Production of an Organic Fertilizer Derived from Blending Vinasse and *Bixa orellana* Seeds Wastes for Use in Conservation Agriculture

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Abstract

Conservation of natural resources through recycling of carbon and mineral elements from agricultural wastes is attractive in agriculture and environmental management. The current oxidation and biological techniques for remediation of agro-industrial by-products such as *Bixa orellana* seeds waste from Norbixin processing and vinasse (by-product product from sugarcane industries) are less effective. Both *Bixa orellana* seeds waste and vinasse are valuable sources of organic carbon and the essential plant nutrients; nitrogen (N), phosphorus (P), and potassium (K). Compared to chemical fertilizers, organic residues as fertilizers are attractive as low-cost substitutes. However, it is necessary to determine the NPK values of the processed organic residues to identify their application areas. In this study, the NPK values 15-20-30 and 10-30-40 were established for vinasse (pH = 3.1) and *Bixa orellana* seeds waste (pH = 9.6), respectively. To produce a blend with pH ≈ 6.8 (standard solubility pH = 5.5-7.0), 30 wt-% *Bixa orellana* seeds waste was essential. The blend had an NPK value of 13-25-33, which is by far better than the highest-rated commercial fertilizers in the Kenyan market with NPK values 23-23-0 and 17-17-17. Hence upgrading of organic residues through blending may be necessary to achieve organic fertilizers with desired NPK values.

Keywords: Vinasse, *Bixa orellana* seeds waste, organic fertilizer, conservation agriculture, NPK fertilizer.

1. Introduction

Food and nutritional security is an essential component of the Government of Kenya's four main development agendas (Government of Kenya, 2017). Increased population especially in developing countries is putting pressure on smallholder farmers to increase their harvests. To boost agricultural output, the use of expensive chemical fertilizers is inevitable. Chemical fertilizers are not only expensive but also are a source of environmental pollution. Most chemical fertilizers contain toxic by-components such as heavy metals, inorganic acids, and organic compounds. Accumulation of these toxic by-components in soil and water matrices has adverse effects on the soil ecology (Cheraghi et al., 2012; Cheraghi et al., 2013; Gupta et al., 2014; Zhou et al., 2015). Crops such as vegetables when grown in these contaminated soils may uptake these by-components e.g. nitrates and heavy metals. The harvesting and consumption of crops grown under contaminated soils may be detrimental to human health and other organisms.

Organic fertilizers derived from animal and agricultural wastes are an attractive alternative to chemical fertilizers. Organic fertilizers are vital sources of organic carbon and the essential plant nutrients: nitrogen (N), phosphorus (P), and potassium (K). The application of organic fertilizers is an important concept in conservation agriculture. Conservation agriculture is a farming system that advocates for minimizing soil disturbance (no-tillage and no chemical fertilizers), encourages permanent soil cover, and promotes diversification of plant species (Knowler and Bradshaw, 2007; Kassam et al., 2012; Ngoma et al., 2021). The application of organic fertilizers offers several benefits such as improving soil fertility, enhance soil ecology, improves plant growth, and increases crop yields (Lee, 2010; Li et al., 2017; Beeby et al., 2020). In addition, organic fertilizers are known to mitigate the problems associated with chemical fertilizers.

Organic fertilizers derived from plant biomass are more suitable than animal wastes due to their high carbon and nutrient content (Davis, 2015). Nevertheless, the nutrient value of plant-based biomass needs assessment before application. Vinasse is a nutrient-rich industrial by-product that has received interest in agriculture. Vinasse is obtained from the processing of various crops such as sugar beet, blue agave (*Agave tequilana*), and sugarcane. Vinasse is the major byproduct of ethanol-producing industries such as sugar processing and biorefineries. It is estimated that for every liter of ethanol produced, an average of 10-15 L of vinasse is produced as waste

(Christofoletti et al., 2013; Bettani et al., 2019). Vinasse is a dark liquid with a characteristic odor, high concentration of organic matter, high biochemical oxygen demand (BOD), high chemical oxygen demand (COD), and low pH (Rodrigues Reis and Hu, 2017; Parsaee et al., 2019). Due to these characteristics, vinasse is the main source of contamination of wastewater from sugar processing industries and biorefineries. Vinasse is a recalcitrant by-product that is difficult to treat by the current conventional techniques based on coagulation/flocculation, ozonation, and biological processes (Martín Santos et al., 2005; Rodrigues Reis and Hu, 2017). Therefore, vinasse in most cases is used in fertigation. Fertigation is the direct application of non-treated vinasse to the soil e.g. for sugarcane cultivation. Although fertigation offers benefits such as improving soil fertility and subsequent increase in crop yields, it can lead to negative effects on the environment which include lowering of soil pH, increasing soil salinization, groundwater contamination, and negatively affect soil biota (Alves et al., 2015). Nevertheless, under controlled conditions, vinasse can be applied in crop cultivation (dos Santos et al., 2013; Rulli et al., 2020).

In this study, we combine vinasse and *Bixa orellana* seeds waste to make an organic fertilizer that can then be incorporated into biodegradable polymers e.g. polylactide for slow release of essential plant nutrients. *Bixa orellana* seeds waste is derived from the Norbixin processing industry. It is disposed of mainly through combustion and open-pit deposition. Preliminary studies reveal that *Bixa orellana* seeds waste contains the essential plant nutrients N, P, and K. In this study, further assessment of the NPK value of *Bixa orellana* seeds waste was established and its suitability as an organic fertilizer considered. Since the nutritional value of biomass can vary greatly, it is demonstrated in this study that blending of different processed biomass can be done to achieve a product of desired NPK value.

2. Materials and Methods

Chemicals and reagents. Analytical grade reagents obtained from different suppliers were used as received without further purification. Carboxymethyl cellulose (CMC), boric acid, NaOH, and acetic acid were supplied by Merck, Germany. Ammonia solution, KCl, ammonium acetate, H_2SO_4, and $CaCl_2$ were supplied by Sigma-Aldrich, Germany.

Sample collection and preparation. Vinasse was collected directly from the ethanol distillation unit at 90-95 °C at Mumias Sugar Company Ltd in Kakamega County, Kenya. After cooling to ambient temperature (22-25 °C), the vinasse was homogenized and stored at 4 °C for further use. *Bixa orellana* seeds waste was collected from the waste disposal point at Kenya Bixa Ltd in Ukunda, Kenya. It was then sun-dried, cleaned with distilled water to remove soil and dust particles, crushed, dried at 80 °C in a thermostat oven for 24 h, and ball-milled for up to 24 h to obtain particles of mesh size < 10 μm. The powdered particles were then heated under pressure for 4 h to obtain a dark brown char-like substance whose exit temperature was about 120 °C. The char-like was dried in a thermostat oven at 100 °C and stored for further use.

Preparation of fertilizer blends. A known amount of dried vinasse was added into 100 mL distilled water ($c_{vinasse}$ = 1.5-4.5 g/L) in a 250 mL Erlenmeyer flask which was being shaken horizontally on a shaker preset at 230 rpm. The appropriate amount of *Bixa orellana* seeds waste was added into the vinasse suspension under constant shaking. CMC (10 wt-% of sample weight) was added as a binder and the mixture was left to shake for about 24 h. Three types of fertilizer blends were prepared. The first blend labeled B50 was prepared by mixing equal masses of each substance. The second and third blends contained 30 and 70 wt-% *Bixa orellana* seeds waste and were labeled B30 and B50, respectively. The blended samples were dried at 100 °C in a thermostat oven to form a soft solid-like product.

Determination of pH. A 200 mg dried sample was added to 20 mL distilled water with a background concentration of 0.5 mM $CaCl_2$. $CaCl_2$ was applied to provide an ionic background that minimizes issues of colloidal species. The suspension was further homogenized and stirred for 30 min and the pH of the suspension was measured using a pH meter.

Determination of N, P, and K. The amount of available P was analyzed as described by Truog using the vanadomolybdate method upon extraction with 1 mM H_2SO_4 supplied at the ratio 1:200 (w/v) (Truog, 1930). The N content was determined by the Kjeldahl method while K extracted by acid digestion of the sample was determined by flame photometric analysis.

3. Results and Discussion

In the current study, the potential of vinasse and *Bixa orellana* seeds waste as organic fertilizers were evaluated through the assessment of the major plant nutrients N, P, and K. N is required for plant growth and development while P is essential for root growth, fruit development, and seeds production. K is required for the optimum functioning of various plant enzymes. Other nutrients such as zinc, iron, manganese, and copper are only required in trace amounts. The N, P, and K contents of vinasse and *Bixa orellana* seeds waste are presented in Table 1.

Table 1. Physicochemical properties of vinasse and *Bixa orellana* seeds waste

Parameter	**Content**	
	Vinasse	***Bixa orellana* seeds waste**
pH	3.1	9.6
Nitrogen (N)	660 ± 50	460 ± 60
Phosphorus (P)	920 ± 30	1345 ± 50
Potassium (K)	1370 ± 150	1810 ± 110
NPK value	15-20-30	10-30-40

Average ± standard deviation of three replica experiments
Content is in mg/L except for pH
Analysis based on sample concentration of 4.5 g/L

As can be seen in Table 1, vinasse contains a higher amount of N compared to *Bixa orellana* seeds waste. However, the contents of both P and K are higher in *Bixa orellana* seeds waste than in vinasse. The difference in nutritional contents could be contributed by various factors e.g. different plant species, different geographical regions where the crops were cultivated, and different growing conditions. The NPK values for vinasse and *Bixa orellana* seeds waste are 15-20-30 and 10-30-40, respectively. Vinasse contains P within the range of common chemical fertilizers used in Kenya. P is much higher in *Bixa orellana* seeds waste than in the existing chemical fertilizers. The major benefit is seen in their K content which is much higher than that present in locally available chemical fertilizers such as NPK 23-23-0 and NPK 17-17-17 (Sanabria et al., 2018). Based on the NPK values, both vinasse and *Bixa orellana* seeds waste can be applied as organic fertilizers. Another factor that also needs consideration is the pH of the samples and its effect on the soil biota in long-term applications. Application of vinasse such as in fertigation can lead to lowering of soil pH. Low pH is a hindrance to the uptake of plant nutrients and may also negatively affect soil biodiversity. On the other hand, *Bixa orellana* seeds waste has a high pH which may affect the solubility of essential plant nutrients and their uptake by plants. Therefore, the blending of the samples was done to address the pH problem. The standard required pH should be in the range between 5.5 and 7.0. The physicochemical properties of the various blends are presented in Table 2.

Table 2. Physicochemical properties of blended samples of vinasse and *Bixa orellana* seeds waste

Parameter	***Bixa orellana* seeds waste content in blended products (wt-%) and their labels**		
	30 (B30)	**50 (B50)**	**70 (B70)**
pH	6.8	8.1	8.6
Nitrogen (N)	585 45	540 ± 50	535 ± 40
Phosphorus (P)	1130 35	1080 ± 25	1190 ± 50
Potassium (K)	1505 110	1620 ± 120	1650 ± 80
NPK value	13-25-33	12-24-36	12-26-36

Average ± standard deviation of three replica experiments
Content is in mg/L except for pH
B50 = 30 wt-% *Bixa orellana* seeds waste in the blend
B30 = 50 wt-% *Bixa orellana* seeds waste in the blend
B70 = 70 wt-% *Bixa orellana* seeds waste in the blend
Analysis based on total sample concentration of 4.5 g/L

As shown in Table 2, blending affects both the sample pH and nutritional composition. The blended samples had a slightly higher N content than in *Bixa orellana* seeds waste. Blended samples also had higher P and K content compared to vinasse. Hence blending processed biomass can be considered a viable option to increase the nutritional

content of organic fertilizers derived from agricultural wastes. Based on pH, the preferred blend is B30. Although this blend contained lower N, the other nutrients (P and K) are much higher than in the locally available chemical fertilizers e.g. NPK 23-23-0 and NPK 17-17-17.

4. Conclusions

In this study, the potential of two agro-industrial wastes, vinasse, and *Bixa orellana* seeds waste as organic fertilizers was demonstrated. Although these two substrates contain lower N content compared to locally available chemical fertilizers, they are far richer in the essential plant nutrients, P and K. Blending was done to cater for mineral deficiencies in either substrate and also to produce a product with the desired pH in the range 5.5-7.0. The suitability for application of vinasse, *Bixa orellana* seeds waste, and their blends is seen when incorporated into biodegradable polymers e.g. polylactide for slow release of the essential plant nutrients.

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References

Alves, P. R. L., Natal-da-Luz, T., Sousa, J. P., Cardoso, E. J. B. N. (2015). Ecotoxicological Characterization of Sugarcane Vinasses When Applied to Tropical Soils. Science of the Total Environment 526: 222-232.

Beeby, J., Moore, S., Taylor, L., Nderitu, S. (2020). Effects of a One-Time Organic Fertilizer Application on Long-Term Crop and Residue Yields, and Soil Quality Measurements Using Biointensive Agriculture. Frontiers in Sustainable Food Systems 4(67).

Bettani, S. R., de Oliveira Ragazzo, G., Leal Santos, N., Kieckbusch, T. G., Gaspar Bastos, R., Soares, M. R., Altenhofen da Silva, M. (2019). Sugarcane Vinasse and Microalgal Biomass in the Production of Pectin Particles as an Alternative Soil Fertilizer. Carbohydrate Polymers 203: 322-330.

Cheraghi, M., Lorestani, B., Merrikhpour, H. (2012). Investigation of the Effects of Phosphate Fertilizer Application on the Heavy Metal Content in Agricultural Soils with Different Cultivation Patterns. Biological Trace Element Research 145(1): 87-92.

Cheraghi, M., Lorestani, B., Merrikhpour, H., Rouniasi, N. (2013). Heavy Metal Risk Assessment for Potatoes Grown in Overused Phosphate-Fertilized Soils. Environmental Monitoring and Assessment 185(2): 1825-1831.

Christofoletti, C. A., Escher, J. P., Correia, J. E., Marinho, J. F. U., Fontanetti, C. S. (2013). Sugarcane Vinasse: Environmental Implications of Its Use. Waste Management 33(12): 2752-2761.

Davis, D. A. Feed and Feeding Practices in Aquaculture. Woodhead Publishing (2015).

dos Santos, J. D., Lopes da Silva, A. L., da Luz Costa, J., Scheidt, G. N., Novak, A. C., Sydney, E. B., Soccol, C. R. (2013). Development of a Vinasse Nutritive Solution for Hydroponics. Journal of Environmental Management 114: 8-12.

Government of Kenya. "The Big Four" – Immediate Priorities and Actions. Government Printer, Nairobi-Kenya (2017).

Gupta, D. K., Chatterjee, S., Datta, S., Veer, V., Walther, C. (2014). Role of Phosphate Fertilizers in Heavy Metal Uptake and Detoxification of Toxic Metals. Chemosphere 108: 134-144.

Kassam, A., Friedrich, T., Derpsch, R., Lahmar, R., Mrabet, R., Basch, G., González-Sánchez, E. J., Serraj, R. (2012). Conservation Agriculture in the Dry Mediterranean Climate. Field Crops Research 132: 7-17.

Knowler, D., Bradshaw, B. (2007). Farmers' Adoption of Conservation Agriculture: A Review and Synthesis of Recent Research. Food Policy 32(1): 25-48.

Lee, J. (2010). Effect of Application Methods of Organic Fertilizer on Growth, Soil Chemical Properties and Microbial Densities in Organic Bulb Onion Production. Scientia Horticulturae 124(3): 299-305.

Li, S., Li, J., Zhang, B., Li, D., Li, G., Li, Y. (2017). Effect of Different Organic Fertilizers Application on Growth and Environmental Risk of Nitrate under a Vegetable Field. Scientific Reports 7(1): 17020.

Martín Santos, M., Bonilla Venceslada, J., Martín Martín, A., García García, I. (2005). Estimating the Selectivity of Ozone in the Removal of Polyphenols from Vinasse. Journal of Chemical Technology & Biotechnology 80(4): 433-438.

Ngoma, H., Angelsen, A., Jayne, T. S., Chapoto, A. (2021). Understanding Adoption and Impacts of Conservation Agriculture in Eastern and Southern Africa: A Review. Frontiers in Agronomy 3(38).

Parsaee, M., Kiani Deh Kiani, M., Karimi, K. (2019). A Review of Biogas Production from Sugarcane Vinasse. Biomass and Bioenergy 122: 117-125.

Rodrigues Reis, C. E., Hu, B. (2017). Vinasse from Sugarcane Ethanol Production: Better Treatment or Better Utilization? Frontiers in Energy Research 5(7).

Rulli, M. M., Villegas, L. B., Colin, V. L. (2020). Treatment of Sugarcane Vinasse Using an Autochthonous Fungus from the Northwest of Argentina and Its Potential Application in Fertigation Practices. Journal of Environmental Chemical Engineering 8(5): 104371.

Sanabria, J., Ariga, J., Fugice, J., Mose, D. Fertilizer Quality Assessment in Markets of Kenya. International Fertilizer Development Centre (IFDC), Nairobi-Kenya (2018).

Truog, E. (1930). The Determination of the Readily Available Phosphorus of Soils. Journal of American Society of Agronomy 22: 874–882.

Zhou, S., Liu, J., Xu, M., Lv, J., Sun, N. (2015). Accumulation, Availability, and Uptake of Heavy Metals in a Red Soil after 22-Year Fertilization and Cropping. Environmental Science and Pollution Research International 22(19): 15154-15163.