Miguel Angelo Mutton; Raffaella Rossetto; Márcia Justino Rossini Mutton. "AGRICULTURAL USE OF STILLAGE", p.423-440. In Luis Augusto Barbosa Cortez (Coord.). **Sugarcane bioethanol — R&D for Productivity and Sustainability**, São Paulo: Editora Edgard Blücher, 2014.
http://dx.doi.org/10.5151/BlucherOA-Sugarcane-SUGARCANEBIOETHANOL_40

10

AGRICULTURAL USE OF STILLAGE

Miguel Angelo Mutton, Raffaella Rossetto and *Márcia Justino Rossini Mutton*

INTRODUCTION

Stillage is a liquid residue from the distillation of wine, resulting from alcoholic fermentation of cane juice, molasses, or a mix of both, to obtain alcohol. It has a high biochemical oxygen demand (BOD), and includes several soil borne chemical elements absorbed by sugarcane. Among them, stillage is rich in potassium and sulfur, containing sizeable amounts of phosphorus, nitrogen, calcium, magnesium, and micronutrients. Each liter of alcohol generates about 10 to 15 liters of stillage.

Due to its high polluting power, its disposal was a problem for industries. Concern about its environmental impact is ancient. There are reports of high fish mortality when stillage was directly dumped in rivers, in the 1950s. Due to its organic nature, and the absence of contaminants, metals, or other undesirable compounds, it lead to the idea of using it on soil, however its pH being extremely acid, some care had to be taken. The first studies on applying stillage on soil were carried out by Professor Jaime Rocha de Almeida's team in the 1950s, at Esalq/USP, in Piracicaba, São Paulo. However, the concern regarding environmental impacts and continuous high fish mortality resulting from stillage disposal in rivers led to Decree-Law n. 303, of February 28th, 1967, which definitively ban on the discharge of such residue to rivers, lakes and water courses.

After this Decree was passed, the first solution found was to apply stillage on the so-called *sacrifice areas*, adjacent to distilleries, which suffered from receiving large quantities of this residue for several years in a row. These areas were rendered useless for agriculture, mostly due to the high salinity of the soil, turning it barren and difficult to remedy.

As Proalcool came up, with the consequent expansion of the sugar-alcohol industry in Brazil, there was a significant increase in the production of alcohol, and consequently of stillage, which in the 2008/2009 harvest season reached about 350 billion liters of stillage. Figure 1 shows the evolution of alcohol production and stillage generation over the years.

Currently applying stillage on sugarcane plantations, like fertiirrigation, is a widespread practice among Brazilian mills and distilleries. However, the technology for the agricultural use of stillage as a fertilizer in growing sugarcane was wholly developed in Brazil, as no other country generates such a huge volume of this kind of residue.

Generally stillage promotes improvements in the agricultural yield of sugarcane, as well as chemical, biological, and physical benefits to the soil, in addition to savings in fertilizer costs.

On the other hand, if overused, it can cause serious changes to the quality of the industrial raw material, such as lower technical quality of the juice.

Though significant technical breakthroughs have been documented advocating the use of this residue, several issues are still being discussed, particularly those related to the environment, as well as other potential uses.

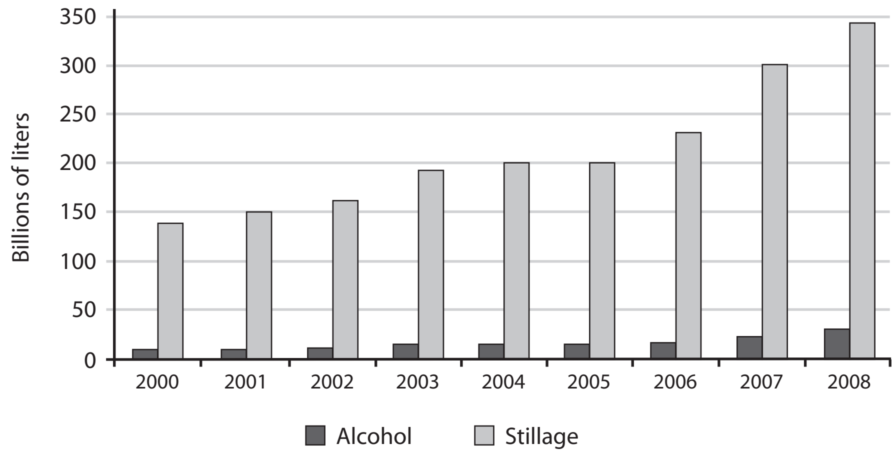

FIGURE 1 Evolution of ethanol and stillage production over the years.

COMPOSITION OF STILLAGE

Stillage composition varies considerably with several factors, among them the type of mash used in fermentation. When sugarcane juice mash is used, the resulting stillage is always less concentrated than the one resulting from molasses or mixed mash (Table 1). Furthermore, the stillage concentration varies from one mill to another, and in one same mill there are variations over the harvest period, resulting from milling different varieties, maturation, soils, yields, among other parameters. Table 2 shows maximum, average, and minimum data for the physicochemical characterization of stillage, as determined by ELIA NETO and NAKAHODO (1995), in São Paulo state production units.

Stillage is an effluent rich in organic matter (mostly as organic acids) and, in lesser quantities, in minerals, featuring high potassium content and significant levels of calcium, magnesium, and sulfur. Being a suspension of mineral and organic solids, stillage has high chemical oxygen demand (COD) and biochemical oxygen demand (BOD), from which its high polluting potential stems from, in addition to low pH and high corrosivety.

The occurrence of heavy metals in stillage results from the sugarcane's own composition, as these are essential nutrients for the plant; they may come from corrosion or abrasive wear of metallic equipments; or entry may also take place via inputs such as lime and sulfur. Table 3 shows the results obtained by BARBOSA (2007), regarding heavy metals content in stillage from Companhia Energética Santa Elisa (Sertãozinho, São Paulo). Reference levels used were taken from the Environmental Protection Agency – EPA (USA), whose regulations dated 1982 (CARVALHO, 2001). Considering the normal yearly intake of the residue, it can be ascertained that all elements are within acceptable limits, hence in quantities supposedly not sufficient to reach hazard levels.

EFFECTS OF STILLAGE IN THE PLANT AND ON THE SOIL

According to MAGRO (2007), until the early 1970s, some production units did the distribution by gravity, on grooves, sometimes flooding the areas.

High doses, around 500 to 2,000 m^3/ha^{-1}, were initially prescribed. GLÓRIA (1975) and GLÓRIA and MAGRO (1976) in innovative papers developed at Usina da Pedra, São Paulo, studied closely stillage composition over two harvests. They discussed more rational ways for its use, considering its chemical composition, and application as a fertilizer, in addition to soil and cultivation conditions.

TABLE 1 Chemical composition of stillage from molasses mash, mixed mash, and juice mash, according to different authors.

Element	Molasses mash			Mixed mash			Juice mash		
	Concentrations			Concentrations			Concentrations		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
N (kg/m^3)	0.57	0.77	1.18	0.33	0.46	0.70	0.25	0.28	0.35
P_2O_5 (kg/m^3)	0.10	0.19	0.34	0.09	0.24	0.61	0.09	0.20	0.49
K_2O (kg/m^3)	5.08	6.00	7.87	2.18	3.06	4.59	1.15	1.47	1.94
CaO(kg/m^3)	1.85	2.45	3.64	0.57	1.18	1.72	0.13	0.46	0.76
MgO(kg/m^3)	0.98	1.04	1.40	0.33	0.53	0.66	0.21	0.29	0.41
SO_4 (kg/m^3)	1.05	3.73	6.40	1.60	2.67	3.74	0.61	1.32	2.03
Mat. org. (kg/m^3)	37.30	52.04	63.94	19.10	32.63	45.10	15.30	23.44	34.70
Fe (ppm)	52	80	120	47	78	130	45	69	110
Cu (ppm)	3	5	9	2	21	57	1	7	18
Zn (ppm)	3	3	4	3	19	50	2	2	3
Mn (ppm)	6	8	11	5	6	6	5	7	10
pH	4.2	4.4	4.9	3.6	4.1	4.6	3.5	3.7	4.3

Source: GLÓRIA and ORLANDO FILHO (1983).

These studies were conclusive by using low volume stillage of up to 35 m^3/ha, totaling 300 kg K_2O/ha^{-1}, revolutionizing the prevailing thought, and prescribing up to 1,000 m^3/ha^{-1}.

In those places deemed sacrifice areas, receiving large quantities of stillage, as much as 10,000 m^3/ha^{-1} or more, there was a heavy salts concentration, easily noticeable by the sugarcane having low resistance to hydric deficits, when planting it in these areas was attempted. FERREIRA (1980) evaluated incremental stillage doses (0, 200, 400, 800, 1200, and 1,600 m^3/ha^{-1}) applied to samples of three soils: Alluvial (51% clay), red-yellow Podsol (38% clay), and hydromorphic (5.5% clay). Using electric conductivity tests, the author ascertained that the hydromorphic soil reached 4.0 mmhos. cm^{-1}, above which the soil is considered saline with doses between 400 and 800 m^3/ha^{-1} of stillage; Podsol required 1,200 m^3/ha^{-1} to reach the saline level, and alluvial – due to its higher clay content – failed to reach that level with any of the doses. For the average stillage doses normally used by mills, around 150 m^3/ha^{-1} with 2 to 3 kg K_2O/m^{-3} content, such saline effect was not observed.

Being a strongly acid liquid residue, it was believed that, when applied to soil, its effect would be to raise acidity; however, ALMEIDA *et al.* (1950) demonstrated precisely otherwise. Results obtained revealed that during the 15 days immediately after applying stillage there was indeed an increase in soil acidity, which tapered off gradually, due to the intense bacterial activity resulting from the addition of organic matter present in stillage.

Studies carried out by LEAL *et al.* (1983) confirmed that after stillage was applied, the soil pH indicated acidification as a result of the addition of organic matter to the soil, which, under aerobic conditions promotes oxidation of the organic carbon, which gives electrons to O_2, generating the O^{2-} ion. This ion, either for its strong alkaline character or due to the presence of the H+ ion, consumes the acidity-generating ions. Another

TABLE 2 Physicochemical characteristics of stillage (average of 64 samples from 28 mills in the São Paulo state).

Stillage character	Concentrations			Standard
	Min.	Avg.	Max.	g or ml L^{-1} álcohol
pH	3.50	4.15	4.9	
Temperature (ºC)	65	89.16	110.5	
Biochemical Oxygen Demand – BOD_5 (mg L^{-1})	6,680	16,949.76	75,330	175.13 g
Chemical Oxygen Demand – COD (mg L^{-1})	9,200	28,450	97,400	297.6 g
Total solids – TS (mg L^{-1})	10,780	25,154.61	38,680	268.9 g
Total suspended solids – TSS (mg L^{-1})	260	3,966.84	9,500	45.71 g
Fixed suspended solids – FSS (mg L^{-1})	40	294.38	1,500	2.69 g
Volatile suspended solids – VSS (mg L^{-1})	40	3,632.16	9,070	43.02 g
Total dissolved solids – TDS (mg L^{-1})	1509	18,420.06	33,680	223.19 g
Volatile dissolved solids – VDS (mg L^{-1})	588	6,579.58	15,000	77.98 g
Fixed dissolved solids – FDS (mg L^{-1})	921	11,872.36	24,020	145.21 g
Sedimentable residues – SR – 1 hora (mg L^{-1})	0.2	2.29	20	24.81 ml
Calcium (mg L^{-1} CaO)	71	515.25	1,096	5.38 g
Chloride (mg L^{-1} Cl)	480	1,218.91	2,300	12.91 g
Copper (mg L^{-1} CuO)	0.5	1.2	3	0.01 g
Iron (mg L^{-1} Fe_2O_3)	2	25.17	200	0.27 g
Total phosphorus (mg L^{-1} P_2O_5)	18	60.41	188	0.65 g
Magnesium (mg L^{-1} MgO)	97	225.64	456	2.39 g
Manganese (mg L^{-1} MnO)	1	4.82	12	0.05 g
Nitrogen (mg L^{-1} N)	90	356.63	885	3.84 g
Ammoniacal nitrogen (mg L^{-1} N)	1	10.94	65	0.12 g
Total potassium (mg L^{-1} K_2O)	814	2,034.89	3,852	21.21 g
Sodium (mg L^{-1} Na)	8	51.55	220	0.56 g
Sulfate (mg L^{-1} SO_4)	790	1,537.66	2,800	16.17 g
Sulfite (mg L^{-1} SO_4)	5	35.9	153	0.37 g
Zinc (mg L^{-1} ZnO)	0.7	1.7	4.6	0.02 g
Ethanol-CG (ml L^{-1})	0.1	0.88	119	9.1 ml
Glycerol (ml L^{-1})	2.6	5.89	25	62.1 ml
Yeast (dry base) (ml L^{-1})	114.01	403.56	1,500.15	44.1 g

Source: ELIA NETO and NAKAHODO (1995).

possible reaction is the compounding of Al^{+3} and organic anions present in stillage. With the multiplication of microorganisms and organic matter transformation, mostly the N, with the reduction of nitrate to nitrite, consumption of H^+ ions is observed and, consequently, pH rises. According to RODELLA *et al*. (1983), effects of rising pH in the soil may be temporary, as there is a trend to resume original values after a certain time.

By the colloidal character of the organic matter contained in stillage, its addition to the soil confers to it a larger quantity of negative charges, reducing cation lixiviation, and consequently increasing cationic exchange capacity – CEC

(GLÓRIA, 1983). CEC increases due to the large input of organic matter represented by the addition of stillage.

Application of stillage increases K content of the soil by successive applications (ROSSETTO *et al.*, 2008). PENATTI (1999a) evaluated the application of increasing doses of stillage (0, 100, 200, and 300 $m^3.ha^{-1}$) on clayous soil (red latosol) during 4 harvests with dose reapplications on the same place, and ascertained that potassium content in the soil increased as a result of applying the stillage doses, mainly in the most superficial layers at 0-250 mm and 250-500 mm depth. K content increased up to 0.10 m depth with the largest stillage studied doses (200 and 300 $m^3.ha^{-1}$).

As a result, the economic benefits derived from complete or partial replacement of chemical fertilization became evident. Organic matter content in stillage also contributed in improving the physicochemical characteristics of soils, increasing its fertility and the productivity threshold in many sugarcane cultivated soils.

Several authors studied the effect of stillage on soils and, over time, concluded that: stillage increases pH in soils (MATIAZZO, 1985); increases CEC; supplies and increases availability of some nutrients; improves soil structure; increases water retention; enhances biologic activity, promoting a large number of small animals (earthworms, beetles etc.), bacteria, and fungi.

Stillage, when applied in proper doses for sugarcane nutrition, using the potassium fertilization recommendation, does not cause any salinization or ion lixiviation problems that may compromise the environment. Soil enrichment occurs in the 0-200 mm (soil surface) and 200-400 mm (soil sub-surface) layers. Occasional negative effects caused to soils or plants resulted from overdoses, according to FERREIRA and MONTEIRO (1987); LEME *et al.* (1987), CAMARGO *et al.* (1983), and GLÓRIA and ORLANDO FILHO (1983).

It should be pointed out that stillage used in fertiirrigation promotes considerable gains in sugarcane productivity, saving money, as most of the potassium-bearing fertilizers are imported. Furthermore, using this residue in agriculture represents a significant contribution for recycling nutrients, with a consequent environmental gain.

Stillage, in addition to improving the soil chemical properties, also improves the soil's physical conditions, as it brings in organic matter. Therefore it contributes to a better soil aggregation, improved water holding, as well as soil conservation. From this standpoint, it offers more environmental gains than losses. Nevertheless, care should be taken so that overdoses on very sandy soils, with waterbeds close to the surface, don not incur in environmental pollution risks, considering especially nitrates and chlorides that may be carried with potassium which, after lixiviation, may reach the water bed. In the state of São Paulo, Cetesb directive (P. 4231/2005), that regulates the use of stillage and sets maximum doses to be applied, represents a significant step towards its safe use within environmental standards; however, it should be constantly reevaluated and improved.

It is important to remember the organic character of this residue, for example, organic agriculture agencies certify that stillage is a wholly accepted in organic and green-seal sugar (ROSSETTO, 2008).

TABLE 3 Quantities of heavy metals found in stillage, application rates used, and a conformity sign relative to annual limits recommended by Usepa – U. S. Environmental Protection Agency.

Element	Annual limit (USEPA $kg.ha^{-1}.year^{-1}$	Stillage 200 $m^3.ha^{-1}$		
		Content $mg.dm^{-3}$	Dose $kg.ha^{-1}$	Signal
Arsenic	2.000	0.001	0.000	Yes
Cadmium	1.900	0.010	0.002	Yes
Chromium	150.000	0.010	0.002	Yes
Copper	75.000	0.530	0.106	Yes
Lead	15.000	0.010	0.002	Yes
Mercury	0.850	0.003	0.001	Yes
Molybdenum	0.900	n/a	n/a	–
Nickel	21.000	0.212	0.042	Yes
Selenium	5.000	n/a	n/a	–
Zinc	140.000	0.050	0.010	Yes

n/a = not ascertained.

The positive effect of stillage in sugarcane productivity has been reported by many researchers in practically all varieties, in most different soil and climate conditions, and it is visible in business areas (PENATTI, 2000). Stillage has raised the productivity threshold in many soils, either by the addition of organic matter or by the nutrients it bears. According to PENATTI (2007), continuous use of stillage has increased productivity in cultivation, and in comparison with areas using mineral fertilization, as much as 10 tons of stalks per hectare in each harvest. Positive effects on the sugarcane fields should also be considered. In some dryer regions, the water contained in this residue promotes ratoon sprouting, and thus may be considered as rescuing fertirrigation.

Stillage is obviously not a complete fertilizer, providing all sugarcane needs, so many researchers studied how, when, and with what type of stillage should be supplemented. For example, ratoons need stillage supplemented with nitrogen.

In spite of its high agricultural value, reflected in the increased sugarcane productivity, the negative effect of high stillage doses on the raw material for producing sugar was evidenced. SILVA *et al*. (1976) researched 16 sugarcane varieties planted with and without stillage irrigation, using a dose of 100 m^3/ha^{-1}, about 590 kg/ha^{-1} of K_2O. Their findings showed that the addition of stillage to the soil, especially with high potassium content, delayed maturation, lowered sucrose and fiber content, and promoted ash accumulation in the juice, impairing raw material quality. It should be observed that potassium in excess is absorbed by the plant (luxury absorption), settling mainly in the core and the leaves, interfering with the industrial juice cleansing process, especially when sugar production is intended.

REGULATIONS ON STILLAGE DISPOSAL

For a long time agriculture has been using the most varied kinds of residue from human activities and, due to its intensive use and the quantities employed, like in the case of stillage, environmental safety concerns have been increasing (ABREU JR. *et al*., 2005). In Brazil, there are no specific laws on using agro-industrial residue in agriculture; however, compliance is required to several laws and decrees, such as:

- Decree n. 24643, of 07/10/1934, Code of Waters, protecting all water bodies from pollutant discharge.
- Law n. 4771, of 09/15/1965, Forestal (Forestry) Code, that sets the minimum tree coverage and strip width for riparian forests.
- Decree-Law n. 1413, of 08/14/1975, rules on control of the environmental pollution caused by industrial activities.
- Decree n. 8468, of 09/8/1976, approved the regulation of Law n. 997, of 5/31/1976, which established the pollution control in waters, air, residue, standards, requirements, licensing, penalties.
- Law n. 997, of 5/31/1976, ruling on environmental pollution control.
- Ministry of Internal Affairs Directive n. 323, of 11/29/1978, forbidding direct or indirect release of stillage to surface water springs, and demands submission of projects for treating and/or using stillage.
- Ministry of Internal Affairs Directive n. 124, of 8/20/1980, established standards relative to water pollution prevention, industry locations, potentially polluting buildings or structures, and protection devices.
- Ministry of Internal Affairs Directive n. 158, of 11/3/1980, extending the previous directive to encompass residual waters and other distillery liquid effluents.
- Conama Resolution n. 0002, of 06/5/1984, determining the execution of studies and projects to control pollution from effluents of alcohol distilleries.
- Conama Resolution n. 0001, of 01/23/1986, which made Environmental Impact Assessment, and Environmental Impact Report mandatory for any new units or expansion of the existing ones.
- Law n. 6134, of 06/2/1988, determining that "liquid, solid, or gaseous residue from agricultural, industrial, commercial or any

other activities may only be conveyed or disposed of in a way that will not pollute underground waters".

- Law n. 6171, of 07/4/1988, ruling on the use, conservation, and preservation of agricultural soil.
- Law n. 7641/91 allowed the irrigation or fertiirrigation of the soil using organic origin industrial effluents, as long as it is evidenced that its chemical characteristics confer high biodegradability to the soil, not having the presence of metallic organic compounds.
- Decree n. 32955, of 06/7/1991, regulated Law n. 6134, of 06/2/1988, ruling on the preservation of natural underground water beds.
- Decree n. 41719, of 04/16/1997, regulating Law n. 6171, of 07/4/1988, ruling on the use, conservation, and preservation of agricultural soil.
- Law n. 9605, of 02/12/1998, determining administrative and penal sanctions for actions and activities that are harmful to the environment.
- Cetesb Decision n. 023/00/C/E, of 06/15/2000, approving the procedure for action in contaminated areas, based on the document titled "Procedure for Contaminated Areas Management".
- Resolution CNRH n. 15, of 06/1/2001, setting guidelines for integrated management of surface, underground, and rain waters.
- Cetesb Management Decision n. 014/01/E, of 07/26/2001, approving the Report on Reference Values for Soils and Underground Waters in the São Paulo state, and the implementation of reference values by Cetesb.
- Resolution Conama n. 357, of 03/17/2005, establishing, among other guidelines, conditions and patterns for effluents disposal.
- In 2005, Cetesb, by means of Technical Norm P4.231, imposed further control on the use of stillage on agricultural soil in the São Paulo state.

STILLAGE DOSE TO BE APPLIED

The dose to be used considers a sufficient supply of potassium for the ratoon cycle. As sugarcane takes in luxury amounts of potassium, it is possible that, in many areas, stillage will add surplus potassium.

Stillage is prescribed in accordance to soil analysis for K and its contents in stillage, just as if it were a chemical fertilizer. For the São Paulo state, Cetesb directive P.4231/2005 determines that the dose of stillage to be applied to soils be calculated according to the equation:

$$\text{m}^3 \text{ of stillage.ha}^{-1} = [(0.05 \text{ x CEC} - \text{ks}) \text{ x } 3744 + 185] / \text{kvi}$$

Where:

0.05 = 5% of CEC

CEC = cationic exchange capacity, expressed in $\text{cmol}_c\text{.dm}^3$ at pH 7.0, given by the soil fertility analysis, carried out by a soil analysis laboratory using the methodology from the Soil Analysis department of the Campinas Institute of Agronomy, duly signed by a technical expert.

ks = concentration of potassium in the soil, expressed in $\text{cmol}_c\text{.dm}^3$, at 0,80 meters deep, given by the soil fertility analysis of the Campinas Institute of Agronomy, duly signed by a technical expert.

3744 = constant to convert the fertility analysis results expressed in $\text{cmol}_c\text{.dm}^3$ or meq.100cm^3 into kg of potassium in a volume of one hectare at 0.80 meters depth.

185 = kg of K_2O extracted by the culture per ha, per harvest.

kvi = potassium concentration in the stillage, expressed in kg of $K_2O.m^3$, as shown on an analytic test report, signed by a technical expert.

Despite the formula, it should be considered that scientific research will indicate the need for adjusting the calculation of the maximum dose to be recommended as restrictive for some soils, mostly those in the Western region of the São Paulo state, the main expansion area of the agribusiness. Some situations may become overly permissive, surpassing by far the doses deemed ideal for adequate plantation nutrition and fertilization.

Stillage provides a remarkable contribution in replacing potassium fertilizer. Considering that currently mineral fertilization in sugarcane is about 120 kg of K_2O.ha^{-1}, and that approximately 40% of the cultivated area receives stillage as potassium fertilization, more than 500,000 tons of potassium chloride (KCl) are saved. This procedure represents a sizeable contribution to recycling and using potassium.

STILLAGE HANDLING FOR OPTIMIZED PRODUCTION

Despite being a nutrient-rich organic material, stillage is not a complete or balanced fertilizer. For this reason, several studies focused on the need of supplementing it with other important nutrients for sugarcane productivity, mostly nitrogen. PENATTI *et al*. (1988), upon evaluating the application of stillage in the doses of 0, 50, 100, and 150 m^3.ha^{-1} and nitrogen in the doses of 0, 50, 100, and 150 kg.ha^{-1} on sandy soil (red-yellow latosol) and clayous soil (red latosol), ascertained that stillage caused productivity increases up to the dose of 150 m^3.ha^{-1} for both soils, response having been higher in the sandy soil. Response for nitrogenated supplement occurred for doses up to 100 m^3.ha^{-1} of stillage. As sugarcane response was linear up to the dose of 150 m^3.ha^{-1}, PENATTI and FORTI (1997) assessed the effects of applying higher stillage doses: 0, 100, 200, and 300 m^3.ha^{-1} of stillage and/or 0, 50, 100, and 150 kg.ha^{-1} of nitrogen on ratoons harvested with and without burning straw. Average potassium (K_2O) content in stillage was 2.4 kg m^3. There was significant response for stillage and/or nitrogen. With reapplication of stillage in later ratoons, PENATTI (1999b) ascertained that in red-yellow, sandy, and low-fertility latosol, application of stillage promoted an increase in sugarcane productivity (t.ha^{-1}) up to the 300 m^3.ha^{-1} dose, if compared to mineral fertilization. There was further increase in productivity when stillage was supplemented with nitrogen. The average results of three harvests from the four experiments also indicate a productivity increase up to 300 m^3.ha^{-1} of stillage. Nitrogen supplementation promoted a productivity increase up to the 200 m^3.ha^{-1} dose of stillage. The need for supplementing stillage with N and P was also studied by MAGRO and GLÓRIA (1977).

Nitrogen supplementation of stillage is still an issue to be studied further. Many mills do not do it in the belief that the response in productivity from nitrogen supplementing is not rewarding. Nitrogen complementation effects also have to be studied further regarding environmental concerns, as nitrates and other anions may be lost in the profile and reach the water bed.

CONCENTRATED AND BIODIGESTED STILLAGE

In addition to natural stillage as a fertilizer, several other options were predicted, such as those suggested by CAMHI (1979): (a) stillage concentration by evaporation, or (b) drying for animal feeding; (c) aerobic fermentation by microorganisms to produce unicellular protein; (d) anaerobic fermentation using methanogenic bacteria to produce methane (biogas). Furthermore, stillage may also be used to produce the so-called stillage soil to make bricks (ROLIM, 1996). It may also be used for burning to recover potassium salts and produce energy (FREIRE, 2000).

Recovery of the organic compounds present in stillage may be done by the concentration process, through multiple effect evaporators, to obtain by-products that may be used as fertilizers (40% ds), animal feed (60% ds) or 60% ds for boiler fuel. In this case, the product has concentration levels that may vary from 35° to 60° Brix.

The first works related to concentration date back to 1950. Among the evaporators used, the falling film type was the most frequently prescribed for liquids having a high content of incrusting salts, to save electric power. They can withstand stillage up to 25° Brix, requiring hydrocyclones for sludge removal and more frequent cleaning.

According to ALBERS (2007), in 1978 Usina Santa Elisa bought a stillage concentrator with Vogelbusch technology, which is still in operation, and that was designed to partially concentrate the stillage produced, to make feasible transporting it to more remote locations. Due to its high energy cost, it started operating regularly after the implementation of an electricity co-generation system; in 2005/2006 it produced about 3.3 $m^3.h^{-1}$ of concentrated stillage. To apply the concentrated stillage, a tanker truck was developed with a pressure pump and an arm large enough for application to 7 sugarcane rows. It applied concentrated stillage in the 2005/2006 harvest over approximately 5,000 ha (BARBOSA, 2006).

According to ALBERS (2007), another technology available for concentrating stillage (Vogelbusch in partnership with Dedini S.A. Indústria de Base) is stillage concentration energy-wise integrated with the distillery. In this case, the alcohol vapor from the top of the rectification column will condense in the body of the first effect of stillage evaporation, and return to the normal distillation process to ensure the qualities of the hydrated ethanol produced.

Using this solution, will avoid an additional vapor consumption to concentrate about 55% of the stillage produced. As a large quantity of water is removed from stillage, when the evaporation is performed, the condensed liquid may be reused in other mill processes, such as return to fermentation to dilute the honey, to drench the mill, among others, reducing water intake from rivers and contributing to recycle water in the system.

Stillage water may also be recovered for industrial re-use. Recent technologies strive to transform up to 80% of the liquid part of stillage in distilled water, reducing water treatment costs, and promoting its reuse. At the same time, it would make it possible to produce pelletized or granulated potassium fertilizer (JORNAL CANA, 2004).

In the next few years it is expected to attain higher efficiency in the ethanol production process from the development of new technologies and/or equipment. It is worth noting the search for osmophlic yeasts, able to consume substrates with higher sugar content, producing wines with higher alcoholic grade, leading to lower stillage production per liter of alcohol, and thus reducing the impact from generating this residue. In order to have a proper fermentation process, temperature control has to be improved in a lower range than usual, to minimize the toxic effect alcohol has on yeasts. Care should also be taken to get more stability in honey/juice proportions in composing mash for fermentation, resulting from stable milling, stable juice quality, i.e. a better raw materials in the process.

Another important point to be considered, according to ALBERS (2007), is to indirectly heat the exhaust column, which receives the wine from fermentation, in addition to exhausting the phlegmass. In indirect heating, the steam used to heat the column is generated by its own base, with the heat from the external steam source, not incorporating this condensed steam to the stillage. In this sense, the falling film (Vogelbusch) system, which accepts smaller temperature gaps, is a more recent option, using the exhaust steam and vegetal steam, recovering condensed liquid to route it back to the boiler. Using such procedure, stillage volume is reduced to 2 to 4 liters per liter of ethanol. Likewise, to reduce the quantity of stillage, it is common to separate phlegmass; this is done when there is a column to exhaust it, in order to prevent the loss of ethanol at the rectification column base. Using this additional column, the partially exhausted phlegm is not returned to the wine exhausting column. There are different uses for the phlegmass removed from this column, as it is basically composed of clean hot water, which can be used to wash fermenters (or fermentation tanks) and heat exchangers. Using such technology, stillage volume is reduced to 2 to 2.5 liters per liter of ethanol.

There are other processes for concentrating stillage, like the one used by the Indian company Praj, which adopts the fluidized bed drying process. The high energetic cost in electricity to concentrate stillage, regardless of the process, is still its major objection.

According to BARBOSA *et al.* (2006), currently, due to the high cost of transportation, areas located close to industrial plants receive high stillage application doses, which represents fertilizer waste, in addition to the risk of contaminating soil and waters. In this scenario, concentrated stillage, due to its reduced volume, becomes a way to make viable its transportation and use in places farther away from industries. A test carried out using combinations of three doses of ammonium nitrate (0, 45, and 90 $kg.ha^{-1}$ of nitrogen), with three doses of potassium chloride (0, 90, 180, $kg.ha^{-1}$ of K_2O), and three doses of concentrated stillage (0, 180, and 270 $kg.ha^{-1}$ of K_2O), whose composition is shown on Table 4, indicated that the use of this product resulted in increased sugarcane and sugar productivity per harvested area unit. Authors ascertained that it is possible to replace, with gain, the use of mineral fertilizers with equivalent doses of NK, or with nitrogen supplementation. Analyzing chemical alterations in an incubated soil with doses of 300 and 750 $kg.ha^{-1}$ of K_2O, using natural, concentrated and dry stillage, CAMARGO *et al*. (1984) observed a rise in pH after 60 days, soil electric conductivity having failed to reach levels hazardous to plants.

Stillage biodigestion is a process that achieves BDO load reduction to a level between 70% and 90%, producing around 0.3 to 0.5 $m^3.kg^{-1}$ of methane gas, using anaerobic reactors, while according to FREIRE and CORTEZ (2000), it is still a little studied and utilized alternative. The resulting stillage, duly normalized, presents the desired physicochemical balance (Table 5), so it can be distributed to agriculture.

This process allows a more efficient use of mineral elements of the soil, by adding or supplementing nutrients such as: nitrogen, phosphorus, and potassium, calcium, and magnesium; on top of contributing to the correction of soil acidity. PERES (2007) pointed out that biodigested stillage is a good fertilizer for sugarcane culture, still including a portion of organic matter, in addition to preserving potassium content. Treated stillage provides better environmental quality by reducing organic matter, thus eliminating its peculiar odor, in addition to avoiding insect population that occur in such environment.

It should be pointed out that new environmental and energetic issues will arise from mills/distilleries that will process sugarcane juice fermentation with hydrolyzed cellulose (bagasse, trash). Likewise, it should also be considered that stillage produced in this process will have different characteristics, observing the possible differentiation aspects. In this case, plants that will adopt bagasse hydrolysis will need additional energy input, which may be obtained from biogas, as part of the bagasse will be routed to ethanol production.

TABLE 4 Composition of natural stillage and concentrated stillage produced by Cia. Energética Santa Elisa.

Components	Natural stillage	Concentrated stillage
	$kg.m^{-3}$	
Soluble solids	45.00	416.00
Total N	0.64	5.85
P_2O_5	0.37	3.47
K_2O	4.50	40.75
CaO	0.72	6.69
MgO	0.24	2.21
SO_4	0.25	2.43

Source: BARBOSA *et al.* (2006).

TECHNOLOGY FOR STILLAGE APPLICATION

According to MAGRO (2007), until the early 1970s, some mills distributed stillage by gravity on grooves, which could be considered as irrigation by flood, or by infiltration grooves. One main line carried stillage to distribution channels, and from these it went to the planting grooves either by flooding or using PVC pipes with outlets to

TABLE 5 Physicochemical characteristics of natural and biodigested stillage.

Components	Natural stillage	Biodigested stillage
pH	4.0	6.9
COD (g/L)	29	9
Total N (mg/L)	550	600
N ammoniacal N (mg/L)	40	220
Total P (mg/L)	17	32
Sulfate (mg/L)	450	32
Potassium (mg/L)	1,400	1,400

each groove. This required a slope between 0.2% and 0.5%. Grooves were dug on the sugarcane interlines (ROSSETTO, 1987). This system was very difficult and inefficient, as stillage application resulted very irregular.

In the early 1970s, pioneer research carried out at Usina da Pedra (Serrana, São Paulo), under the coordination of Prof. Dr. Nadir Almeida da Glória, evaluated stillage composition over 2 harvests and the recommended dose, which was up to 1,000 $m^3.ha^{-1}$. They contributed to the prescription of using low volumes, which made possible the distribution via tanker trucks taking up to 8,000 liters each, being the tanks made of wood and distribution by shower.

Using higher power trucks, tank capacity was increased to 15,000 liters, made of stainless steel, carbon steel, marine carbon steel. Later, tanks were made of fiberglass.

By late 1970s, conventional semi-fixed (low-range) sprinklers began to be replaced with hydraulic cannon systems mounted directly on motor-pump assemblies, drawing water directly from the channels. Next, stillage distribution using this system had some improvements, placing the sprayer cannon on pipe extensions. These systems allowed for better control on the doses applied.

According to MAGRO (2007), since the 1990s tank capacity was increased up to 40,000 liters, for trucks fitted with very high power. Distribution on the field began to be made with take-up reels, a breakthrough for applying stillage. Spraying was carried out by a self-propelled unit with medium-density polyethylene piping, which allowed more automation, better operating efficiency, more efficiency, lower labor demand, and a smaller number of equipment changes and transportation (LEME *et al.*, 1987). It is worth noting that the tanker truck had restrictions, mostly in terms of soil compaction, difficult application in rainy days, and application over large distances, which did not happen with application by spraying with the hydraulic cannon, which became the most widely used system.

Considering that the leading system is still spraying, according to SOUSA (2007), in certain cases trucks have been adapted to the self-propelled system with two tanks and bottom-loading. The advantage of this system is in the transportation to smaller and segmented areas, as well as when it is necessary to go through third-party properties, which cannot be done with channels. The downside of this system is transportation during rainy seasons, as well as the higher operating cost, especially for distances over 35 km from the mill.

Then, pressurized main lines with removable pipes began to be used, to reduce the quantity of channels, or the truck circulation in the area. Some recent proposals consider distribution by spraying from a central pivot, a towable linear pivot, and surface dripping. The first would result in improved irrigation-borne fertilization quality, as compared to self-propelled and directly mounted systems, however it involves higher implementation costs and requires equipment resistant to stillage corrosion. For fertiirrigation, the most adequate option seems to be the towable pivot, though technical and economical feasibility must be assessed. Surface dripping also has a high implementation cost.

There are also two situations that remain, as of today: natural or water-diluted stillage application with other effluents from mills (sugarcane washing water, condensation water, barimetric column water, floor washing water etc., generally known as wastewater).

Stillage, initially stored in decantation ponds or sacrifice areas, began to be stored in buffer tanks, using large storage facilities, up to 4-6 milling days. These tanks became source of undesirable odor. After Cetesb Directive P4231/2005, those tanks became buffers for storing milling hours, no longer days, minimizing odor release, which is highly desirable for the communities close to the milling areas (CARVALHO, 2007).

Among all alternatives introduced for using stillage, the one offering highest economical benefits and efficiency from the agricultural standpoint, and that therefore became widespread and adopted by most mills, was sugarcane plantation fertiirrigation. Though widely used in the industry, the expression fertiirrigation is not proper, since it fails to comprise irrigation in the sense of controlling water beds and the frequency this would be required. In the case of stillage, it refers to applying liquid residue, which also wets the soil (FREIRE, 2000).

Spraying with a winding spool, according to HERNANDEZ (2006), in spite of requiring less initial investment – if compared to other irrigation systems, is the one presenting highest operating costs.

In a survey among 54 mills, 25 of them in the São Paulo state, representing 22.5% of the sugarcane milled in Brazil, NUNES JR. *et al*. (2005) determined that stillage is preferably distributed by channels and applied by spraying with a take-up spool system (Tables 6 and 7).

Share analysis of the various stillage application systems in the São Paulo state, carried out by SOUSA (2007), showed that conventional tanker truck still represent 6%, other spray systems 94%; 10% of still being the directly-mounted cannon; 53% with self-propelled plus groove; and 31% with truck plus self-propelled (spool). According to LUZ (2007), the transportation and distribution system may comprise: tank, channel, pipe network, and truck, employing these methods for application: spraying, direct mount, take-up spool, irrigation rod, towable pivot, in addition to local application by dripping.

According to CARVALHO (2007), there are still other application models using fixed input lines and distribution channels, or a system comprising tanker trucks for transporting and movable input pipe, which may be considered adequate and economically viable, since the cost of the trucks system is approximately 50% higher.

TABLE 6 Distribution of stillage in various Brazilian regions during the 2003/2004 harvest seasons.

Region	Distribution of stillage (%)	
	Channels	Truck
São Paulo	76.6	23.4
Center-South	80.9	19.1
Northeast/East	100	0
Brazil	82.5	17.5

Source: NUNES JR. *et al*. (2005).

The application of concentrated stillage, with 40% solids content, is feasible at distances of 100-120 km, according to research by BARBOSA (2006), at Usina Santa Elisa (Sertãozinho, São Paulo).

Stillage-conducting channels coating is required by Cetesb Directive n. 4231/2005-Cetesb, and it may be done with asphalt lining, or HDPE (high density polyethylene) lining or pipes. Among these, CARVALHO (2007) pointed out channel piping, with 350 mm diameter PVC pipes, and with 1:1000 slope, which provides flow rates of 250 to 270 $m^3.h^{-1}$. In this case, though the initial investment may be somewhat higher than HDPE lining, there are operational and environmental advantages, such as less odor, insect propagation, and weed control, as well as lower risk of wild animals falling into channels, and vandalism in puncturing liners. On the short term, by subscribing to the agro-environmental agreement with the São Paulo state government, 100% of the cultivated sugarcane will be harvested without burning. In this case, the open channel, even if lined, will become a collector of trash, resulting in a clogged system. In this context, attention must be paid to the predefined changes.

Another important issue refers to stillage feed piping automation, regarding both security and operational safety. According to CARVALHO (2007), there are systems monitored by radiofrequency systems, placed at strategic points, such as pumping stations, waterways crossings, and end of lines. These systems provide leak detection, and information and control on stillage line pressure, temperature and flow rate. This automation aspect is important, as it allows full flow control on the network, making it possible to distribute stillage directly from the mill's integrated operation control center.

USE OF STILLAGE AND ENVIRONMENTAL ISSUES

The continuous use of stillage on the same soil, even with small doses, one year after another, may cause cation saturation, mostly potassium in soil CEC, resulting in problems from lixiviation of its components to underground waters.

TABLE 7 Ways of applying stillage in various Brazilian regions during the 2003/2004 harvest season.

	Spray		Truck	
	Direct mount	**Take-up spool**	**On the field**	**With spool**
São Paulo	6.7	69.9	9.9	13.5
Center-South	24.0	56.9	9.2	9.9
Northeast/East	100	0	0	0
Brazil	30.3	52.2	8.4	9.1

Source: NUNES JR. *et al.* (2005).

Potassium lixiviation to the sub-surface is not an environmental issue, as this element is not a water pollutant. Nevertheless, its high concentration favors the formation of chemical compounds which, having neutral charge, are easily lixiviated. The (K)+ and (NO_3)complex formed is a specific concern from the environmental stance, as nitrate is a major water pollutant.

In the São Paulo state, Directive P4.231/2005 (Cetesb) regulated criteria and procedures for applying stillage, implementing standards for its storage, transportation, and disposal on the soil. That norm being effective, many areas will undergo restrictions, as industry is preparing to transport stillage over longer distances, and/or making other uses viable, such as its concentration.

Though there are some signals of ions from stillage in water beds, such as Cl^{-1}, $SO4^{-2}$, water bed contamination from the use of stillage in doses currently employed on fertiirrigation over sugarcane trash may be a remote possibility, limited to certain conditions, such as marginal, sandy, or shallow soils. If it occurs, it is likely that the contamination process will take too long to be detected. However the simple potential of this possibility justifies caution.

For deep clayous soils, there is a thick layer for adsorbing potassium. CUNHA *et al.* (1987) studied lixiviates from a soil where 800 $m^3.ha^{-1}$ of stillage had been applied. Assessments detected no K+ movement below 40 cm depth in the soil. As sugarcane, especially ratoons, has a very deep root system, K intake may occur even if it is lixiviated to deeper layers. ORLANDO FILHO *et al.* (1995) studied NO_3- and NH_4+ in sandy soil, applying mineral nitrogen (60 $kg.ha^{-1}$) and doses of stillage (0, 150, 300, and 600 $m^3.ha^{-1}$). Results from four sampling periods and at three soil depths (up to 2 m) showed that there was no nitrogen lixiviation up to 25 weeks after application.

CRUZ *et al.* (1990) reported results from a long-term study on the influence of stillage applied at a dose of 300 $m^3.ha^{-1}.year^{-1}$ on soil properties (up to 1.5 m deep) and subsurface waters. The experiment assessed periods comprising 0, 5, 10, and up to 15 years, ascertaining an improvement on soil fertility properties over the years. Increments in organic matter and P contents were observed in the superficial layer, while for Ca, Mg, and S it was detected both in superficial and deeper layers. Nitrate was found in sub-surface waters, however in concentration levels below those hazardous to human health.

GLOEDEN *et al.* (1990) evaluated the influence of applying stillage at 150 and 300 m^3/ha doses on low CEC sandy soils, on soil fertility and ion lixiviation to water beds. They ascertained that the water had an increase of ions: chloride, ammonia, organic carbon, and forms of organic nitrogen. K remained seized in the soil and was absorbed by sugarcane, not reaching waterbeds during the study period. However the authors alert to the fact that organic forms of N were actually found, and that these might have generated nitrates, very detrimental to human health.

It is important to keep in mind that stillage is an organic source material, free from metals or other contaminants that could prevent its use in agriculture. From this standpoint, it is perfectly accepted by organic agriculture, and there are no restrictions to its use as a source of nutrients, according to certifying agencies. Stillage will represent an important source of K to be considered in organic agriculture. For producing organic sugar, stillage may provide all N, and all K sugarcane requires (ROSSETTO, 2008).

STILLAGE AND AGRIBUSINESS SUSTAINABILITY

ALTIERI (1989) notes that traditional agriculture simplifies agroecosystems, decomposition is altered, since the plant is harvested, and fertility is preserved, not by recycling but through fertilizers instead, depending on continuous human intervention; and recommends using production methods that restore homeostatic devices, optimize the return rate, and recycle organic matter and nutrients. On the other hand, it is worth observing that the use of fertilizers is important to increase fertility, and, hence, the production of biomass.

According to GOMES *et al*. (2000), the principle of ecosystems' sustainability is in ODUM's (1971) statement: "The longer elements can be maintained within an area, and used by successive generations of microorganisms, the smaller the losses will be, therefore the need to replace these elements from external sources will be lower." The operation of ecosystems is based on circulating nutrients between the different compartments, the cycle of these elements spanning over several generations, made up of phases with live organisms (bio) and lifeless phases (geo). This statement serves as grounds for harvesting trash without burning, and using agribusiness residue in agriculture, from the biogeochemical cycle management standpoint for the sustainability of sugarcane production. Burning causes the release of elements to the atmosphere, either by volatilization or by carrying away non-volatile particles; yet, the ashes laid on the ground, in the absence of trash, will be easily carried away by water and lost from the ecosystem. On the other hand, the return of residues from industrial processing of sugarcane to agriculture is absolutely necessary, to minimize the use of external sources for fertilizers.

According to SIQUEIRA and FRANCO (1988), organic residues are important components of natural ecosystems and agro-ecosystems. They represent a large quantity of reduced carbon, an immense repository of mineral nutrients, important for heterotrophic organisms that live in the soil, as well as mineral nutrients for plants. The biologic activity of soils, which is dominated by decomposing organisms, transforms them into a huge biologic incinerator; a decomposing machine driven by the microorganisms proliferating within itself, and that, through their various activities, control the carbon and essential nourishing elements' flow and cycling.

The growth of sugarcane cultivation, driven by global demand for renewable energy, is causing sustainability concern. Witnin this context, BARBOSA (2007) developed a research showing a systemic view of the sugarcane agro-industrial process, from the biogeochemical cycles stance, with the recycling of residues and effluents. It comprised models of the ways and strategies for using residues and effluents for N, P, K, Ca, Mg, and S, in the various compartments of the production process. The author set and discussed certain indicators (fertilization index, return index, and emission index), that allowed for analyses of nutrients flow in the agro-industrial system. In the scenario analyzed, it was found that the quantities of potassium, calcium, and magnesium in circulation were sufficient for fertilizing the culture with adequate quantities, while nitrogen, phosphorus, and sulfur were insufficient, requiring external supplementation. Therefore, the conclusion was that modern sugarcane agro-industry is conceptually very favorable to sustainability, being the use of residues and effluents, especially stillage, extremely important to reach such condition.

TECHNOLOGICAL BOTTLENECKS AND REQUIREMENTS

Technological bottlenecks are restrictions that limit activities related to new products and processes, as well as improvements to existing products and processes, on top of aspects such as management, information, and logistics; they can be understood as a current, potential, or future inhibitor, preventing a more proper development of the production system. These are critical points that, if overcome, will significantly contribute to the industry development.

Considering the agricultural use of stillage, the following technological bottlenecks stand out:

- Weaknesses in the development and/or adaptation of industrial processes aiming to reduce the volume of stillage.
- Weaknesses in the development of new products related to storage, distribution, and application of stillage produced, or that may be produced such as concentrated or biodigested stillage.
- Gaps in characterization and on the effects of stillage to be produced by new cellulosic materials fermentation processes.
- Gaps in the knowledge and needs of altering/adapting facilities and production processes.
- Gaps resulting from governmental regulation.
- Gaps in environmental management.
- Weaknesses in monitoring stillage handling systems in different soil/climate conditions.
- Gaps in institutional support and in strengthening basic research.
- Gaps in human resources training and development.
- Weaknesses in alternative possibilities for using stillage.
- Gaps in the participative involvement of the production industry, and in research for design, planning, and implementation of public policies.
- Circumstantial gaps.

Requirements are represented by the need for new knowledge, research and technology development, aiming to reduce the impact of the restrictions identified in the generation and use of stillage in the various parts of the sugarcane agro-industrial production system, aiming to improve the quality of its processes and products, production efficiency, competitiveness, and sustainability.

FINAL CONSIDERATIONS

Reports from the 1970s by the present Companhia de Tecnologia de Saneamento Ambiental (Cetesb-SP) pointed out at the sugar-alcohol industry as a major source of environmental pollution, both qualitative and quantitatively, because of its liquid residues, especially stillage, which were poured directly to rivers.

Ever since, the techno-scientific knowledge amassed has been used to guide towards a more rational and economical use of stillage, as well as less aggressive to the environment, seeking sustainability for the sugar-alcohol industry. However it is known that a lot has yet to be researched and developed to attain such objectives more completely.

The agricultural use of stillage produced by the sugarcane industry has undergone several changes over the years. Together with the concern for higher agronomical efficiency and the optimization in using this residue, a worldwide heightened environmental awareness – developed after the 1990s – should be highlighted. This reality behooved the industry to get organized before the new problems arising from the use of large quantities of this residue on soils, capable of causing problems, such as lixiviation of chemical elements, and their consequent conveyance to underground waters and aquifer pollution.

The use of stillage over decades represented productivity gains in the culture, in improving physical and chemical properties of soils, promoted recycling of nutrients and savings in inputs and money for the country, representing environmental gains for the production chain. Under this scope, Cetesb Directive P. 4231/2005 represented some considerable progress by establishing parameters that shall guide technical procedures for handling this residue, aiming to minimize the impact on the environment.

Brazil is the country that holds the technology for using stillage in agriculture, based on techno-scientific knowledge developed over the past 30 years. Nevertheless, basic research and technical, economic, social, and environmental viability studies are still missing to characterize impacts and/or guide other ways of using stillage, such as concentrated stillage, biodigestion, incineration etc. There are many parameters to be considered to understand what takes place in the soil and in the plant when concentrated/biodigested stillage is applied. A similar situation occurs regarding reutilization of water evaporated in the industrial process, reducing external sourcing. There is also a lack of information that validate the production and use of dry or pelletized stillage as animal food and fertilizer.

In this context, it is noticeable that current procedures for handling and monitoring stillage – from technical, economic, social and environmental stances – are partially adequate, requiring more detailed and extended studies, under different edaphic-climatic conditions that are sufficient to determine its distribution and application systems, and its use under even lower risks.

On the other hand, the ethanol production technology development from cellulosic materials, surplus bagasse, or trash remaining from sugarcane harvesting without burning, or even from whole sugarcane (stalks and leaves), will produce stillage that may have physicochemical characteristics different from the current one. This should determine additional research to ascertain the possible impacts caused on the soil, culture, and environment. Consequently, distilleries adopting this process will need additional energy inputs, which may be obtained from biogas and/or burning residue, as part of the bagasse will be led to ethanol production.

REFERENCES

ABREU JÚNIOR, C. H.; BOARETTO, A. E.; MURAOKA, T.; KIEHL, J. C. Uso agrícola de resíduos orgânicos potencialmente poluentes: propriedades químicas do solo e produção vegetal. **Tópicos Especiais em Ciências do Solo**, Viçosa, v. 4, p. 391-470, 2005.

ALBERS, M. Tratamento da Vinhaça: Concentração e outros. In: Workshop Tecnológico sobre Vinhaça. Projeto de Políticas Públicas Fapesp. Realizado em 10 out. 2007, na FCAV/Unesp – Campus de Jaboticabal. Jaboticabal. Disponível em: <http://www.apta.sp.gov.br/cana/workshops.php>.

ALMEIDA, J. R.; RANZANI, G.; VALSECHI, O. La vinasse dans 1' Agriculture. In: VIII Congresso Internacional das Indústrias agrícolas, Proceedings. Bruxelas, p. 13-21, 1950.

ALTIERI, M. A. **Agroecologia:** as bases científicas para a agricultura alternativa. Rio de Janeiro: Projeto e Tecnologias/Fase, 1989. 240 p.

BARBOSA, V. **Ciclos biogeoquímicos como subsídio para a sustentabilidade do sistema agroindustrial da cana-de-açúcar.** 2007. 117 f. Dissertação (Mestrado em Agronomia) – Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista, Jaboticabal, 2007.

BARBOSA, V. Novas tecnologias no uso da vinhaça e aspectos legais. In: MARQUES, M. O. *et al*. (Ed.) **Tópicos em tecnologia sucroalcooleira**. Jaboticabal, Unesp, p. 141-150, 2006.

BARBOSA, V.; DURIGAN, A. M. P. R.; GLÓRIA, N. A. da; MUTTON, M. A. Uso da vinhaça concentrada na adubação de soqueira de cana-de-açúcar. **Stab: Açúcar, álcool e subprodutos**, Piracicaba, v. 24, n. 6, p. 26-29, 2006.

CAMARGO, O. A. de.; VALADARES, J. M. A. S. da; BERTON, R. S.; SOBRINHO T. J. Aplicação de vinhaça no solo e efeito no teor de nitrogênio, fósforo e enxofre inorgânicos e no de alguns metais pesados. **Boletim Técnico IAC**. Instituto de Agronomia de Campinas, Campinas, SP, (8), 15 p, 1987.

CAMARGO, O. A. de; VALADARES, J. M. A. S. da; GERALDI, R. N. Características químicas e físicas de solo que recebeu vinhaça por longo tempo. **Boletim Técnico IAC.** Instituto de Agronomia de Campinas, Campinas, SP, (76), 1983, 30 p.

CAMARGO, O. A. de; BERTON, R. S.; GERALDI, R. N.; VALADARES, J. M. A. S. Alterações de características químicas de um latossolo roxo distrófico incubado com resíduos da indústria álcool-açucareira. **Bragantia**, v. 43, n. 1, p. 125-139, 1984.

CAMHI, J. D. Tratamento do vinhoto, subproduto da destilação de álcool. **Brasil Açucareiro**, v. 94, n. 1, p. 18-23, 1979.

CARVALHO, A. J. L. de. Métodos de utilização e aplicação de vinhaça. In: Workshop Tecnológico sobre Vinhaça. Projeto de Políticas Públicas Fapesp. Realizado em 10 out. 2007, na FCAV/Unesp – Campus de Jaboticabal. Jaboticabal. Disponível em: <http://www.apta.sp.gov.br/cana/workshops.php>.

CARVALHO, P. C. T.; CARVALHO, F. J. P. C. Legislação sobre biosólidos. In: **Biosólidos na Agricultura**. São Paulo: Sabesp, 2001.

CETESB – Companhia de Tecnologia de Saneamento Ambiental – Secretaria do Meio Ambiente. Vinhaça – critérios e procedimentos para aplicação em solos agrícolas. Norma Técnica P 4231/2005, Homologação n. 035/2005/E, de 09 mar. 2005. São Paulo-SP.

CRUZ, R. L.; RIGHETTO, A. M.; NOGUEIRA, M. A. Experimental investigation of soil and groundwater impacts caused by vinasse disposal. In: International Seminar of Pollution, Protection and Control of Ground Water, Porto Alegre, RS, Brazil, 1990. p. 66-74.

CUNHA, R. C. de A.; COSTA, A. C. S. da; MASET FILHO, B.; CASARINI, D. C. P. Effect of irrigation with vinasse and the dynamic of its constituents in the soil. In: Physical and chemical aspects. **Wat. Sci. Tech**, v. 10,n. 8, 1987, p. 155-165.

ELIA NETO, A.; NAKAHODO, T. Caracterização físico-química da vinhaça – projeto n. 9500278. Relatório Técnico da Seção de Tecnologia de Tratamento de Águas do Centro de Tecnologia Copersucar, Piracicaba, 1995. 26 p.

FERREIRA, W. A. Efeito da vinhaça em solos de diferentes texturas. Piracicaba, 1980. 67 f. Dissertação (Mestrado) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, 1980.

FERREIRA, E. S. da; MONTEIRO, A. O. de. Efeitos da aplicação da vinhaça nas propriedades químicas, físicas e biológicas do solo. **Boletim Técnico Copersucar**, São Paulo, v. 36, p. 3-7, 1987.

FREIRE, W. J.; CORTEZ, L. A. B. **Vinhaça de cana-de-açúcar**. Ed. Agropecuária, Guaíba. 2000. 203 p.

GLOEDEN, E.; CUNHA, R. C. A.; FRACCAROLI, M. J. B.; CLEARY, R. W. The behavior of vinasse constituents in the unsaturated and saturated zones in the Botucatu aquifer recharge area. In: International Seminar of Pollution, Protection and Control of Ground Water, **Proceedings**, Porto Alegre, RS, Brazil, p. 225-235, 1990.

GLORIA, N. A. Utilização agrícola da vinhaça. **Brasil Açucareiro**, Rio de Janeiro. v. 86, n. 5, p. 11-17, 1975.

GLÓRIA, N. A.; MAGRO, J. A. Utilização agrícola de resíduos da usina de açúcar e destilaria na Usina da Pedra. In: Seminário Copersucar da agroindústria açucareira, 4., Águas de Lindoia, 1976. **Anais**... São Paulo, Copersucar, p. 163-180. 1977.

GLORIA, N. A.; ORLANDO FILHO, J. **Aplicação da vinhaça como fertilizante**. Boletim técnico. Planalsucar, Piracicaba, 38 p., 1983.

GOMES, M. A. F.; SOUZA, M. D. de; BOEIRA, R. C.; TOLEDO, L. G de. **Nutrientes vegetais no meio ambiente: ciclos bioquímicos, fertilizantes e corretivos**. Jaquariúna: Embrapa Meio Ambiente, 2000. 50 p.

HERNANDEZ, F. B. T. **Irrigação aumenta produtividade e qualidade da cana.** Disponível em: <http://www.agr.feis.unesp.br/rcn_abril2006>. Acesso em: 27 jan. 2007.

JORNAL CANA 2004. Disponível em: <www.jornalcana.com.br>. Acesso em: 12 jan. 2007.

LEAL, J. R.; AMARAL SOBRINHO, N. M. B.; VELLOSO, A. C. X.; ROSSIELLO, R. O. P. Potencial redox e pH: variações em um solo tratado com vinhaça. **R. bras. Ci. Solo.** Campinas, 7: 257-61, 1983.

LEME, E. J. A.; SILVA, V. C.; HENRIQUE, J. L. P; MICKLOS, J. E. O uso do autopropelido na aplicação de vinhaça por aspersão: viabilidade técnico-econômica. Piracicaba, IAA Planalsucar, 1987. 65 p. Boletim.

LUZ, P. H. de C. Métodos de utilização e aplicação de vinhaça. In: Workshop Tecnológico sobre Vinhaça. Projeto de Políticas Públicas Fapesp. Realizado em 10/10/2007, na FCAV/Unesp – Campus de Jaboticabal. Jaboticabal. Disponível em: <http://www.apta.sp.gov.br/cana/workshops.php>.

MAGRO, J. A. Vinhaça e seus efeitos no solo e na planta. In: Workshop Tecnológico sobre Vinhaça. Projeto de Políticas Públicas Fapesp. Realizado em 10/10/2007, na FCAV/Unesp – Campus de Jaboticabal. Jaboticabal. Disponível em: <http://www.apta.sp.gov.br/cana/workshops.php>.

MATIAZZO, M. E.; GLÓRIA, N. A. da. Efeito da vinhaça na acidez do solo. **Stab – Açúcar, Álcool e Subprodutos**, Piracicaba, SP, v. 4, n. 2, p. 35-40,1985.

NUNES Jr., D.; PINTO, R. S. A. 2005. **Indicadores de desenvolvimento da agroindústria canavieira, Safra 2005/2006.** IDEA. Ribeirão Preto, 117 p.

ORLANDO FILHO, J.; BITTENCOURT, V. C. de.; ALVES, M. C. Aplicação de vinhaça em solo arenoso do Brasil e poluição do lençol freático com nitrogênio. In: Congresso Nacional da Sociedade de Técnicos Açucareiros e Alcooleiros do Brasil. **Anais...** Stab, v. 13, n. 6, Rio de Janeiro, 1995. p. 14-17.

PENATTI, C. P. Doses de vinhaça versus doses de nitrogênio em cana-soca durante quatro safras. Relatório Interno Copersucar, Usina São Luiz S.A., solo argiloso (LR-2). 1999a.

PENATTI, C. P. Doses de vinhaça versus doses de nitrogênio em cana-soca durante quatro safras. Relatório Interno Copersucar (RT928), Usina São José da Estiva, solo arenoso (LVA-9). 1999b.

PENATTI, C. P. Vinhaça e seus efeitos no solo e na planta. In: Workshop Tecnológico sobre Vinhaça. Projeto de Políticas Públicas Fapesp. Realizado em 10/10/2007, na FCAV/Unesp – Campus de Jaboticabal. Jaboticabal. Available at: <http://www.apta.sp.gov.br/cana/workshops.php>.

PENATTI, C. P.; CAMBRIA, S.; BONI, P. S.; ARRUDA, F. C. de O.; MANOEL, L. A. Efeitos da aplicação de vinhaça e nitrogênio na soqueira da cana-de-açúcar. **Boletim Técnico Copersucar**, São Paulo, v. 44, 1988. p. 32-38.

PENATTI, C. P.; DONZELLI, J. L. Uso da vinhaça na lavoura de cana-de-açúcar. Documentos Copersucar, 2000. 22 p.

PENATTI, C. P.; FORTI, J. A. Doses de vinhaça versus doses de nitrogênio em cana-soca. In: VII Seminário de Tecnologia Agronômica. Piracicaba, 1997. **Anais...**, Copersucar, nov, 1997. p. 328-39.

PERES, C. S. Tratamento da Vinhaça: Biodigestão Anaeróbia. In: Workshop Tecnológico sobre Vinhaça. Projeto de Políticas Públicas Fapesp. Realizado em 10/10/2007, na FCAV/Unesp – Campus de Jaboticabal. Jaboticabal. Available at: <http://www.apta.sp.gov.br/cana/workshops.php>.

RODELLA, A. A.; ZAMBELLO JUNIOR, E.; ORLANDO FILHO, J. Variação da capacidade de troca catiônica do solo em função do pH e de níveis de carbono orgânico. **Stab – Açúcar Álcool e Subprodutos**, Piracicaba, v. 1, n. 5, p. 25-28, 1983.

ROLIM, M. M. Avaliação físico-mecânica do material solo-vinhaça concentrada e sua utilização para fins de fabricação de tijolos. 1996. Dissertação (Mestrado) – Unicamp – Faculdade de Economia Agrícola, Campinas, 1996.

ROSSETTO, A. J. Utilização agronômica dos subprodutos e resíduos da indústria açucareira e alcooleira. In: **Cana-de-açúcar – Cultivo e Utilização**, v. 2, p. 435-504, 1987.

ROSSETTO, R. A cana-de-açúcar e a questão ambiental In: DINARDO-MIRANDA, L. L.; VASCONCELOS, A. C. M; LANDELL, M. G. A. (Ed.) **Cana-de-açúcar**. 1. ed., Campinas: IAC, 2008, v. 1, p. 869-882.

ROSSETTO, R.; DIAS, F. L. F.; VITTI, A.; TAVARES, S. Potássio. In: DINARDO-MIRANDA, L. L.; VASCONCELOS, A. C. M; LANDELL, M. G. A. (Ed.) **Cana-de-açúcar**. 1. ed. Campinas: IAC, 2008, v. 1, p. 289-311.

SILVA, G. M. de A.; POZZI de CASTRO, L. J.; MAGRO, J. A. Comportamento agroindustrial da cana-de-açúcar em solo irrigado e não irrigado com vinhaça. IV Seminário Copersucar da indústria Açucareira. **Anais...** Águas de Lindoia, 1976. p. 107-122.

SIQUEIRA, J. O.; FRANCO, A. A. **Biotecnologia do solo: fund**amentos e perspectivas. Brasília: MEC, Lavras: ESAL, 1988. 236 p.

SOUSA, S. A. V. de. Métodos de utilização e aplicação de vinhaça. In: Workshop Tecnológico sobre Vinhaça. Projeto de Políticas Públicas Fapesp. Realizado em 10/10/2007, na FCAV/Unesp – Campus de Jaboticabal. Jaboticabal. Disponível em: <http://www.apta.sp.gov.br/cana/workshops.php>.