

Review Article

Filter Cake and Vinasse as Fertilizers Contributing to Conservation Agriculture

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Utilising organic residues in agriculture contributes to the conservation of natural resources by recycling carbon and mineral elements. Organic residues produced by the sugar and alcohol agroindustries have great potential for use in conservation agriculture. The production of sugar and alcohol generates large quantities of byproducts, such as filter cake and vinasse, which can be used as soil improvers and substitutes for inorganic phosphorus and potassium fertilizers. However, the use of these residues in agriculture requires specific recommendations for each pedoclimatic condition to prevent environmental damage.

1. Introduction

Recently, the high cost of fertilizers and concerns about environmental protection have been great incentives to study the recycling of the large quantities of organic residues produced as byproducts of the sugar and alcohol agroindustries in agriculture.

The mechanized harvest of sugar cane, which is used widely in countries producing this crop, leaves about 6–24 t ha⁻¹ of residues on the soil surface [1]. The layer of residues protects the soil against erosion, inhibits weed germination, improves water retention, ameliorates physical and biological soil properties, and is a source of plant nutrients. In addition, industrial processing of sugar cane to produce sugar and alcohol also generates residues, such as filter cake and vinasse, which have a great potential for use in agriculture as soil improvers and fertilizers. Commercial uses of industrial residues strengthen the sugar and alcohol agroindustries [2].

Filter cake, a residue from the treatment of sugar cane juice by filtration, is a rich source of phosphorus and organic matter and has a large moisture content. It has been used as a complete or partial substitute for mineral fertilizers in sugar cane cultivation [3, 4], in the cultivation of other crops [5–10], in composting [11], in vermicomposting [12], and as a substrate in the production of seedlings [13, 14].

Vinasse is an aqueous effluent of the distillation unit in the sugar-alcohol industry and a problem to the sector due to the large quantities produced and its potential effects as an environmental pollutant. It is largely composed of water, organic matter, and mineral elements. The environmental damage caused by discarding vinasse into the soil or running waters was an incentive to studies aiming to find alternative, economic applications for this residue. Results from such studies indicate that, properly used, vinasse contributes to improvements in soil quality [15–25] and agricultural productivity [19, 24–30].

Recycling organic residues is a sustainable activity, which is increasingly necessary when dealing with natural resources [31]. It is recognized that the use of filter cake and vinasse, which are low cost materials, can improve soil fertility. Some authors even suggest that their use is beneficial to soil physical attributes, such as stability and average weighted diameter of aggregates [32]. It is possible to estimate the potential contribution of byproducts produced by the sugar-alcohol agroindustry to the annual recycling of nitrogen, phosphorus, and potassium in cultivated land with sugar cane in Brazil (Table 1). These amount to 293 kt N, 99.6 kt P₂O₅, and 197 kt K₂O. It should be noted that nitrogen and phosphorus are present as organic compounds and must be mineralized before becoming readily available to plants [33].

TABLE 1: Estimates of the potential contribution of byproducts produced by the sugar-alcohol agroindustry to the annual recycling of mineral elements in agriculture (adapted from [33]).

Residues	Nutrients			Volume of residues	Returning nutrients		
	N	P ₂ O ₅	K ₂ O		N	P ₂ O ₅	K ₂ O
	(% in dry residue)				(t yr ⁻¹)		
Filter cake ¹	1.40	1.94	0.39	2.34 million t dry cake yr ⁻¹ (Mt dwt)	32800	45400	9130
Straw ²	0.46	0.11	0.57	34.5 million t dry straw yr ⁻¹	158700	37950	196650
	(g m ⁻³ vinasse)						
Vinasse ³	375	60	2.035	270 billion L yr ⁻¹	101250	16200	549450
Total	—	—	—	—	292750	99550	755230

¹Supposing that the cultivated area in Brazil is 6.9 million hectares and 475 million tons of cane sugar are harvested, of which 223 million tons are utilized for sugar production generating 35 kg of filter cake ton⁻¹ of crushed cane; filter cake with 70% moisture content. ²Generation of 5 t ha⁻¹ of dry straw, considering that 100% of the sugar cane cultured area in Brazil is not burnt. ³Alcohol production: 20.8 billion liters; vinasse generation: 13 L L⁻¹ of produced alcohol.

The objective of this review is to evaluate the potential for the agricultural use of filter cake and vinasse and to discuss not only recent advances but also the necessity for further research.

2. Filter Cake

Filter cake is utilized as fertilizer in several countries, including Brazil, India, Australia, Cuba, Pakistan, Taiwan, South Africa, and Argentina. The residue is produced in large volumes (30–40 kg t⁻¹ of crushed cane) and it contains a considerable amount of organic matter and mineral elements required for plant nutrition, characteristics that explain its potential for agriculture. It can partially substitute for mineral fertilizers [4], and some suggestions have been made as to the amounts to be applied in the cultivation of sugar cane. In Brazil, the recommended applications of filter cake pre-planting are 80–100 t ha⁻¹ if applied to the whole area, 15–30 t ha⁻¹ if applied in the planting grooves, or 40–50 t ha⁻¹ if applied between the grooves [34].

The chemical composition of filter cake is a function of the variety and maturation of the sugar cane, type of soil, procedure of juice clarification, and various other factors. Table 2 shows chemical composition data from various reports. Of the mineral constituents of filter cake, phosphorus is the most significant as a fertilizer in agriculture and, for this reason, it is intensely studied. Phosphorus is the nutrient mostly commonly applied to tropical soils due to its low natural availability, its high capacity for adsorption to soil colloids, and its joint precipitation with iron and aluminum oxides and hydroxides [35].

The main effects of filter cake on soil chemical properties are increased nitrogen, phosphorus, and calcium concentrations, increased cation exchange capacity (CEC), and reduced concentrations of exchangeable aluminum (Al³⁺), which is toxic to plants [37]. Beneficial effects on physical and biological soil properties are also observed. Thus, due to its characteristics, filter cake can play a fundamental role in agricultural production, in the maintenance of soil fertility, and as a soil conditioner [33].

TABLE 2: Concentrations of organic matter (OM) and mineral elements, pH values, and C/N ratios determined in filter cake calculated on dry weight basis. Data are taken from reports of different authors for contrasting pedoclimatic conditions.

Determinations	Filter cake				
	(*)	[10]	[12]	[36]	Average
OM (%)	29.6	15	—	—	22.3
pH	8.2	—	7.1	—	7.7
N (%)	1.4	4.8	1.6	0.3	2.0
P (%)	1.2	1.8	1.3	0.1	1.1
K (%)	0.2	0.3	0.4	0.4	0.3
Ca (%)	2.7	1.6	2.5	1.7	2.1
Mg (%)	1.1	0.4	—	0.2	0.6
S (%)	0.2	0.3	—	—	0.25
C/N ratio	12	—	25	36	24

*: Data of the authors. —: Not determined.

3. Effects of Filter Cake Application on the Production and Quality of Various Crops

A report from Egypt [7] showed that the use of filter cake, enriched by rock phosphate in the presence or absence of a biofertilizer, in organic onion culture resulted in improved plant nutrition, growth and crop production, in addition to better export quality.

The productivity of sugar cane crops receiving organic and mineral fertilizers was analyzed in a study conducted in Cuba [38]. It was observed that soil structure was improved when natural and organic fertilizers were used rather than chemical fertilizers. The authors reported that application of 15 t ha⁻¹ of filter cake plus 2 t ha⁻¹ zeolite, 4 t ha⁻¹ of compost and 2 t ha⁻¹ of phosphate and calcareous rock had better residual effects on soil properties that were reflected in the agricultural and industrial yield of sugar cane for over three years.

In Swaziland, the destination of filter cake is a problem to the country. It is not widely used as a fertilizer, but one report [6] considers that this organic product should be better studied and used, for example, in the cultivation of

manioc, in a similar manner to maize [39] and sweet potato cultivation [5]. There are indications that addition of filter cake at 60 t ha^{-1} has potential as an organic amendment in manioc production by preventing competition with weeds and increasing productivity by 50% compared to mineral fertilization [6].

Another study in Swaziland [8] reports that the use of filter cake application is of great importance due to limited funds to buy chemical fertilizers in addition to its environmental benefits. The authors studied the application of different amounts of filter cake in maize cultivation (0, 10, 20, 40 t ha^{-1}) and reported that the higher applications increased soil organic matter. Soil phosphorus concentrations increased from 6 mg kg^{-1} (without fertilizer) to 56 mg kg^{-1} , while treatments with mineral fertilizer led to a phosphorus concentration of only 24 mg kg^{-1} . Micronutrient concentrations were also increased, with exception of boron and copper. Maize yields were also increased by the addition of filter cake. Yields of maize crops receiving the largest amounts of filter cake ($5,254 \text{ kg ha}^{-1}$) were comparable to those receiving chemical fertilizers ($5,046 \text{ kg ha}^{-1}$), and both were much larger than the control treatment ($3,732 \text{ kg ha}^{-1}$).

In a study conducted in Indonesia [9], ashes of rice husks and filter cake were applied at two amounts to cabbages and phosphorus availability in soil, phosphorus uptake by plants, and plant growth were determined. The results indicated that phosphorus availability increased 120% and 78%, when rice husk ashes and filter cake were applied, respectively. The treatments increased silicon concentrations, cation exchange capacity, solution pH, and anion concentrations in the soil. The authors also observed that in soils containing high amounts of organic matter, addition of rice ashes and filter cake increased phosphorus uptake 3-fold and 2-fold and increased plant growth by 197% and 231%, respectively. In soils poor in organic matter addition of rice ashes and filter cake increased phosphorus uptake by 1.9-fold and 2.7-fold and increased plant growth by 17% and 11.9%, respectively, compared to untreated soils.

In a report from India [40] the combined application of N (0, 75, 100, and 150 kg ha^{-1}) and filter cake (0, 10, 20, 30 t ha^{-1} , with 80% water content) to sugar cane indicated that 10 t ha^{-1} of filter cake together with 75 kg ha^{-1} N produced equivalent yields to 150 kg ha^{-1} N, resulting in the saving of 75 kg ha^{-1} of chemical N fertilizer.

Assays conducted in a Vertisol in Sudan [41] indicated that filter cake applications to crops increased soil concentrations of organic matter, organic carbon, total nitrogen, and available phosphorus.

Studies conducted in Brazil [42] evaluated the effects of filter cake in combination with mineral fertilizers (0, 50, and 100% of the recommended dose) in sugar cane production. It was observed that filter cake improved soil fertility, expressed as increased concentrations of macro- and micronutrients, and reduced soil acidity and concentrations of soil aluminum. Sugar cane plants showed a positive response to the addition of filter cake through increased concentrations of phosphorus, potassium, and copper in the aerial parts. The authors concluded that the use of filter cake in combination with

mineral fertilizers can maximize productivity and reduce the costs associated with mineral fertilizers.

In another Brazilian experiment [4], the response of vegetative growth and productivity of sugar cane to the application of fertilizers containing filter cake enriched with soluble phosphate was studied. It was verified that phosphorus increased productivity in sugar cane and that the application of filter cake to the planting grooves could substitute for part of the inorganic phosphate fertilizer. The best combination suggested by the authors to optimize the concentration of soluble solids and sugar production was $2.6\text{--}2.7 \text{ t ha}^{-1}$ of filter cake in combination with $160\text{--}190 \text{ kg ha}^{-1}$ of P_2O_5 .

The yield of lettuce in Brazil [10] showed a linear increase with the application of filter cake from 0 up to 40 t ha^{-1} .

The beneficial effects of filter cake were also demonstrated in Brazil [3] in a field study of ratoon cane where the application of 70 t ha^{-1} of fresh filter cake increased the production of cane sugar internodes.

4. Other Applications of Filter Cake in Agriculture (Composting, Vermicomposting, and Substrate)

Some factors, such as lack of solubility and unbalanced concentrations of nutrients, limit the application of filter cake to soil [12]. The strong disagreeable smell during biological degradation [43], the high temperature of the residue (65°C), and the long period of natural decomposition [44] are additional disadvantages. Reports in the literature mention immobilization of nutrients and phytotoxicity after application of residues that are not composted or otherwise stabilized [45]. Discarding the raw residue is of concern in developing countries, as for example, in India [12].

Vermicomposting is an important technique for the utilization of filter cake. Filter cake has a high potential [12] as a starting material for vermicomposting and results in a biologically stable product that is free of pathogens, as confirmed by coliform counting. In India [46], vermicomposting of filter cake in combination with equine manure accelerated mineralization of nutrients and was adequate for growth and reproduction of earthworms.

Other authors suggest composting as a viable use of filter cake [11]. In countries like Thailand, enhanced performance at composting facilities for organic products needs improvements to preserve nitrogen concentration and produce a stable product in the short term. The C/N ratio in filter cake is around 14 and in sugar cane bagasse, another sugar cane residue, it is 100. Therefore, the filter cake composting could result in considerable ammonia N loss through volatilization due to the low C/N ratio. On the other hand, bagasse composting is only possible with the addition of N due, in this case, to the high C/N ratio. Since composting maturation is highly dependent on the nature of organic residues, investigators in Thailand [11] determined the time required for filter cake to compost to a stable product and considered that composting a mixture of bagasse and filter cake (2:1 by weight) would prevent N losses by increasing the C/N ratio. The authors concluded that nitrogen loss was

TABLE 3: The chemical requirements for oxygen (CRO), biological requirements for oxygen (BRO), electrical conductivity (EC), total dissolved solids (TDS), pH values, sodium and macronutrient concentrations of vinasse according to reports of various authors.

Determinations	Vinasse				Average
	(*)	(51)	(17)	(15)	
CRO (mg L ⁻¹)	21.450	26.771	48.860	—	32.360
BRO (mg L ⁻¹)	10.000	5.000	21.275	—	12.092
EC (dS m ⁻¹)	14.12	11.5	9.65	3.6	9.72
TDS (mg L ⁻¹)	7.940	11.352	19.000	—	12.764
pH	4.5	4.4	4.6	5.7	4.8
N (mg L ⁻¹)	410	—	—	560	485
P (mg L ⁻¹)	160	—	175	190	175
K (mg L ⁻¹)	3.100	1.123	1.392	960	1.644
Na (mg L ⁻¹)	350	113	110	—	191
Ca (mg L ⁻¹)	640	352	728	280	500
Mg (mg L ⁻¹)	340	16	29	130	129

*: Data of the authors. —: Not determined.

reduced by 12–15% and that both products have potential use in agricultural production. They also observed that during the first five days of composting the temperature of the mixture rose to about 55°C but decreased considerably (<40°C) in the next 15–20 days. The time for complete composting took approximately 90 days.

Another application for filter cake is as a substrate for seedling production. Some trials conducted in Brazil have indicated that filter cake mixed with bagasse could be an adequate substrate for the production of eucalyptus [47] and citrus seedlings [14]. Citrus plants cultivated in this substrate were ready for grafting 120 days after transplanting, whilst plants growing in commercial substrate were not ready at this time. The addition of 18 g k⁻¹ N to plants growing in substrate containing filter cake resulted in taller plants with more leaves, greater leaf area, and larger aerial dry matter than plants grown in commercial substrate [14].

Evaluation of different substrates in the production of vegetable seedlings [13] verified that composted filter cake enriched with 4 kg m⁻³ of plain superphosphate produced better plant responses than commercial substrates.

5. Vinasse

Alcohol production generates large quantities of agroindustrial residues, the main one being vinasse, an aqueous effluent of the distillation unit in the sugar-alcohol industry [29]. The effluent is troublesome for the sector, not only because large volumes are produced but mainly because it can contribute to pollution.

The quantity of vinasse produced depends on the processing technique employed and also on the wine composition, varying between 10 and 18 liters of vinasse per liter of alcohol produced [48]. It originates from three sugary musts: molasses, mixed must, and juice. Vinasse *in natura* is

a dilute solution and its application to soil is made in high quantities, making use difficult in areas distant from the sites of production. However, vinasse can be concentrated by evaporation, resulting in a product with higher economic viability that can be transported to distant locations.

Organic matter, K, N, Ca, and Mg are the main chemical components of vinasse (Table 3), K being the most important mineral element for the agricultural use of the residue. Therefore, vinasse is a source of nutrients, organic matter, and water and its use can contribute to increased productivity of sugar cane [29], with effects on the chemical [15], physical [20], and biological [49] soil attributes.

However, the amount of vinasse applied in agriculture must follow appropriate guidelines, which vary according to soil characteristics. Specific recommendations must be followed for each region to prevent excessive use and consequent mineral lixiviation, for example, of nitrate and potassium, and contamination of subterranean waters. Also, the high content of organic matter in vinasse can contribute to significant pollution.

6. Vinasse as a Pollutant

The use of vinasse in agriculture is an important conservation practice, but its use has been challenged due to its high polluting potential to both soil and subterranean waters [48].

Characteristics of vinasse that contribute to pollution are high CRO (chemical requirements for oxygen) and BRO (biological requirements for oxygen) values, an acidic pH, the elevated temperatures during production, and the consequent corrosive power [49]. Continuous application of high volumes of vinasse leads to increased soil nitrogen and potassium, the main chemical components of this residue [50, 51]. Vinasse also promotes soil alterations, such as improved aggregation, but this culminates in higher water infiltration, lixiviation of mineral elements, and contamination of subterranean waters.

Studies conducted in Mexico [52] studied the influence of the raw material and anaerobically-aerobically treated vinasse (a treatment conducted in the presence and absence of oxygen to remove dissolved organic matter) on soil chemical properties. The authors concluded that untreated vinasse posed a risk of soil salinization and contamination by zinc and manganese. A report from Colombia [53] compared the physicochemical properties of vinasse residues for sugar cane processing with synthetic substrates. The results indicated that the use of both residues affected water quality and had environmental impacts. The authors suggested that the impacts of vinasse could be reduced by biological treatments, such as aerobic and anaerobic technologies that removed organic matter, nitrates, and dissolved solids.

Analysis of ground water quality in areas of sugar cane production fertigated with *in natura* vinasse in volumes of 300 m³ ha⁻¹ soil [50] concluded that the practice minimizes the polluting potential of the residue but still affected the quality of ground water, irrespective of the soil type.

Another report from Brazil [54] relates studies on the effects of vinasse (300 m³ ha⁻¹) on properties of various soils,

including weakly humic Gley and Cambisol, conducted over 10 years. The authors concluded that the amounts of heavy metals were not changed and there was little risk of soil contamination with these elements.

The effect of *in natura* vinasse applied at 0, 350, and 700 m³ ha⁻¹ on the leaching of mineral elements was studied in three soils [51]. It was shown that cation concentrations in the leachate were less than those in the vinasse, indicating the high cation retention of soils. In a complementary study [55] the physicochemical properties of percolates in soils, which received vinasse applications of 0, 350, and 700 m³ ha⁻¹ for different lengths of time (30 and 60 days), were evaluated and the parameters analyzed (CRO, BRO, EC, TDS, and pH) indicated lack of environmental problems and that the risk of polluting subterranean waters was low.

It is obvious that there is no consensus about the polluting capacity of vinasse. The two main lines of thought indicate, on one side, deleterious effects on ground and surface waters while the other side claims that rational use of the residue does not result in environmental risk. However, it should be emphasized that depending on the amount of vinasse applied it might act as a pollutant or a beneficial soil conditioner. In this context, a review article [48] concludes that a consensus among authors is that the appropriate application of vinasse must consider the soil chemical and physical characteristics, besides aspects like the history of residue application, the intensity of cultivation in the agricultural area, and the proximity of water springs.

7. Effects of Vinasse on the Improvement of Soil Quality

Vinasse is being utilized in irrigation, mainly in sugar cane culture with results indicating improved quality in soil chemical, physical, and biological properties. In Brazil, several studies show the beneficial effects of the use of vinasse on soil chemical and physical properties. Increased concentrations of K, Ca, and Mg, improved soil macroaggregation, and a better development of the radicular system in sugar cane have all been observed following the application of vinasse [15]. The use of vinasse in fertigation increased cation concentrations in the soil, especially potassium [16]. In this context, the effects of application of vinasse to sugar cane in Brazil were evaluated over 10 years [17]. It was concluded that macronutrients were more abundant in the soil profile, but micronutrient availability was reduced.

In a comparative study of different soil types before and after application of vinasse [18], it was observed that the residue increased the pH and potassium concentrations in depths varying according to the type of soil. Another group of investigators [19] also verified increased potassium and organic carbon concentrations when studying the chemical properties of soils treated with vinasse and used for sugar cane production. Therefore, if vinasse is an important source of potassium, its use could reduce the need for inorganic potassium fertilizers.

The effects on soil physicochemical properties after continuous application of vinasse for three years were analyzed

in a study conducted in China [20]. The results showed a decrease in soil density, increased capillary porosity and, again, increased concentrations of potassium. It was concluded that continuous application of the residue promotes conditions able to sustain the growth and productivity of sugar cane. Another report from the same country [21] concluded that vinasse used as a fertilizer increases soil fertility in sugar cane production systems.

The populations of microorganisms, bacteria in general, and actinomycetes, in soil cultured with sugar cane fertilized with different organic residues [22] were larger when soils were treated with vinasse and filter cake compared to other residues, implying an improvement in the biological quality of soil when these residues are used.

The beneficial effects and risks of applying vinasse from wine production to the soil over extended periods have been studied in Spain [23]. The treatment resulted in increased soil electrical conductivity and a small decrease in pH. Another study in the same country on vinasse from sugar beets [24] showed increased concentrations of soil organic matter and nitrogen and an increase in soil cation exchange capacity.

Studies in Greece [25] have described the effects of the addition of vinasse on the physicochemical properties of soils used for wheat production. The results indicated that the application of vinasse resulted in increased, but nontoxic, concentrations of potassium, sodium, and manganese in the soil. As a whole, it is possible to conclude that agricultural use of vinasse leads to improvements in soil quality with consequent benefits for crop productivity.

8. Plant Response to Application of Vinasse

The use of vinasse in fertigation systems has advantages because it can contribute substantial amounts of water and mineral nutrients, support soil quality and crop productivity [56], and finally, but no less importantly, can solve the environmental problem of the disposal of this agro-industrial residue.

In China sugar cane treated with vinasse has increased productivity and sucrose yields [26, 27]. In Brazil [19, 28], long-term application of vinasse (150 m³ ha⁻¹ year⁻¹) in sugar cane production confirmed positive effects on productivity and increased potassium concentration in soil, as already discussed. Other Brazilian studies [29] involving the application of vinasse and management of the straw cover in sugar cane production also indicated gains in productivity and sugar production. Applications of vinasse of 300–400 m³ ha⁻¹ were considered adequate to increase sugar and alcohol production [30]. In Greece, wheat production was increased by vinasse application, confirming the beneficial effects of the residue in agriculture. In Spain [24], yields of beets and maize were compared after treatments with an organic compound based on vinasse or a mineral fertilizer. Crop production was similar in both treatments indicating that the utilization of vinasse is a viable alternative for mineral fertilizers. Therefore, conservation practices, like the employment of residues in agriculture can contribute to increased agricultural productivity whilst minimizing environmental pollution.

9. Concluding Remarks

Filter cake and vinasse, which are produced in large quantities by sugar-alcohol agroindustries in various countries, have great potential for agricultural use. Filter cake has been utilized with good results, as a substitute for phosphate mineral fertilizers in field crop production, in composting and vermicomposting processes, and as a substrate for the production of seedlings. The use of vinasse in fertigation is increasing in several agricultural areas, substituting for potassium mineral fertilizers and furnishing water, organic matter, and other mineral nutrients in smaller quantities. The use of both filter cake and vinasse should be optimized for each agricultural system and follow recommendations of responsible organisations to prevent environmental damage.

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