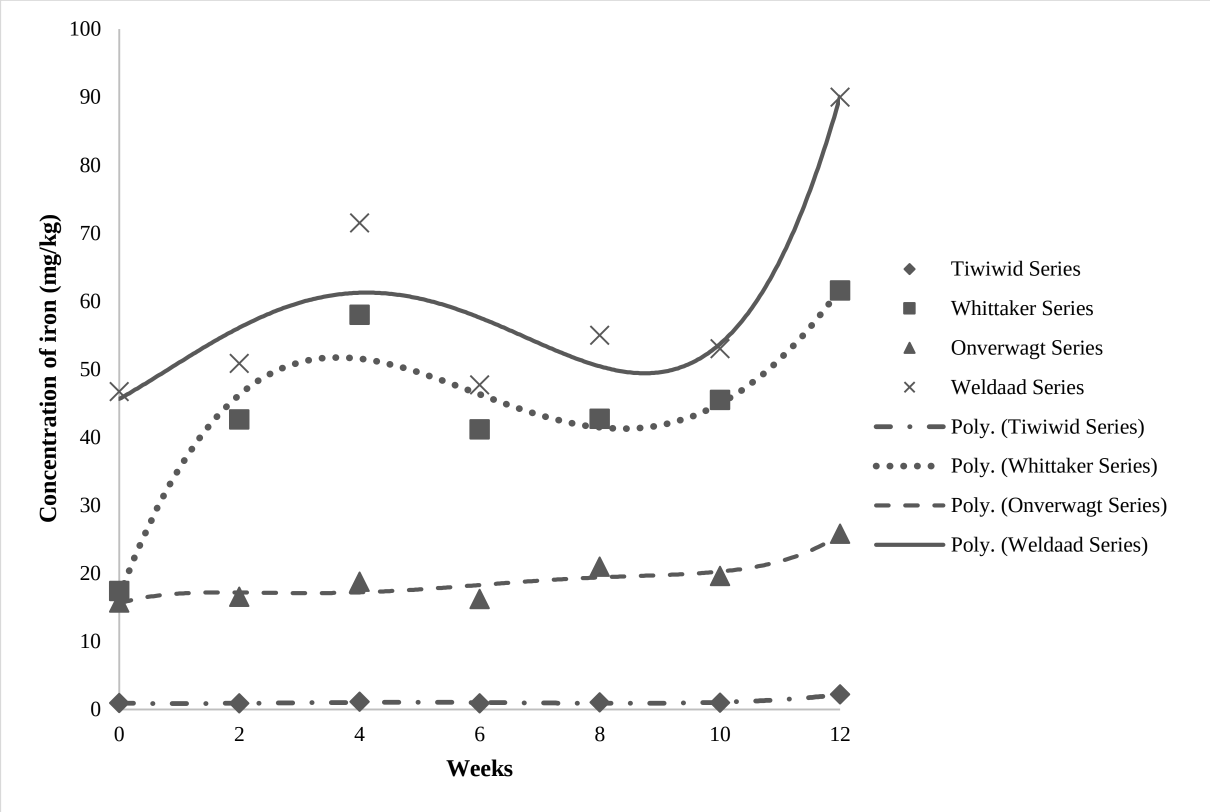

Fig. 9 Iron Concentration over twelve weeks after vinasse application(n=3)

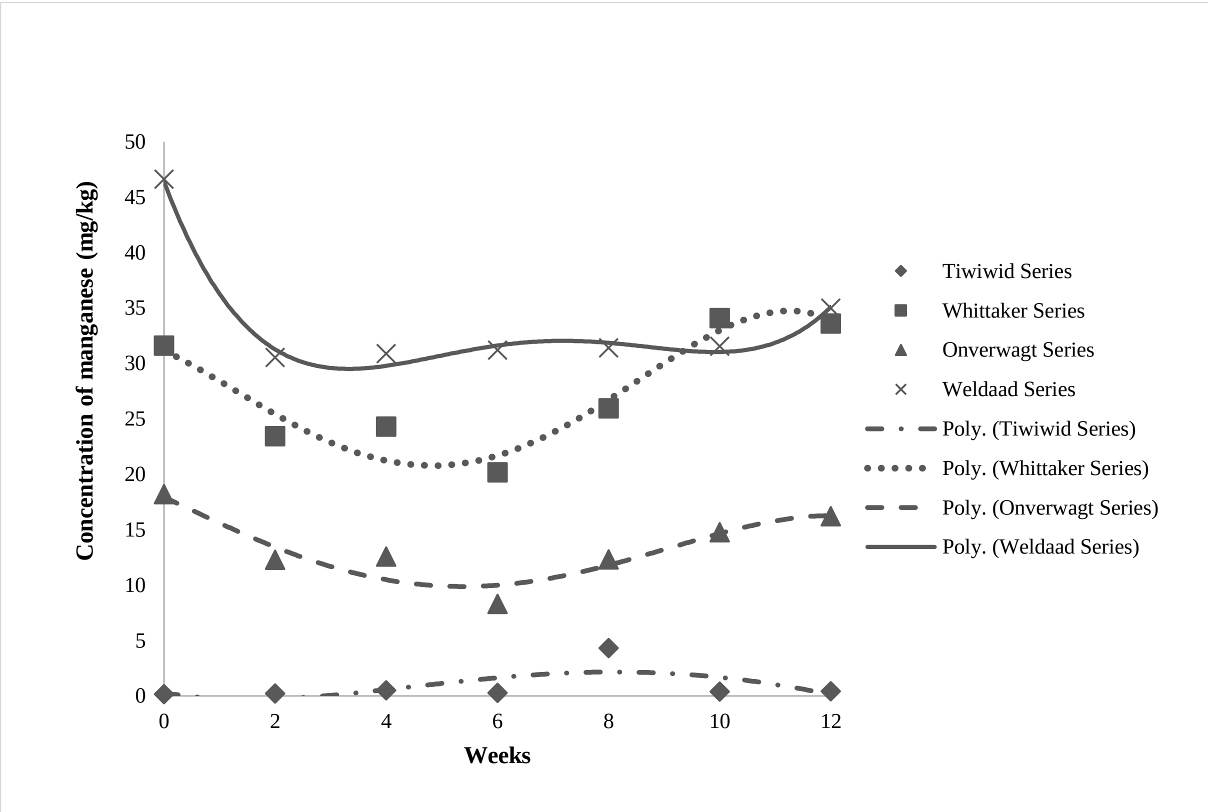

Fig. 10 Manganese concentration over twelve weeks after vinasse application(n=3)

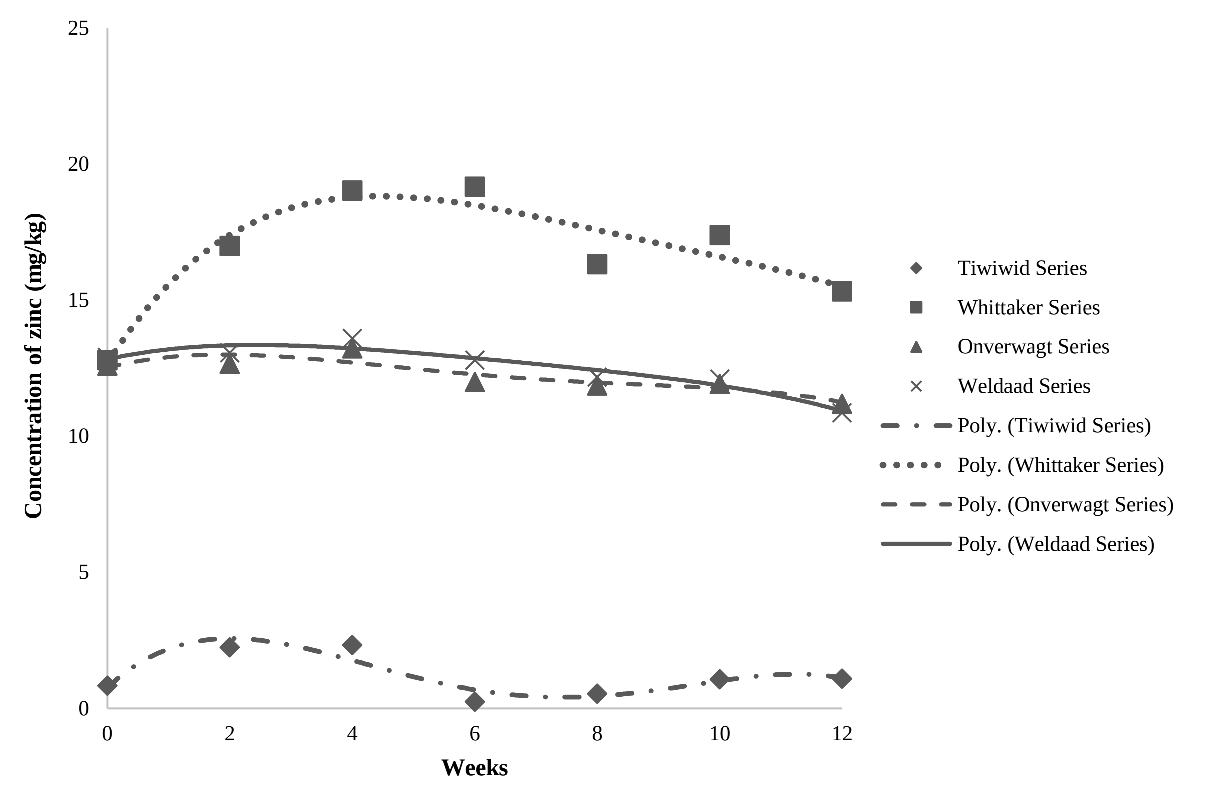

Fig. 11 Zinc concentration over twelve weeks after vinasse application(n=3)

A general trend observed for all nutrients in the four soil types is a steady increase in nutrients after vinasse application, peaking between weeks six and eight and declining thereafter. However, nutrients were continuously being released over the 12 weeks' period and this coincides with the findings of Arafat and Yassen (2002). They found that the utilization of vinasse as a soil amendment slows the release rate of nutrients into the soil. Such a phenomenon makes vinasse an advantageous replacement for chemical fertilizers. The results of this study indicate that the soil type in which the vinasse was applied can influence the amount of nutrient released due to the interaction between the nutrients of the vinasse and the other constituents of the soil. Table 4 show the nutrient release rates for soils studied. Typically, a single dose of fertilizer is applied when cultivating lettuce (Liu et al. 2014; Lairon et al. 1984). From these results, it can be assumed that a single application of vinasse would be sufficient for short term (a growing period of approximately 12 weeks) crops such as *Lactuca sativa* (lettuce) since majority of the nutrient was continuously released over the 12 weeks. With the exception of sandy soils which leach nutrients rapidly because of its porous nature, vinasse application would ensure nutrients availability throughout the growing period of the crop unlike chemical fertilizers that release their nutrients within two to four weeks.

Many plants thrive well in soils of pH range between 5.5-7.5. Tiwiwid sand, Whittaker Series, Onverwagt Series and Weldaad Clay initially had pH of 6.26, 5.03, 5.05 and 3.95. Adding vinasse at these acidic pH values would serve to fix nutrients to the soil as outlined by Jensen (2010) where they found that most of the nutrients especially micronutrients tend to be less available when soil pH is above neutral rather are optimally available at a slightly acidic pH. EC is known to correlate with the moisture holding capacity of soils (Hanlon 2015), as such the clays had high EC while Tiwiwid sand had a very low EC (Table 2). The EC of the soils coincides with the release rates of some nutrients over the twelve weeks' period. As EC increases and peaks between week six to eight, most nutrients also peak during that time. This suggests that the nutrients are more available in a plant-ready form during that period.

Table 4 Nutrient release equations for the soils studied

Element	Soil Type	Equation#	R^2
Electrical Conductivity	Tiwiwid Series	$y = -0.1681x^4 + 4.3842x^3 - 38.295x^2 + 124.88x + 22.075$	0.651
	Whittaker Series	$y = 0.0176x^4 - 0.488x^3 - 5.0796x^2 + 117.51x + 147.03$	0.901
	Onverwagt Series	$y = -0.1937x^4 + 3.9622x^3 - 25.395x^2 + 88.588x + 113.59$	0.879
	Weldaad Series	$y = 0.0424x^4 - 0.3168x^3 - 7.7978x^2 + 82.84x + 202.81$	0.706
Nitrogen	Tiwiwid Series	y = 2.9376x4 - 74.466x3 + 580.53x2 - 1332.8x + 1792.1	0.684
	Whittaker Series	y = 2.9593x4 - 88.963x3 + 853.01x2 - 2595.4x + 4209.6	0.593
	Onverwagt Series	y = 1.8071x4 - 66.577x3 + 733.21x2 - 2446.2x + 4484.6	0.717
	Weldaad Series	y = -1.0357x4 + 1.7966x3 + 224.27x2 - 1220.1x + 4856.8	0.684
Phosphorous	Tiwiwid Series	y = 0.0042x4 - 0.1091x3 + 0.918x2 - 2.6176x + 3.1135	0.985
	Whittaker Series	y = 0.0099x4 - 0.1469x3 - 0.1752x2 + 6.8058x + 19.944	0.609
	Onverwagt Series	y = 0.0021x4 + 0.0084x3 - 0.6175x2 + 3.0013x + 19.802	0.879
	Weldaad Series	y = 0.0088x4 - 0.1904x3 + 1.181x2 - 1.8713x + 6.5981	0.609
Potassium	Tiwiwid Series	$y = -0.0067x^4 + 0.219x^3 - 2.2552x^2 + 6.4658x + 13.031$	0.710
	Whittaker Series	$y = -0.5118x^4 + 14.656x^3 - 139.38x^2 + 461.31x + 168.63$	0.964
	Onverwagt Series	$y = -0.5657x^4 + 15.884x^3 - 147.7x^2 + 476.37x + 168.84$	0.915
	Weldaad Series	$y = -0.6201x^4 + 17.135x^3 - 154.16x^2 + 460.02x + 170.16$	0.962
Calcium	Tiwiwid Series	$y = -0.0696x^4 + 1.6881x^3 - 12.896x^2 + 31.997x + 8.5023$	0.680
	Whittaker Series	$y = 3.6447x^4 - 77.257x^3 + 507.72x^2 - 976.12x + 385.41$	0.967
	Onverwagt Series	$y = 3.2058x^4 - 69.047x^3 + 458.73x^2 - 875.96x + 352.9$	0.953
	Weldaad Series	$y = 0.5529x^4 - 13.843x^3 + 105.43x^2 - 210.04x + 184.77$	0.841
Magnesium	Tiwiwid Series	$y = -0.0104x^4 + 0.2459x^3 - 1.931x^2 + 6.2172x + 1.6235$	0.985
	Whittaker Series	$y = -0.2924x^4 + 1.7834x^3 + 34.482x^2 - 162.71x + 382.29$	0.965
	Onverwagt Series	$y = -0.8425x^4 + 15.139x^3 - 70.466x^2 + 152.92x + 566.94$	0.992
	Weldaad Series	$y = -0.2068x^4 + 3.6398x^3 - 12.774x^2 - 0.8839x + 197.06$	0.927
Iron	Tiwiwid Series	$y = 0.0043x^3 - 0.0609x^2 + 0.2137x + 0.844$	0.898
	Whittaker Series	$y = -0.0076x^4 + 0.3787x^3 - 5.101x^2 + 23.561x + 16.625$	0.932
	Onverwagt Series	$y = 0.0019x^4 - 0.0289x^3 + 0.1058x^2 + 0.4238x + 15.701$	0.854
	Weldaad Series	$y = 0.0226x^4 - 0.3426x^3 + 0.7518x^2 + 4.9309x + 45.633$	0.832
Manganese	Tiwiwid Series	$y = 0.0009x^4 - 0.0347x^3 + 0.3558x^2 - 0.8579x + 0.2932$	0.380
	Whittaker Series	$y = -0.0084x^4 + 0.167x^3 - 0.5773x^2 - 2.2994x + 31.139$	0.901
	Onverwagt Series	$y = -0.0028x^4 + 0.0516x^3 - 0.0357x^2 - 2.3728x + 17.956$	0.856
	Weldaad Series	$y = 0.0141x^4 - 0.3849x^3 + 3.6211x^2 - 13.39x + 46.425$	0.988
Zinc	Tiwiwid Series	$y = -0.0031x^4 + 0.0861x^3 - 0.7561x^2 + 2.0977x + 0.7614$	0.840
	Whittaker Series	$y = -0.0014x^4 + 0.0511x^3 - 0.6812x^2 + 3.5258x + 12.684$	0.900
	Onverwagt Series	$y = -0.0009x^4 + 0.0235x^3 - 0.2122x^2 + 0.5768x + 12.523$	0.809
	Weldaad Series	$y = -0.0005x^4 + 0.0143x^3 - 0.1485x^2 + 0.4983x + 12.833$	0.926

y – nutrient/element in the soil, x- time after application in weeks

Conclusion

The study found that vinasse contains essential macro and micro nutrients and after application, they were identified in the soil except for Cu which was not detected in some soil types. Over the course of the experiment, the concentration of all nutrients increased in varying non-linear patterns. The three clay soils showed greater nutrient availability than the sandy soil. It was recognized that as the EC of the soils increased between weeks five and ten, nutrient concentrations increased correspondingly. This implies that nutrients are more available for plants to uptake in this period. The results of this study indicate that a single application of vinasse would result in continuous nutrient availability for at least twelve weeks except for sandy soils. Also, the availability of N, Ca, Mg, Fe, and Mn increased during the period of week 6-12 which is the fruit and foliage growth period for most short-term crops. This would ensure nutrients availability throughout the growing period of short-term crops. The Intermediate Savannahs, the area proposed for the expansion of Guyana's agricultural frontier is dominated with the tiwiwid soil type. The nutrient response for tiwiwid sand suggests vinasse would not be a suitable fertilization source for this region. Field experiment should be done to assess the soil nutrient dynamics, effect on crop yield and quality, and nutrient uptake.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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