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EFFECT OF SPREADING VINASSE ON MAIZE PERFORMANCE AND SOIL PROPERTIES

Armelle Noukeu Nkouakam, Fati Mefire Masietmo, Emmanuel Youmbi and Eddy Léonard Ngonkeu Mangaptche

Laboratory of Plant Biotechnology and Environment, Department of Plant Biology, University of Yaounde I, Cameroon. PO Box 812 Yaounde Cameroon.

*Corresponding author: Armelle Noukeu Nkouakam (noukeukoua@yahoo.fr);

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ABSTRACT

This study focuses on the use of vinasse in agriculture. The study was carried out during the 2022-2023 first agricultural season. Vinasse and soil characterisation were conducted using standard methods. Plant morphological parameters were measured. The results of the physicochemical parameters of the vinasse indicated an effluent with a deep colour (4757±2139.46 Pt/co) ; with an acid pH (5.46±1.07). Three forms of nitrogen were measured in the vinasse: Ammonium (NH4+) with a concentration of 32.49±7.17 g/l; Nitrites (N02-) 0.69±0.38g/l and Nitrates (N03-) 151.13±57.82g/l. The available phosphorus content (PO43-) was 16.62±8.93 g/l in the effluent. The average Chemical Oxygen Demand (COD) content was 81.13±78.94 g/l, while the Biological Oxygen Demand (BOD5) content was 11.53±6.85 g/l. Potassium ion (K+) was 2.12±0.78 g/l. Soil characteristics according to each treatment showed a pH variation from 3.65±0.071 to 5.73±0.70 in all treatments. Nitrogen concentrations were high in treatments T3 and T5. The carbon to nitrogen ratio was high in treatments T01, T1 and T3. Cation exchange capacity was higher in treatment T5. Vinasse treatment increased phosphorus concentrations in the T4 treatments soils. There were major differences for each parameter. Morphological parameters showed a high emergency rate at T2 (87%). The highest values for plant height, collar diameter, number of leaves and leaf area were obtained with treatment T4 (8L/m2). The amount of potassium in the soil increased with doses of vinasse. The C/N ratio decreased as soil organic matter reduced. Compared with chemical fertilisers, vinasse can be a sustainable alternative for organic farming.

Keywords: Vinasse, Nutrients, Treatment, Maize, Soil.

1. INTRODUCTION

The consistent demand for the use of wastewater is escalating as a reliable alternative water source. Wastewater is no longer considered a problem desperate for a solution, but rather a part of the solution to the challenges societies face today [1-3]. Wastewater can be a cost-effective and sustainable source of energy, nutrients, and other useful by-products [4]. In a circular economy setting, where economic development is counterbalanced with natural resource protection and Sustainable Development, industrial wastewater constitutes a widely accessible and valuable resource [5]. Agri-food industries in Cameroon use substantial quantities of fresh water to manufacture their products. During their various production activities, large volumes of liquid effluent are generated by distillery industries [6, 7]. Distillery industries generate wastewater known as vinasse [8, 9]. Vinasses are mainly disposed of by two distillery industries in Cameroon, FERMENCAM in Douala and NODISCAM in Mbandjock. These two industries produce ethanol from sugarcane molasses collected from the SOSUCAM sugar industry [6]. During distillation, the ethanol produced generates large quantities of vinasse. In general, each litre of ethanol generates 10 to 15 litres of vinasse, with 300 billion litres produced annually in Brazil alone [10]. According to the research carried out by [6], the volumes of vinasse Cameroon distilleries produce daily are a major source of organic pollution for the environment. The problem here is how to manage this wastewater. In India, there are about 579 sugar mills and 285 distilleries, with a capacity of producing 2.7 billion liters of wastewater per year [11, 12]. Disposing of such large volumes of wastewater is a major concern for ecologists and agronomists around the world. This is why using distillery effluents in agriculture have been successful in India since the beginning of industrialisation. In some regions, water scarcity has compelled farmers to use vinasse for soil irrigation and fertilisation [13]. In Cameroon, the problem with wastewater from the agri-food industry is its limited exploitation. Among the potential areas for wastewater reuse, irrigation in agriculture is the most suitable [14]. Therefore, spreading vinasse on agricultural fields could be an interesting method for disposing of and exploiting this by-product [15, 16]. Several research projects have focused on the exploitation of vinasses. The use of vinasses as a fertiliser started in the 1950s [17]. This practice has enabled sugar companies in Brazil, India, China and Mexico to reduce the purchase and use of chemical fertilisers in sugarcane fields and achieve good yields [18-22]. Studies have also focused on the use of vinasses to increase yields in the production of maize [23-25]; rice [26,27]; wheat [28]; sugarcane [29,30]; to enrich the soil with nutrients, thereby reducing soil fertilisation costs [31-33] as well as for plant germination and growth [13, 34]. This is because vinasses are characterised by their high concentrations of organic matter, sulphates and nutrients such as potassium, nitrogen and phosphorus [5, 8, 35]. Vinasses are an environmentally friendly resource, toxic metals free, because they are derived from sugarcane and are also a very good source of major elements and micronutrients readily available to improve soil fertility and crop yields [36, 37]. The nitrogen content of manure ranges from 1660 to 4200 mg/l, phosphorus from 225 to 3038 mg/l and potassium from 9600 to 17475mg/l. Calcium (2050 - 7000 mg/l), magnesium and chloride are also present in significant quantities [38, 39]. Recently, the presence of a significant amount of plant growth stimulators, specifically gibberellic acid and indole acetic acid, has also been identified [31]. Spreading vinasse therefore offers several advantages. It provides agriculture with a valuable resource and it is also an alternative to discharging into receiving environments which may have limited absorption capacities. In addition, their use could also prevent eutrophication and avoid growing algae in discharging areas. If vinasse is accepted as a positive input rather than a by-product of industrial activity that needs to be disposed of, then it is logical and preferable that, rather than disposing of it, it should be used prospectively [40, 41]. There is insufficient information available on the effect of distillery effluents on crop performance and soil health in Cameroon. This study focused on the use of vinasse in maize farming. Maize (*Zea mays*) was chosen for this study because it is one of the most widely cultivated cereals in the world for human and animal consumption. It is a high-value strategic crop in Cameroon for food security and sovereignty. It is cultivated in all five agro-ecological zones of Cameroon. Moreover, the main constraints to maize production include declining soil fertility [42-44]. This study could be a possible alternative to the challenges facing agriculture in Cameroon on the one hand, and sustainable development concerns on the other. The overall objective of this study was to examine the effect of distillery effluents on maize growth and soil properties. More precisely, it involved:

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- carrying out a physicochemical characterisation of vinasse;
- showing the effect of different vinasse treatments on maize growth;
- assessing the effect of different vinasse treatments on the physicochemical characteristics of the soil.

2. MATERIALS AND METHODS

2.1.1. Presentation and Description of the Experimental Site

The study was carried out in Zamengoe, in the Okola council of the Lekie Division in the Centre Region of Cameroon. It has a geographical coordinate of 03°56’51” North Latitude, 11°26’59” East Longitude and 790m Altitude. Located in Cameroon's agro-ecological zone V (a bimodal rain forest with 4 seasons), it is noted for its savannah climate with an average temperature of 23.5°C and average rainfall of 831.7 mm according to the classification of Köppen-Geiger.

2.1.2. Physicochemical Characterisation of NODISCAM Vinasses

Samples were collected using one liter polyethylene bottles. These samples, collected from the NODISCAM distillery, were taken to the Biotechnologies and Environment laboratory at the University of Yaounde 1 for physicochemical analysis. The physicochemical parameters were measured using the standard protocols described by [45, 46]. The pH was measured by immersing the glass electrode in the vinasse sample; conductivity, salinity, total dissolved solids (TDS) and temperature were measured using a multiparameter and the values were read off the digital display screen. The Chemical Oxygen Demand (COD) was determined using the “Anaerobic Reactor” method; Biochemical Oxygen Demand was determined over 5 days using the “manometric” method with a WTW BOD_5 incubator [47]. Ammonium ions were measured using the “Nessler” method on a mineralised sample and the value was read using a DR3900 spectrophotometer at a wavelength of 380 nm. Nitrate ions were measured using the cadmium reduction method with a spectrophotometer DR3900 by Hach. Orthophosphate was measured by filling a cell with 10 ml of the sample. The contents of a sachet of PhosVer 3 reagent powder was introduced into the cell. A blue colour will appear if the sample contained phosphorus. Nitrite ion (NO_2^-) contents were measured by the diazotization method using a spectrophotometer DR3900 [48]. After introducing 10 ml of the sample into a spectrophotometer cell, the Nitriver 3 Nitrite reagent was added. Then, after homogenisation, the mixture was allowed to rest for 10 minutes (reaction time). The concentration was measured using a spectrophotometer at 373 nm against 10 ml of effluent as a reference. The results were reported in mg/L of NO_2^-.

2.1.3. Physicochemical characterisation of collected soil samples

Soil sampling was carried out 30 cm from the soil profile on the upper part using the composite sampling method. The samples were stored in polyethylene packaging and labeled, then brought to the FASA Soil Science Laboratory in Dschang. Soil physicochemical parameters were measured using standard protocols. The pH was measured following the ISO 10390 international standard. The Organic matter (OM) and organic carbon (OC) were measured using the [49]. method as described by [50]. The total nitrogen was measured using Kjeldahl method referred by [50]. The sum of exchangeable bases (SEB) in the soil were measured using the Metson method for soils with a pH of less than 7, and the extraction was done using ammonium acetate at pH 7 and the colorimetric method to determine the cation exchange capacity (CEC). Available phosphorus was measured using Bray 2 method [51]. and particle size analysis using Robinson-Köhn pipette method.

2.1.4. Setting up the experimental device on the study site

The study site was completely cleared, cleaned and ploughed. The vinasse was spread in each experimental block and sowing took place the following day. The experiment was carried out in a completely randomised block of 100 m^2 with six different treatments: the T0 sample reference (no fertilisation), the T1 chemical fertiliser treatment and the different doses of vinasse (T2 = 1.6 L/m^2, T3 = 4 L/m^2, T4 = 8 L/m^2 and T5 = 16 L/m^2). Each treatment was repeated 3 times and randomly distributed over the plot. The sub-blocks were 1 m apart, [52-54].

2.1.5. Recording Morphological Parameters

Zea mays L. CMS8704 was sown directly in the field at a rate of three seeds per hole. After germination and seed emergence, seedlings were pruned and separated. The assessed parameter was the emergence rate, which was recorded eight days after sowing and calculated using the following formula: (Number of emerged plants /total number of seeds sown) × 100 [55].

Two weeks after sowing, growth parameters measured were plant height, collar diameter, number of leaves, leaf length and width to determine leaf area. Plant height was determined by direct measurement using a measuring tape. Measurements were taken from the base of the ridge where the stem emerges to the petiole of the youngest leaf [56]. Results were recorded in centimeters (cm). The diameter of the collar was determined using a digital caliper. The measurement was taken 2cm from the stem's base and the value read off the device's display screen. The results were recorded in millimetres (mm). Moreover, the number of leaves was determined by counting them directly on each plant from the base upwards, i.e. from the oldest to the youngest leaves. The leaf area was measured using the following formula: 2/3 (Lxl) where L and l represent the length and width of the leaves respectively. The length and width of the leaves were measured using a measuring tape until the first flower appeared. These measurements were taken in cm and the leaf area in centimeters square (cm^2). The chlorophyll index was determined using a chlorophymeter during the grain development stage. The number of maize ears was determined by counting [57].

2.1.6. Data Analysis

The results obtained were recorded using Excel 2016 software. They were then tested by analysis of variance (ANOVA) using SPSS, I. [58]. The averages obtained were separated using Duncan's test and compared using the MSD (minimum significant difference) at the 5% threshold.

3.1 Results

3.1.1. Physicochemical Characteristics of Vinasse

The pH of an effluent corresponds to the concentration of hydrogen ions. It measures the acidity or alkalinity of water. The pH obtained in the distillery effluent was acidic (5.46±1.07). Electrical Conductivity (EC), Total Dissolved Salts (TDS) and Salinity were found to be good indicators of the degree of mineralisation of an effluent. The conductivity and total dissolved salt contents were low at 44.25±67.84 µs/cm and 8.44±0.69 mg/l. The value for suspended solids (SS) was 107±62.16 mg/l. Ca_2^+ and Mg^{2+} ions showed concentrations of 308.51 ± 16.45 mg/l and 84.62 ± 1.08 mg/l respectively. Three forms of nitrogen were measured in the vinasse effluents: ammonium (NH_4^+) with a concentration of 32.49±7.17 g/l; nitrites ($N0_2^-$) 0.69±0.38g/l and nitrates ($N0_3^-$) 151.13±57.82g/l. The available phosphorus content (PO_4^{3-}) was 16.62±8.93 g/l in the effluent. The average COD content was 81.13±78.94 g/l, while the BOD_5 content was 11.53±6.85 g/l. The COD/BOD_5 ratio was seven.

Table 1 below shows all the physicochemical parameters measured in the water. The average values are presented with the values of the wastewater discharge standards

Table 1. Physicochemical Characteristics of NODISCAM Vinasse

Parameters	Effluent value	WHO [59]	Parameters	Effluent value	WHO [59]
pH	5.46±1.07	6.5-8.5	COD (g O2/l)	81.13±78.94	< 90mg/l
EC (µs/cm)	44.25±67.84	-	BOD5 (g O2/l)	11.53±6.85	< 30mg/l
T °C	75.67 ± 6.01	< 30°C	NH4 (mg/l)	32.49±7.17	< 1 mg/l
Turbidity (NTU)	234.33±68.04	-	Nitrite N02 (g/l)	0.69±0.38	1 mg/l
Oxidizability (mg/l)	616.12±169		Nitrates N03 (g/l)	151.13±57.82	< 0.5 mg/l
CO2 (mg/l)	1652±1104.76	-	$PO4^{3-}$ (g/l)	16.62±8.93	< 2
Dissolved oxygen	4.43±1.07	-	Mg^{2+} (mg/l)	84.62 ± 1.08	
TSS (mg/l)	107±62.15	< 20mg/l	Ca^{2+} (mg/l)	308.51 ± 16.45	
Colour (Pt/co)	4757±2139.46	-	K^+ (g/l)	2.12±0.78	-
Salinity (US)	10.67±0.85		Cd^+ (mg/l)	0.065 ± 0.003	
Alkalinity (mg/l)	456.67±232.52		Pb (mg/l)	0.11 ± 0.42	

2.1.2. Effect of different treatments on maize growth parameters

The various treatments significantly (P<0.05) improved maize collar diameter (Fig.1.A), treatments T4 (27.55±2.27mm) and T2 (21.21±3.85mm) showed a significant difference (P<0.05) compared to T0 (15.32±5.08mm); treatments T5 (24.30±2.74mm) and T3

(23.20±2.97mm) showed no significant difference (P>0.05). The best collar diameter was obtained from treatment T4. The effect of the different treatments on the average number of leaves showed a significant difference ($P < 0.05$) between treatments T2 (11.30±1.23) and T0 (8.17±2.61) (Fig. 1.B). The best treatments were in T3 (12.27±0.89), T4 (12.20±0.66) and T5 (12.17±0.98). The various treatments significantly improved maize plants height (Fig.1.C), the best plants height was obtained from treatment T4. The effect of the different treatments on the chlorophyll index (Fig.1.D), showed a significant difference ($P<0.05$) between treatments T1 (54±8.76) and T2 (42.54±10.13) and no difference between treatments T0 (49.19±3.80), T3 (50.10±6.75), T4 (49±5.01) and T5 (46.60±3.19). In terms of the number of ears according to the different treatments (Fig.1.E), a significant difference ($P < 0.05$) was observed between treatments T5 (10.33±2.31), T2 (4.33±1.53) and T0 (2.00±1.73). Treatment T5 showed a better effect on the number of ears. The effect of the different treatments on leaf area (Fig.1.F) showed that treatments T4 (707.8±95.8 cm2) and T5 (665.7±60.8 cm^2) were significantly different ($P< 0.05$) from T0 (359.4±90.9 cm^2). Treatment T4 had a higher average than the other treatments. The seedling emergence rate (Fig.1.G), according to the different treatments showed a rate of 87% for treatment T2, followed by T5 (73%) and T2 (67%). Treatment T0 showed a low emergence rate (47%).

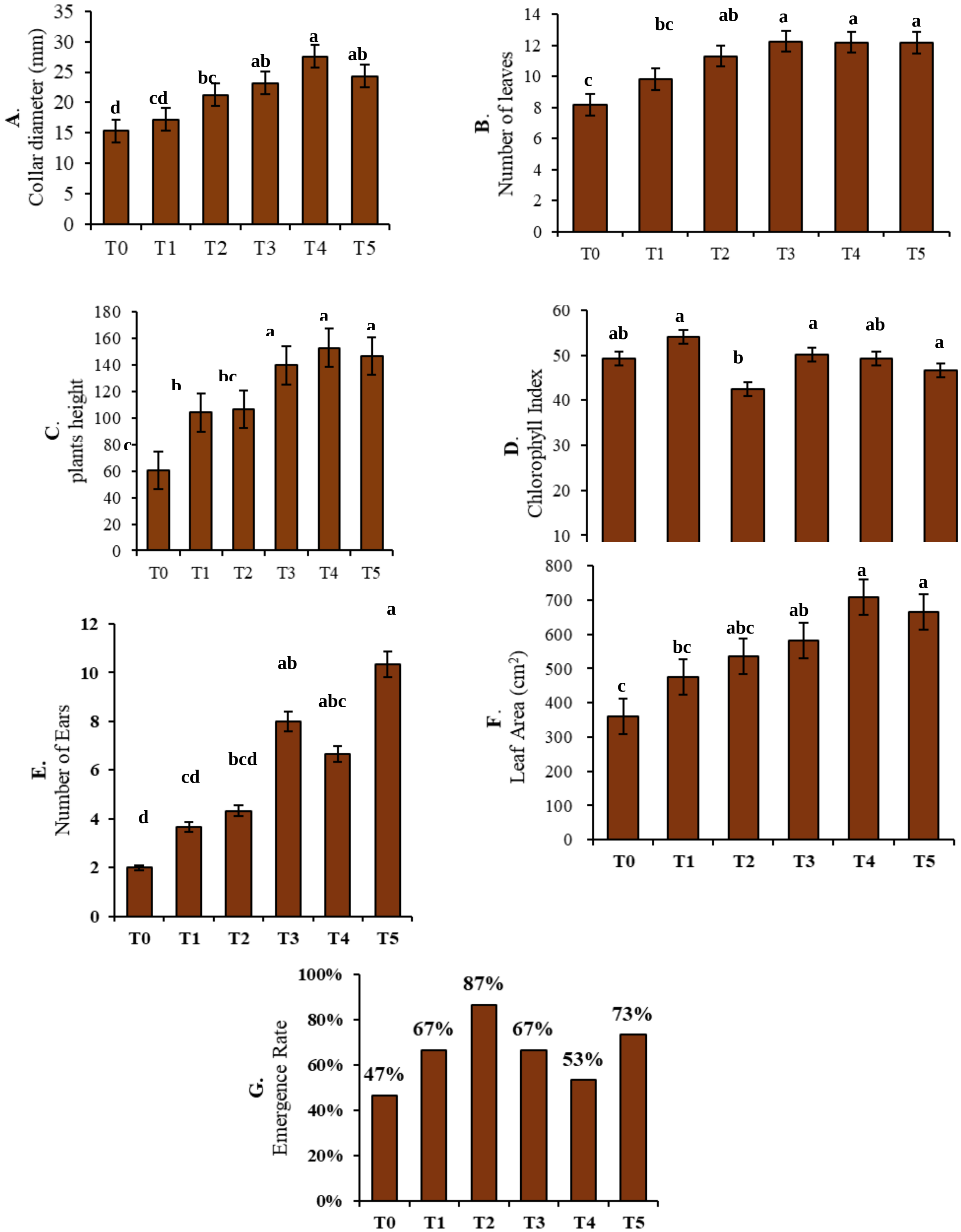
A.
Collar diameter (mm)
0 5 10 15 20 25 30 35
d cd bc ab a ab
T0 T1 T2 T3 T4 T5
B.
Number of leaves
0 2 4 6 8 10 12 14
c bc ab a a a
T0 T1 T2 T3 T4 T5
C.
plants height
0 20 40 60 80 100 120 140 160 180
T0 T1 T2 T3 T4 T5
D.
Chlorophyll Index
10 20 30 40 50 60
ab a b a ab a
E.
Number of Ears
0 2 4 6 8 10 12
d cd bcd ab abc a
T0 T1 T2 T3 T4 T5
F.
Leaf Area (cm²)
0 100 200 300 400 500 600 700 800
c bc abc ab a a
T0 T1 T2 T3 T4 T5
G.
Emergence Rate
0% 20% 40% 60% 80% 100%
47% 67% 87% 67% 53% 73%
T0 T1 T2 T3 T4 T5

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Fig.1. Maize growth parameters with different treatments**.** A. Collar Diameter; B.Number of leaves; C. Plants height; D.Chlorophyll index; E.Number of Ears; F. Leaf Area ; G. Emergence Rate. Treatments:T0= sample reference; T1 = chemical fertiliser; T2= 1.6 L/m^2; T3=4 L /m^2; T4= 8L/m^2; T5= 16 L/m^2.

3.1.3. Physicochemical characteristics of soil samples before and after vinasse spreading

- Particle size

The percentage of each fraction of solid particles analysed in the soil samples collected indicated that the overall samples were rich in clay and sand.

- Soil Physicochemical Parameters

Soil pH ranged from 3.65±0.071 to 5.73±0.70 in all treatments. The highest organic carbon contents were observed in the treatment soils T0, T3 and T5. High concentrations of organic matter were found in T3 and T01. Calcium and magnesium decreased in the vinasse treatments soils. The value of the sum of exchangeable bases was high in treatments T4 and T5 compared to T0 and T01. Nitrogen concentrations were high in treatments T3 and T5. The carbon to nitrogen ratio was high in treatments T01, T1 and T3. Cation exchange capacity was higher in treatment T5. Treatment with vinasse increased phosphorus concentrations in the treatment soils T4. These results are presented in Table 2 below.

Table.2. Physicochemical characteristics of the soil before and after different treatments with vinasse.

Physicochemical parameters	Soil before Maize cultivation T0	Different treatments applied					
		T01	T1	T2	T3	T4	T5
pH EAU	4.4±0.283	4.75± 0.07	4.83± 0.29	4.66±0.34	4.9± 0.294	5.38±0.499	5.73± 0.70
pH KCl	3.65±0.071	3.95±0.07	3.97± 0.23	3.92±0.15	4.03± 0.21	4.3±0.294	4.45±0.48
ΔpH	-0.75±0.1	-0.8±0.00	-0.87±0.06	-0.75±0.19	-0.88± 0.096	-1.075±0.275	-1.28± 0.54
CO (g/kg)	20.17± 3.8	31.26±0.48	24.20±7.58	23.53± 5.1	27.06±2.71	24.03±0.37	24.71±0.644
MO (g/kg)	34.77±6.6	53.89± 0.82	41.72±1.31	40.57± 8.72	46.65±4.67	41.434±6.374	42.59±1.11
Ntotal (g/kg)	1.48±0.18	1.453±0.124	1.50±0.095	1.61± 0.149	1.825±0.23	1.72±0.214	1.79±0.172
C/N	13.84±4.23	21.59±1.51	16.21±5.46	14.64± 3.17	15.03±2.71	14.036±1.72	13.91±1.56
Ca (méq/100g)	0.80±0.9	0.36± 0.17	0.53±0.303	0.24±0.113	0.5±0.27	0.460± 0.256	0.44±0.103
Mg (méq/100g)	0.76± 0.51	0.4±0.23	0.35±0.092	0.54±0.24	0.48±0.34	0.440±0.296	0.620±0.482
K (méq/100g)	0.183± 0.01	0.16±0.026	0.20± 0.023	0.43±0.27	0.371±0.12	0.903±0.348	1.3±0.881
Na (méq/100g)	0.133± 0.048	0.234±0.00	0.21±0.039	0.25±0.034	0.27±0.04	0.403±0.087	0.437±0.156
SBE (méq/100g)	1.88±1.46	1.16±0.37	1.29±0.22	1.46±0.452	1.62±0.34	2.206±0.630	2.797±0.944
CEC (méq/100g)	10.61± 0.56	9.55±0.64	10.13±0.76	9.76±0.94	9.15±0.95	10.908±1.66	12.45±1.44
Ptotal (mg/kg)	13.07±1.50	14.16±0.043	10.43±0.11	13.84±2.7	11.74± 2.35	14.231±2.92	14.14±4.43

3.1.4 Effect of different treatments on soil characteristics

There were significant differences for each of these parameters. Figure 2 show the different treatments according to the parameters measured in the soil.

- Soil pH water and pH KCl

The results obtained revealed that the pH water and pH KCl varied according to the different treatments. The pH water of treatment T5 (5.73± 0.70) was significantly different (P< 0.05) from all treatments T0 (4.4±0.283), T01 (4.75± 0.07), T1 (4.83± 0.29), T2 (4.66±0.34), T3 (4.9± 0.294). No significant difference was observed between T0, T01 and T2 (Fig.2.A). The pH KCl of treatment T5 (4.45±0.48) was significantly different (P<0.05) from all treatments T0 (4.4±0.283), T01 (4.75±0.07), T1 (4.83±0.29), T2 (4.66±0.34), T3 (4.9±0.294). No significant difference (P<0.05) was observed between T3 and T1 (Fig.2.B).

- The C/N Ratio and soil nitrogen

The different treatments significantly (P<0.05) improved soil carbon and nitrogen concentrations, resulting in a significant difference between the soil C/N ratio values for each treatment. Figure.2.C shows that treatment T5 (1.79±0.172) was significantly different (P<0.05) from treatments T0 (1.48±0.18), T01 (1.453±0.124), and T3 (1.825±0.23). An increase of 20.76% compared to the sample reference soil was obtained for treatment T3 with total nitrogen (Fig.2.D).

- Effect of different treatments on soil SEB and CEC

The results obtained showed that the SEB (Sum of Exchangeable Bases) and CEC (Cation Exchange Capacity) varied according to the different treatments. The SEB (Fig.2.E) of treatment T5 (2.797±0.944) was significantly different from all treatments T0 (1.88±1.46), T01 (1.16±0.37), T1 (1.29±0.22), T2 (1.46±0.452), T3 (1.62±0.34). The CEC (Fig.2.F) of treatment T5 (12.45±1.44) was significantly different (P<0.05) from treatments T0 (10.61±0.56), T01 (9.55±0.64), T1 (10.13±0.76), T2 (9.76±0.94) on the one hand and T3 (9.15±0.95) and T4 (10.908±1.66) on the other. However, no significant difference (P> 0.05) was observed between T0 (10.61± 0.56), T01 (9.55±0.64), T1 (10.13±0.76), T2 (9.76±0.94) and T4 (10.908±1.66). A variation in soil CEC was observed for treatment T5, an increase of 17.37% compared to T0.

- Effect of different treatments on soil potassium and total phosphorus contents

The results obtained showed that the total phosphorus and potassium in the soil varied according to the different treatments. Soil phosphorus in treatment T5 (14.14±4.43) was significantly different from treatment T1 (14.16±0.043). However, no significant difference (P<0.05) was observed between T4 and T5. Treatment T5 showed a better result (Fig.2.G). The potassium of treatment T5 (1.3±0.881) was significantly different (P<0.05) from treatments T0 (0.183±0.01), T01 (0.16±0.026), T1 (0.20±0.023), T2 (0.43±0.27), T3 (0.371±0.12). These results are shown in Figures 2.H.

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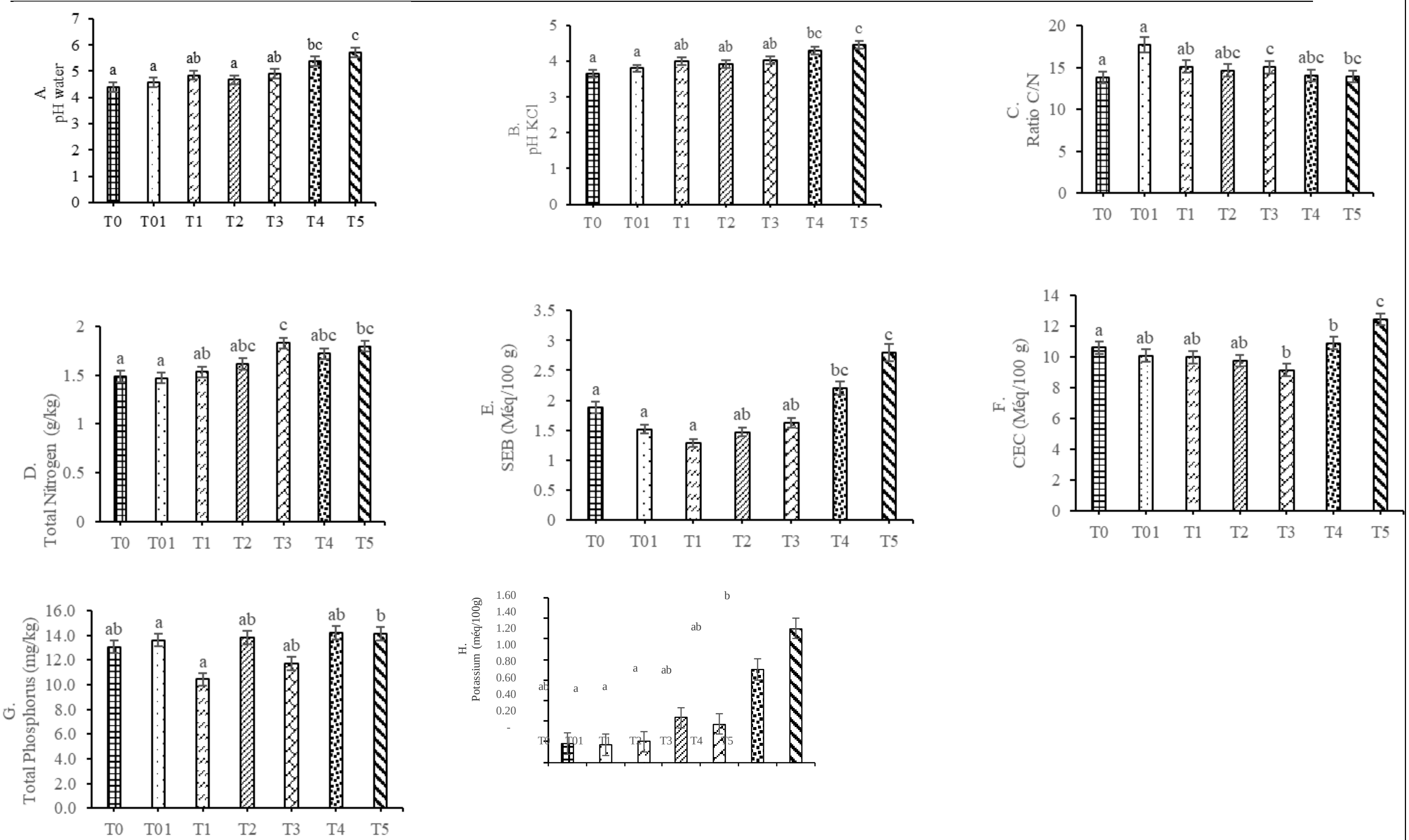

Fig.2. Soil characteristics with different treatments**.** A. pH water; B. pH KCL; C. C/N Ratio; D. Total Nitrogen; E. SEB; F. CEC ; G. Total Phosphorus ; H. Potassium. Treatments:T0= soil before spreading; T01= control without fertiliser; T1 = chemical fertiliser; T2= 1.6 l /m^2; T3= 4 l /m^2; T4= 8 l /m^2; T5= 16 l /m^2. Histogram bars with the same letters are not significantly different at the 5% threshold.

3.2 Discussion

- Physicochemical characteristics of vinasse

The physicochemical parameter values obtained in this study were influenced by the composition of the sugarcane molasses [14]. The acidic pH (5.46±1.07) of vinasses can be accounted for by their high concentrations of organic acids. Similar results were obtained by [27, 60] with pH values between 3.5 and 6.5. The high BOD_5 and COD contents (Table 1) are identical to the work by [31, 61]. These authors justified the increase in BOD_5 and COD contents by the low molecular weight of the compounds contained in vinasses, which can comprise melanoidins and phenolic compounds that can inhibit or reduce the activity of micro-organisms. As a result, vinasse was considered to be a material with a high chemical oxygen demand (COD) and a high biochemical oxygen demand, with levels ranging from 50 to 150 kg/m^3 and 20 to 80 kg/m^3 respectively [62]. However there were several methods such as dehydration by physiochemical processes to dry the effluent, the use of smaller quantities by dilution or ozone treatment to manage the use of vinasse in agriculture in an optimal and non-harmful way, resulting in a decrease of about 95% of COD, complete removal of phenolic compounds and more than 80% of total nitrogen [84]. Vinasse has been recorded as an agricultural fertiliser for NPK and water recycling in organic crop production since 1940 [1]. In this regard, [63] reported that vinasse contains important macronutrients such as N, K, Ca, sulphate and Mg, vitamins and organic acids such as vitamin B complex and amino acids from yeast autolysis, which are necessary for crop production and improving soil organic matter content. It also contains chelated organic matter containing micronutrients such as Fe, Mn, Zn and Cu. In addition, vinasse contains organic acids such as acetic, lactic, nicotinic, malic and citric acids, which can play an important role in reducing soil alkalinity. All these characteristics of vinasse are presented in Table 1. High concentrations of Potassium K^+ in the vinasses were observed (2.12±0.78 g/l). Potassium is an important element due to its multiple roles in plant growth. It improves the photosynthesis process, maintains cell turgor and regulates the water content of plant tissue. It is also essential in activating some enzymes in cells [64]. Accordingly, many research studies have examined the dosage of vinasse which could substitute fertiliser requirements for many crops, for example, Yassen and Arafat [65] showed that approximately 62% P and 100% K were required for wheat yield. Similarly, Gómez and Rodríguez [66] indicated that the addition of 50 m^3 of vinasse/ha-1 would substitute 55% of N, 72% of P_2O_5 and 100% of K_2O.

- Effect of different treatments on maize growth parameters

The different treatments used in this study were T01, the sample reference with no fertilizer added; T1, the treatment with chemical fertilizer applied; while T2, T3, T4 and T5, were the treatments applied with different doses of vinasse. Plant growth parameters such as collar diameter; number of leaves; leaf area and number of ears showed high values for treatments T3; T4 and T5. This result can be credited to the positive impact of the increase in chlorophyll index, which allowed an efficient use of photosynthesis to store the net assimilation rate of synthesis output, thereby accelerating vegetative growth and increasing leaf area as explained by [67]. In this study, the higher concentration of vinasses did not favour seed germination for all treatments; this is probably due to the presence of a higher salt content. Excessive amounts of inorganic salts and higher conductivity might have inhibited seed germination by altering the interaction between seeds and water, which is necessary to trigger enzyme activity [23]. The vegetative growth of *Z. mays* was reduced with higher vinasse concentrations. A high EC indicated a higher salt content in the higher effluent concentrations, and this reduced the number of leaves and leaf area. The vegetative growth was associated with the development of new shoots, twigs, leaves and leaf areas. This may be due to plants absorbing maximum amounts of nitrogen, phosphorus and potassium. The improvement in vegetative growth can be attributed to the role of potassium in transferring nutrients and sugars in plants and to the turgor pressure in plant cells. It is also involved in cell enlargement and in triggering the growth of young tissues or meristematic growth [68]. Nitrogen (N) and phosphorus (P) are essential for flowering and grain filling. A higher amount of N can delay or prevent flowering, while P deficiency is sometimes associated with low flower production or floral abortion. A high number of Z mays ears was obtained with treatments T3 and T4, which could be due to the fact that the vinasses contain sufficient N and P. Besides, N and P prevented flower abortion during grain filling. This was probably due to the higher metal content in the soil, which inhibited the uptake of PO_4^{3-} and K^+ by plants at higher concentrations [23]. The role of K^+, Fe^{3+}, Mg^{2+} and Mn^{2+} at maturity was important and, combined with chlorophyll synthesis, improved grain formation at harvest [69]. These results were consistent with the work of Naveed et al [27] who reported that vinasse improved *Z. mays* production. However, the chlorophyll index was higher with treatment T1 (chemical fertiliser). These results could be explained by the chemical nature of the fertilizer enriched in NPK mineral nutrients that favor plant growth and morphogenesis in order to achieve good photosynthesis. However, the average number of leaves and leaf area were higher with the T0 treatment.

- Effect of different treatments on soil characteristics

The effect of different vinasses treatments on the soil refers to its nutritional value and the optimization of soil properties. The addition of vinasses can lead to a significant increase in organic carbon (OC) in the soil, thereby improving the overall state of soil fertility. The high CO and nutrients present in the vinasses served as a source of energy for the growth, enzymatic processes and microbe multiplication [85]. Table 2 shows an increase in soil physicochemical parameters from treatment T01 to treatment T5. Vinasses contain valuable macro- and micronutrients and can therefore be a valuable fertilizer for crop production [70, 16, 71]. In another study, the application of vinasse dramatically improved sugarcane growth and yield characteristics as well as nutrient uptake compared to the application of recommended fertilizer alone [72]. Chemical analyses of the soils on the cultivation site revealed that these soils had acidic pH values ranging from 4.4 to 6.1 for pH (H_2O) and from 3.7 to 4.7 for pH (KCl). Cameroon's soils are acidic [57]. According to Kars and Ekberli [73], maize can grow and yield well at pH values ranging from 6.0 to 7.0 (pH H_2O). However, it has been established that pH values (5.8 to 6.3) are adequate for good biological activity and nutrient exchange in the soil [74]. Soils in the harvest site had a high C/N ratio (13-21.6), reportedly reflecting slow decomposition of organic matter [75]. This ratio indicated a medium level of total nitrogen deficiency. The soil on the cultivation site had a very low level of available phosphorus. The values recorded were all below 30 ppm. Bationo et al. [76]. stated that the low phosphorus content of soils and the impact of acidity on soil CEC were characteristic of tropical soils. Cation exchange capacity (CEC) refers to the soil's ability to retain and exchange cations that can be assimilated by plants. Of the four exchangeable bases determined, the percentage of calcium (Ca^{2+}) was highest compared to potassium (K^+), magnesium (Mg^{2+}) and sodium (Na^+).

Vinasses are a rich source of macro- and micronutrients and can be used as a main source of fertilizer for agriculture. However, the indiscriminate disposal of these wastes can constitute a problem for soil health and environmental quality. Overall, vinasses have been characterised as an important source for improving soil properties such as nutrient availability, bulk density, soil porosity, nutrient and water holding capacity, hydraulic conductivity and microbial activities, as well as crop growth and development [15]. The application of vinasse might have improved the microbial population and its activities, which would have increased the decomposition of organic matter and therefore the availability of carbohydrates and humified substances. Vinasses improved soil macro-aggregates with more biodegradable C and N than the sample reference soil. Vinasse increased OM content. Vinasse can lead to a significant increase in CEC compared to untreated soil. The pH, EC, total Kjeldahl nitrogen, total organic carbon and available phosphorus, exchangeable Na, K, Ca and Mg increased in soil irrigated with distillery effluents [77]. The pH is an important soil parameter and the availability of nutrients in the soil determines the soil pH. Adhikary [78] reported that higher concentrations of effluent irrigated soil were naturally acidic. Kumar and Dhankhar [79] stated that soil pH can influence plant growth and development. The increase in pH values in effluent treated soil could be due to either the alkaline reaction of the effluent used or the increase in potassium, calcium, magnesium and sodium levels in the soil. Kumar [23] pointed out that pH is an important plant nutrition parameter and only a particular pH range contains the presence of many nutrients for plant uptake. A pH between 6.0 and 8.2 allowed predominant bacterial activity and was conducive to higher crop yields. EC is an important factor and was used to monitor soil salinity. Soil EC values increased with higher concentrations of vinasse-treated soil. Nitrate is the most essential and available form of nitrogen for plants. The increase in soil nitrogen due to effluent irrigation was positively associated with soil health. Lower doses of effluent-irrigated soil had potassium and phosphorus availability which may be due to increased mineralisation activity that helped to increase soil fertility and plant development. Micronutrients, including nitrogen, and microbial activity were reduced in acidic soil, which affected plant growth [80]. Effluent concentrations in irrigated soil have shown the presence of a large amount of organic compounds that affect BOD_5 and soil aeration [53]. Nitrate, potassium, calcium and magnesium increased in the effluent-treated soil with different doses, resulted in a positive correlation with the increase in effluent concentration. Kumar et al. [81] observed similar results for paper mill effluent and [82] for oil mill effluent. The mineralisation of the organic matter contained in the effluent and the nutrients available in the effluent could be responsible for such an increase in the nutrients available to plants [53].The use of wastewater from other industrial sources has had adverse effects on soil fertility. Changes in the chemical constituents of the soil were a direct manifestation of the physicochemical properties of the effluent. The effluent was capable of altering soil fertility and this alteration had an adverse effect on growth and yield [31, 83, 85].

4. CONCLUSION

Industries dispose of their untreated effluent into the natural environment. The NODISCAM distillery is one of them, as it disposes of vinasse. It is in this context that this work, which focused on the sustainable management of effluent discharges, was carried out. The overall objective was to determine the effect of distillery effluents on maize growth and soil properties. The physicochemical characterisation of the vinasse showed an acid pH (5.46±1.07). Very high COD and BOD_5 values (81.13±78.94 g/l and 11.53±6.85 g/l respectively) were found. Vinasses also contained macro- and micro-elements necessary for plant growth, such as magnesium (l84.62 ± 1.08 mg/l), calcium (308.51 ± 16.45 mg/l) and potassium (2.12±0.78 g/l). Of the forms of nitrogen measured, only nitrates showed high values (151.13±57.82 g/l). Lead and cadmium concentrations were very low compared to discharge standards. On the experimental site, six different treatments were applied to monitor maize growth. Treatments T4, T1 and T2 showed significant differences with $P < 0.05$ for collar diameter, plant height, average number of ears and leaf area. Measurements of soil physicochemical parameters collected in the different treatment blocks showed significant differences with $P < 0.05$ between T4; T5; T1 and T3 for pH water; pH KCl; CEC; SEB; available phosphorus; total nitrogen and potassium parameters. The best yields were observed with treatments T_3; T_4; and T_5. At the end of this study, it emerged that distillery effluents can improve soil characteristics and crop yields by being a sustainable substitute to chemical soil fertilisation.

REFERENCES

[1] Fuess, L. T., Rodrigues, I. J., Garcia, M. L. (2017). Fertirrigation with sugarcane vinasse: Foreseeing potential impacts on soil and water resources through vinasse characterization. *Journal of Environmental Science and Health, Part A, 52*(11), 1063-1072.

[2] WWAP (Programme mondial pour l'évaluation des ressources en eau). (2017). Rapport mondial des Nations Unies sur la mise en valeur des ressources en eau: Les eaux usées-Une ressource inexploitée. Paris, UNESCO. 203 p. (http://www.unesco.org/open-access/terms-use-ccbysa-en).

[3] Mikucka, W., Zielińska, M. (2020). Distillery stillage: characteristics, treatment, and valorization. *Applied biochemistry and biotechnology*, *192*, 770-793.

[4] Rachbauer, L., Granda, C. B., Shrestha, S., Fuchs, W., Gabauer, W., Singer, S. W., Urgun-Demirtas, M. (2024). Energy and nutrient recovery from municipal and industrial waste and wastewater—a perspective. *Journal of Industrial Microbiology and Biotechnology*, *51*, kuae040.

[5] Pinto, L. E., Cordeiro, C. F. D. S., de Araujo, A. S., Araujo, F. F. D. (2022). Vinasse improves soil quality and increases the yields of soybean, maize, and pasture. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *26*, 335-340.

[6] Noukeu N. A., Gouado I., Priso R. J., Ndongo D., Taffouo V. D., Dibong S. D., Ekodeck G. E. (2016). Characterization of effluent from food processing industries and stillage treatment trial with *Eichhornia crassipes* (Mart.) and *Panicum maximum* (Jacq.). Water Resources and Industry ; (16), 1–18 p.

[7] Azevedo-Santos, V. M., Fernandes, J. A., de Souza Andrade, G., de Moraes, P. M., Magurran, A. E., Pelicice, F. M., & Giarrizzo, T. (2024). An overview of vinasse pollution in aquatic ecosystems in Brazil. *Environmental Management*, *74*(6), 1037-1044.

[8] Da silva, J. J., da Silva, B. F., Stradiotto, N. R., Petrović, M., Gros, M., Gago-Ferrero, P. (2021). Identification of organic contaminants in vinasse and in soil and groundwater from fertigated sugarcane crop areas using target and suspect screening strategies. *Science of The Total Environment*, *761*, 143237.

[9] Del Pino, A., Casanova, O., Hernández, J., Takata, V., Panissa, G. (2022). Vinasse for sugarcane crop nutrition: accumulation and efficiency in the use of nutrients. *Australian Journal of Crop Science*, *16*(9), 1107-ii.

[10] Sica, P., Marabesi, A. O., Seleghim, A. R., Das, K. C., Baptista, A. S. (2024). Effects of vinasse concentration on biogas production: an experimental work and case study in the context of RenovaBio in Brazil. *Bioresource Technology Reports*, *25*, 101698.

[11] Chhonker, P.K., Datta, S.P., Joshi, H.C., Pathak, H. (2000). Impact of industrial effluents on soil health and agriculture—Indian experience: Part I. Distillery and paper mill effluents. J. Sci. Ind. Res. 59, 350–361.

[12] Chowdhary, P., Raj, A., Bharagava, R. N. (2018). Environmental pollution and health hazards from distillery wastewater and treatment approaches to combat the environmental threats: a review. *Chemosphere*, *194*, 229-246.

[13] Carrilho, E. N. V. M., Soares, M. R. (2024). Vinasse, a byproduct of the bioethanol industry-A valuable resource for sustainable agriculture and renewable energy production. In *Environmental Materials and Waste* (pp. 193-239). Elsevier.

[14] Montiel-Rosales, A., Montalvo-Romero, N., Garcia-Santamaria, L. E., Sandoval-Herazo, L. C., Bautista-Santos, H., Fernández-Lambert, G. (2022). Post-industrial use of sugarcane ethanol vinasse: A systematic review. *Sustainability*, *14*(18), 11635.

[15] Rashed, S. H., & Hammad, S. (2023). Effect of vinasse and foliar application of compost tea on physico-chemical soil properties and yield of wheat in salt affected soil. *Environment, Biodiversity and Soil Security*, *7*(2023), 1-12.

[16] Hassan, M.U., Aamer, M., Chattha, M.U., Haiying, T., Khan, I., Seleiman, M.F., Rasheed, A., Nawaz, M., Rehman, A., Talha Aslam, M., Afzal, A., Huang, G. (2021). Sugarcane distillery spent wash (DSW) as a bio-nutrient supplement: a win-win option for sustainable crop production. Agronomy 11, 183. https://doi.org/ 10.3390/agronomy11010183.

[17] Rodrigues Reis, C. E., Hu, B. (2017). Vinasse from sugarcane ethanol production: better treatment or better utilization?. *Frontiers in Energy Research*, *5*, 7.

[18] Brito, L. F. P. D., Espíndola, E. L. G., Ogura, A. P. (2024). Tolerance of free-floating aquatic macrophytes to sugarcane vinasse and its implications for phytoremediation strategies. *Journal of Water, Sanitation and Hygiene for Development*, *14*(4), 325-331.

[19] Moran-Salazar, R. G., Sanchez-Lizarraga, A. L., Rodriguez-Campos, J., Davila-Vazquez, G., Marino-Marmolejo, E. N., Dendooven, L., Contreras-Ramos, S. M. (2016). Utilization of vinasses as soil amendment: consequences and perspectives. *SpringerPlus*, *5* (1), 1007.

[20] You, Q., Su, T. M., Zhong, Y. (2009). Effects of vinasse on sugarcane field. *Guangxi Agricultural Sciences*, *40* (6), 677-680.

[21] Jiang, Z. P., Li, Y. R., Wei, G. P., Liao, Q., Su, T. M., Meng, Y. C., Lu, C. Y. (2012). Effect of long-term vinasse application on physico-chemical properties of sugarcane field soils. *Sugar Tech*, *14*, 412-417.

[22] Vaithiyanathan, T., Sundaramoorthy, P. (2017). Analysis of sugar mill effluent and its influence on germination and growth of African marigold (Tagetes erecta L.). *Applied Water Science*, *7*, 4715-4723.
[23] Kumar, V. (2014). Sugar mill effluent utilization in the cultivation of maize (Zea mays L.) in two seasons. *Journal of waste management*, *2014*(1), 408509.
[24] Da Silva, S. F., Garcia, G. D. O., dos Reis, E. F., Dalvi, L. P. (2020 a). Foliar nutrient content and maize yield with vinasse application during three crops. *Revista Brasileirade Ciencias Agrarias*, v.15, n.1, e6285, 2020.DOI:10.5039/agraria.v15i1a6285.
[25] Bastos, A. V. S., Teixeira, M. B., Soares, F. A. L., da Silva, E. C., dos Santos, L. N. S., Gomes, F. H. F. (2021). Immediate and residual effects of mineral and organomineral nitrogen sources associated with concentrated vinasse on maize. *Journal of Soil Science and Plant Nutrition*, *21*(2), 1382-1396.
[26] Raza, Q. U. A., Bashir, M. A., Rehim, A., Raza, H. M. A. (2022). Role of sugarcane industrial byproducts on soil physicochemical properties and metal accumulation in rice. *Environmental Science and Pollution Research*, *29*(17), 24726-24736.
[27] Naveed, S., Rehim, A., Imran, M., Anwar, M. F., Hussain, S. (2018). Effect of distillery spentwash fertigation on crop growth, yield, and accumulation of potentially toxic elements in rice. *Environmental Science and Pollution Research*, *25*, 31113-31124.
[28] 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.
[29] Da Silva, A. M. R., Lopes, I. G., Braos, L. B., Da Cruz, M. C. P. (2020 b). Nitrogen mineralization and sugarcane growth in soils fertilized with vinasse. *Sugar Tech*, *22*(6), 1076-1085.
[30] Kaloi, G. M., Memon, M. (2021). Influence of Sugar Industry Wastewater on Sugarcane Juice Quality and Soil Health. *Pakistan Journal of Agricultural Research*, *34*(4).
[31] Stephen, G. S., Shitindi, M. J., Bura, M. D., Kahangwa, C. A., Nassary, E. K. (2024). Harnessing the potential of sugarcane-based liquid byproducts—molasses and spentwash (vinasse) for enhanced soil health and environmental quality. A systematic review. *Frontiers in Agronomy*, *6*, 1358076.
[32] Arslanoğlu, H., Tümen, F. (2021). Potassium struvite (slow release fertilizer) and activated carbon production: Resource recovery from vinasse and grape marc organic waste using thermal processing. *Process Safety and Environmental Protection*, *147*, 1077-1087.
[33] Bettani, S. R., de Oliveira Ragazzo, G., Santos, N. L., Kieckbusch, T. G., Bastos, R. G., Soares, M. R., Da Silva, M. A. (2019). Sugarcane vinasse and microalgal biomass in the production of pectin particles as an alternative soil fertilizer. *Carbohydrate polymers*, *203*, 322-330.
[34] Doke, K. M., Khan, E. M., Rapolu, J., Shaikh, A. (2011). Physico-chemical analysis of sugar industry effluent and its effect on seed germination of Vigna angularis, Vigna cylindrical and Sorghum cernum. *Annals of Environmental Science*, *5*(1), 2.
[35] Buller, L. S., da Silva Romero, C. W., Lamparelli, R. A. C., Ferreira, S. F., Bortoleto, A. P., Mussatto, S. I., Forster-Carneiro, T. (2021). A spatially explicit assessment of sugarcane vinasse as a sustainable by-product. *Science of the total environment*, *765*, 142717.

[36] Vadivel, R., Minhas, P. S., Kumar, S., Singh, Y., Nageshwar, R. D. V. K., Nirmale, A. (2014). Significance of vinasses waste management in agriculture and environmental quality-Review. *African Journal of Agricultural Research*, *9*(38), 2862-2873.

[37] Kalaiselvi, P., Mahimairaja, S. (2011). Effect of distillery spentwash on yield attributes and quality of groundnut crop. *Middle East Journal of Scientific Research*, *7*(2), 189-193.

[38] Bhukia, T. D., Patil, S. G., Angadi, S. S. (2009). Crop nutrition through distillery spentwash in maize (Zea mays L.). *Journal of Environmental Science & Engineering*, *51*(2), 87-92.

[39] Carpanez, T. G., Moreira, V. R., Assis, I. R., Amaral, M. C. S. (2022). Sugarcane vinasse as organo-mineral fertilizers feedstock: Opportunities and environmental risks. *Science of The Total Environment*, *832*, 154998.

[40] Senatore, D., Queirolo, A., Monza, J., Bajsa, N. (2023). Using sugar cane vinasse as a biofertilizer: effects on soil microbial community due to periodical application. *Environmental Sustainability*, *6*(2), 173-182.

[41] Pereira, A. D., Da Silva Taveira, J. H., Fernandes, P. B., Silva, P. C., Costa, A. R., Araujo, C. M. C., Corioletti, N. S. D. (2024). Effect of increasing vinasse doses, in association with different harvest times, on sweet sorghum production. *Food Science and Technology*, *44*.

[42] Ngonkeu, E. L. M., Tandzi, L. N., Dickmi, C., Nartey, E., Yeboah, M., Ngeve, J., Gracen, V. (2017). Identification of farmer’s constraints to maize production in the humid forest zone of Cameroon. *Journal of Experimental Agriculture International*, *15*(3), 1-9.

[43] Ngonkeu, M. E. L., Tandzi, L. N., Tagne, A., Djocgoue, P. F. (2024). Agro-morphological Characterization of Maize (Zea mays L.) Hybrids Under Acid Soils in Two Contrasting Environments. *Journal of Agricultural Science*, *13*(3), 1-32.

[44] Wang, L. Q., Ma, D. L., Liu, H. Y., Hu, S. P., Yu, X. F., Gao, J. L. (2025). Soil fertility differences due to tillage methods modulate maize yield formation at different planting densities. *Scientific Reports*, *15*(1), 2437.

[45] Rodier J., Legube B., Merlet N., Brunet R. (2009). L'analyse de l'eau: Eaux naturelles, eaux résiduaires, eau de mer, 9ème Edition Dunod, Paris, France.

[46] Eaton A. D., Franson M. A. H. (2005). Standard methods for the examination of water and wastewater. American Public Health Association, 21st editionWashington, DC.1217 p.

[47] APHA (2005). (American Public Health Association), American Water Works Association, Water and Environment Federation. Standard Methods for the Examination of Water and Wastewater 21st ed. Washington, DC.

[48] Hach, (1998). Hach Water Analysis Handbook. 3rd ed. Hach Company, Loveland, Colorado, USA. 831 p.

[49] Walkley, A., Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, *37*(1), 29-38.

[50] Pauwels, J. M., Verloo, M. Mvondo A. (1992). Manuel de laboratoire de pedologie. Methodes d'analyses de sols et de plantes, equipement, gestion de stocks de verrerie et de produits chimiques. *Publications Agricoles (Belgium). Administration Generale de la Cooperation au Developpement. no. 28.*

[51] Bray, R. H., Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science*, *59*(1), 39-46.

[52] Menet M., Godefert M., Delas J., Vessot B., Catherine Juste. (1990). Effet de l'epandage de vinasses de distillerie vinicole sur le comportement du mais et quelques proprietes du sol.. *Science du sol*, 1990, 28 (3), pp.257-267. ⟨hal-02710537⟩

[53] Kumar, V., Chopra, A. K. (2012). Fertigation effect of distillery effluent on agronomical practices of Trigonella foenum-graecum L.(Fenugreek). *Environmental Monitoring and Assessment*, *184*(3), 1207-1219.

[54] Dias, A. S., Carneiro, P. A., Boloy, R. A. M., Da Silva César, A., De Oliveira, U. R. (2024). Advancements in Vinasse Application: An Integrated Analysis of Patents, Literature and Research Profile. *Cleaner Engineering and Technology*, 100795.

[55] Bousselot, J. M., Muenchrath, D., Knapp, A. D., Reeder, J. D. (2017). Emergence and seedling characteristics of maize native to the southwestern US. *American Journal of Plant Sciences*, *8*(06), 1304.

[56] Tekeu, H., Ngonkeu, M. E. L., Tandzi, L. N., Tagne, A., Djocgoué, P. F., Ghana, A., & Tekeu, H. (2021). Agro-morphological Characterization of Maize (Zea mays L.) Hybrids Under Acid Soils in Two Contrasting Environments. *Journal of Agricultural Science*, *13*(3).

[57] Petmi, C. L., Ngonkeu, E. L. M., Tandzi, N. L., Ambang, Z., Boyomo, O., Bell, J. M., Noé, W. (2016). Screening of maize (Zea mays L.) genotypes for adaptation on contrasted acid soils in the humid forest zone of Cameroon. *J. Exp. Agric. Int*, *14*, 1-15.

[58] SPSS, I. (2011). IBM SPSS (Statistical Package for the Social Sciences) Statistics Software for Windows, Version 20.0; IBM Corp. *Armonk, NY, USA*.

[59] World Health Organization. (2006). *WHO guidelines for the safe use of wasterwater excreta and greywater* (Vol. 4). World Health Organization.

[60] Oliveira, B. G., Lourenço, K. S., Carvalho, J. L. N., Gonzaga, L. C., Teixeira, M. C., Tamara, A. F., Cantarella, H. (2022). Soil pH does not interfere with nitrification inhibitor efficiency for reducing N_2O emissions from soils treated with concentrated vinasse and urea. *Geoderma*, *426*, 116087.

[61] Reis, C. E. R., Carvalho, A. K. F., Bento, H. B., De Castro, H. F. (2019). Integration of microbial biodiesel and bioethanol industries through utilization of vinasse as substrate for oleaginous fungi. *Bioresource Technology Reports*, *6*, 46-53.

[62] Khalil, S., Makhlouf, B., El-Gabry, K. (2020). Using Vinasse as a Source of Potassium Fertilization for Sugar Beet and a Sandy Soil Amendment. *Egyptian Journal of Agronomy*, *42*(3), 235-248.

[63] Parnaudeau, V., Condom, N., Oliver, R., Cazevieille, P., Recous, S. (2008). Vinasse organic matter quality and mineralization potential, as influenced by raw material, fermentation and concentration processes. *Bioresource technology*, *99*(6), 1553-1562.

[64] Hasanuzzaman, M., Bhuyan, M. B., Nahar, K., Hossain, M. S., Mahmud, J. A., Hossen, M. S., Fujita, M. (2018). Potassium: a vital regulator of plant responses and tolerance to abiotic stresses. *Agronomy*, *8*(3), 31.

[65] Yassen, A. A., Arafat, S. M., Zaghloul, S. M. (2002). Maximizing use of vinasse and filter mud as by· products of sugar canes on wheat production. *Journal of Soil Sciences and Agricultural Engineering*, *27*(11), 7865-7873.

[66] Gómez, J., Rodríguez, O., 2000. Effects of vinasse on sugarcane (Saccharum officinarum) productivity. Rev. Fac. Agron. Luz. 17, 318–326.

[67] 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.

[68] Bastos, R. G., da Silva, M. A., Mattos, L. F. A., Junior, L. C. A., Codato, C. B. (2022). Challenges for microalgae cultivation in sugarcane processing wastewater (vinasse) for biodiesel production: From the bench to pilot scale. In *3rd Generation Biofuels* (pp. 1001-1018). Woodhead Publishing.

[69] Bruwier, C. (2019). Impacts à long terme d'une fertilisation minérale contrastée sur la dynamique du phosphore et du potassium dans un sol limoneux cultivé.matheo.uliege.be.

[70] Kumar, V. (2016). Agronomical Response of High Yield Cultivar of Fenugreek (Trigonella foenum-graecum L.) After Irrigation with Treated Sugar Mill Effluent Under Nursery Polybags Trials. *EC Agriculture*, *3*(4), 708-718.

[71] Ratna, S., Rastogi, S., Kumar, R. (2021). Current trends for distillery wastewater management and its emerging applications for sustainable environment. *Journal of Environmental Management*, *290*, 112544.

[72] Rath, P., Pradhan, G., & Misra, M. K. (2011). Effect of distillery spentwash (DSW) and fertilizer on growth and chlorophyll content of sugarcane (*Saccharum officinarum* L.) plant. *Recent Research in Science Technology*, *3*, 169–176.

[73] Kars, N., Ekberli, I. (2020). The relation between yield indices of maize plant and soil physicochemical characteristics. *Eurasian Journal of Soil Science*, *9*(1), 52-59.

[74] Neina, D. (2019). The role of soil pH in plant nutrition and soil remediation. *Applied and environmental soil science*, *2019*(1), 5794869.

[75] Bimüller, C., Dannenmann, M., Tejedor, J., von Lützow, M., Buegger, F., Meier, R., Kögel-Knabner, I. (2014). Prolonged summer droughts retard soil N processing and stabilization in organo-mineral fractions. *Soil Biology and Biochemistry*, *68*, 241-251.

[76] Bationo, A., Mughogho, S. K., Mokwunye, U. (1986). Agronomic evaluation of phosphate fertilizers in tropical Africa. In Management of Nitrogen and Phosphorus Fertilizers in Sub-Saharan Africa: Proceedings of a symposium, held in Lome, Togo, March 25–28, 1985 (pp. 283-318). Dordrecht: Springer Netherlands.

[77] Baskaran, L., Chidambaram, A. A., Sundaramoorthy, P., Unnikannan, P. (2009). Bioreclamation of Sugar Mill Effluent Polluted Soil Using Earthworm and its Responses on Greengram (Vigna radiata L.). *Journal of Phytology*, *1*(1).

[78] Adhikary, B., Dash, P. K., Sajib, K., & Mannan, M. A. (2016). Yield response of tomato under different combination of manures and fertilizers. *Journal of Agriculture and Veterinary Science*, *9* (1), 6-16.

[79] Kumar, S., Dhankhar, R. (2020). Assessment of change in soil properties before and after flooding due to the rainy season in Bhindawas wetland, Jhajjar, Haryana (India). *Indian Journal of Science and Technology*, *13*(20), 2057-2064.

[80] Patterson, S. J., Chanasyk, D. S., Mapfumo, E., & Naeth, M. A. (2008). Effects of diluted Kraft pulp mill effluent on hybrid poplar and soil chemical properties. *Irrigation Science*, *26*, 547-560.

[81] Kumar, V., Chopra, A. K., Pathak, C., Pathak, S. (2010). Agro-potentiality of paper mill effluent on the characteristics of Trigonella foenum-graecum L.(Fenugreek). *New York science journal*, *3*(5), 68-77.

[82] Magdich, S., Ahmed, C. B., Jarboui, R., Rouina, B. B., Boukhris, M., Ammar, E. (2013). Dose and frequency dependent effects of olive mill wastewater treatment on the chemical and microbial properties of soil. *Chemosphere*, *93*(9), 1896-1903.
[83] Kumar, V., Chopra, A. K. (2010). Influence of sugar mill effluent on physico-chemical characteristics of soil at Haridwar (Uttarakhand), India. *Journal of Applied and Natural science*, *2*(2), 269.
[84] Junior, A. D. N. F., Etchebehere, C., Perecin, D., Teixeira, S., Woods, J. (2022). Advancing anaerobic digestion of sugarcane vinasse: Current development, struggles and future trends on production and end-uses of biogas in Brazil. *Renewable and Sustainable Energy Reviews*, *157*, 112045.
[85] Brito, F.L.; Rolim, M.M.; Pedrosa, E.M.R. (2009). Effect of vinasse application in chemical characteristics of soils from forest zone of Pernambuco. Agraria 2009, 4(4), 456–462.