

*Full Length Research Paper*

## Significance of vinasses waste management in agriculture and environmental quality- Review

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Vinasse is a waste material from distillery industries which has lot of organic and inorganic loads. It is utilized in agriculture for cheap nutrients source, ameliorating agents and animal feed beyond the limitation of high biochemical oxygen demand (BOD; 46100 to 96000 mgL<sup>-1</sup>), chemical oxygen demand (COD; 104000 to 134400 mgL<sup>-1</sup>) and total dissolved salts (30.5 to 45.2 dSm<sup>-1</sup>) content even after the pollutant removal treatments. Vinasse treatments with combined approach of aerobic and anaerobic methods are more effective by both cost and pollutant on removal efficiency. Optimized dose of vinasse application has significance over soil properties, crop qualities and yield improvement. Globally, it has high potential to substitute potassium and nitrogen nutrients to the present level of annual consumption. It also contributes a substantial amount of phosphorous, calcium, sulphur and micronutrients to crops. In developed countries, starchy vinasse used as animal feed on a lean season to animals that improved the feed digestibility and animal quality where feed shortages are experienced. However, inadequate knowledge of vinasse properties and mode of utilization in agriculture questioned environmental quality for ground water pollution. Further research is needed to be strengthened for increased pollutant removal efficiency and diversified utilization in different cropping system (temporal scale) for effective utilization and safe disposal to the ecosystem. This article aimed to give the vinasse kinds and their characteristics features, soil-vinases interaction mechanism and its influence on plant, soil and water quality as consequence in agriculture.

**Key words:** Chemical oxygen demand (COD), biochemical oxygen demand (BOD), eco-friendly, utilization, environmental quality.

### INTRODUCTION

Vinasse is a waste material from distillery industries which has potential to cause major environmental problems across the world. It is also referred to as stillage or molasses spent wash in Asian countries (Sajbrt et al., 2010; Muhammad et al., 2012). More than 95% of ethanol production comes from sugar and starch materials based industries and it is contributing 42 and

58% to the total production, respectively (Tolmasquim, 2007). An average of 12 to 15 ft<sup>3</sup> vinasse per ft<sup>3</sup> of ethanol is produced and the absolute production anticipated increase with changing market scenario and government policies on ethanol production and fuel utilization (Renewable Fuels Association, 2011). In 2008, the global ethanol production is 79 billion litres and

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**Table 1.** Continent wise annual vinasse potential share of plant primary nutrients sources to its consumption in 2010.

S/N	Continents	Vinasse production (billion litres)	Nutrient content in vinasse (g/L)			Potential Share of N, P <sub>2</sub> O <sub>5</sub> and K <sub>2</sub> O to nutrient consumption* (%)			References
			N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	
1	North and Central America	844.0	1.34	1.41	7.26	7.00	25.07	119.84	Gamboa et al. (2011)
2	South America	644.2	0.35	0.24	1.54	3.50	2.66	17.81	Alexander et al. (2006)
3	Europe	66.3	32.50	0.26	34.0	15.8	0.49	54.34	Tejada and Gonzalez (2006)
4	Asia	82.01	5.30	0.20	11.4	0.60	0.07	6.27	Jiang et al. (2012)
5	Australia	4.9	1.83	ng	1.01	0.70	ng	2.64	Carmen (2006)
6	Africa	2.1	0.83	1.11	0.22	0.10	0.11	0.12	Musee et al. (2007)

\*International Fertilizer Industries Association (2010) and Food and Agriculture organization (2010), ng, Negligible.

it approximately generates vinasse of  $2.4 \times 10^{12}$  L (Carmen, 2006; Krzywonos et al., 2008). According to Renewables Fuel Association Report (2011), approximately 67% of the global ethanol production used for fuel and the same data used here confirm the status of vinasse production and mineral nutrient supply potential to agriculture (Table 1). The vinasse had been disposed directly to the flowing water that affected water quality, ecosystem and human health but only few countries improved upon these issues by making stringent amendments and still many counties have a long way to go about it (EPA, 2012). An alternate management to control the water pollution, significant proportion of vinasse have been disposed to agriculture for their manure value even though it has potential for other commercial utilization like production of single cell protein, glycerol, enzymes, astaxanthin, hormones, bio polymers and organic acid (Nataraj et al., 2006).

Here, the term environmental quality is taken as change in properties and function of environmental components of soil, plant and animal as consequence of vinasses application in agriculture (Johnson et al., 1997). Large proportion of lands are degraded either directly or indirectly by faulty

practice of cultivation, grazing etc. that limit the soil and plant capacity and eventually food security of the world (IILRI, 1988). Vinasse have been utilized in large area of agriculture by time and space, now it is need to assess their significance and/or impacts an environmental components for eco-friendly utilization as well as safe disposal to agriculture and effectively manage the challenges in handling of vinasses in the upcoming years.

### VINASSE CHARACTERIZATION

Vinasse is a by-product of distillery industries produced mostly from raw materials of corn, wheat, rice, potatoes, sugar beets, sugarcane and sweet sorghum. Its composition (Table 2) varied considerably from one distillery to another for raw materials and stages at which it is used in the process, fermentation type and adopted distillation process (Bustamante et al., 2005; Krzywonos et al., 2009). It is light-brown liquid which contains basically of water (93%) and organic solids and minerals (7%) that condensed to 60% (on wet basis) dry matter (Gemtos et al., 1999). Sugarcane vinasse is produced from juice and

often with molasses, has more concentration of carbon, potassium, phosphate, sulphate, calcium, iron, sodium and other micronutrient than former (Gopal and Kammen, 2009) and has lot of organic compounds such as glycerol, lactic acid and acetic acid (Decloux et al., 2002).

Similarly, sugar beet vinasse has significant amount of organic compounds like glycerol, betaine, oxalate, lactate and malate (Parnaudeau et al., 2006). Grapes vinasse has low nitrogen in comparison to sugarcane and sugar beet vinasse, however, rich in potassium, organic acids such as tartaric acid, malic acid, succinic acid, acetic acid and lactic acids, sugars, soluble proteins and phenolic compounds (Vlyssides et al., 2005; Melamane et al., 2007). Vinasse of corn and sweet sorghum are rich in nitrogen, phosphorous, potassium, sodium and amino acids of alanine and proline (Resende et al., 2005; Rausch and Belyea, 2006).

Usually, vinasses are characterized by low pH (4.5 to 5.5), high salts (30.5 to 45.2 dSm<sup>-1</sup>), high biochemical oxygen demand (BOD; 46100 to 96000 mgL<sup>-1</sup>) and chemical oxygen demand (COD; 104000 to 134400 mgL<sup>-1</sup>) medium to high amount of micronutrients and hormones (Mahimairaja and Bolan, 2004). Awful color in

**Table 2.** Vinasse kinds and their chemical composition.

Parameter	Sweet sorghum	Sugarcane spent wash	Sugar beet	Wine	Wine lees	Carrot
pH	4.5	4.1	4.9	4.2	3.8	4.4
EC (dS/m)	na	22 dS/m	na	na	na	na
BOD (mg/L)	46000	50000	na	16300	67500	22750
COD (mg/L)	79900	96000	na	27500	122000	44000
OC (mg/L)	na	156000	400	21000	84000	na
N (%)	0.08	0.13	3.25	0.07	1.74	0.15
P (%)	0.2	0.00	0.03	0.01	0.74	na
K (%)	na	0.79	12.60	0.12	0.02	0.22
Ca (ppm)	na	na	39.0	12	240	na
Na (ppm)	na	na	21000	120	80	358.6
Fe (ppm)	317	12.7	226	18	25	na
Mn (ppm)	na	0.42	3.4	na	na	na
Zn (ppm)	na	0.7	12	12	21	na
Cu (ppm)	37	0.27	2.1	0.05	1.2	na
References	Wilkie et al. (2000)	Kumari and Phogat (2010)	Tejada et al. (2007)	Vlyssides et al. (2005)	Vlyssides et al. (2005)	Aimaretti et al. 2013
Country	USA	India	Spain	Greece	Greece	Argentina

vinasse/distillery spent wash is due to recalcitrant compounds such as caramels, melanoidines and its sister products like hydroxyl methyl furfural and colloidal nature of caramels are resistant to decomposition and possess toxicity to microflora (Bustamante et al., 2005). Further, presence of putrescible organic compounds namely indol, 3- methyl indol and sulphur-containing substance causes bad odour and serious aesthetic problems (Pant and Adholeya, 2007a). Therefore, alteration of spent wash character is needed for these bad qualities before disposal to environment for the consideration of soil, plant, animal quality (Rath et al., 2010).

#### VINASSE TREATMENTS: AEROBIC AND ANAEROBIC METHODS

The pollutant in vinasse are attributed to various

processes namely, chemical treatment, sugar production, alcohol fermentation and high quality biologically oxidisable organic matter for raw materials (Rosabal et al., 2007; Farhadian et al., 2007). High level recalcitrant organic and inorganic in vinasse are potential to pollute environment by oxygen depletion, salinity and specific ion toxicity to the environmental components (Mane et al., 2006).

They have been brought down to the safe level at industry outlet by various treatments and they are categorized into aerobic and anaerobic methods (Prasad and Srivastava, 2009; Murthy and Chaudhari, 2009). Each has its own efficiency in pollutant removal and combination of practices hold good than single practice (Satyawali and Balakrishnan, 2008).

According to Wolmarans and Villiers (2002) and Orendain (2006), both efficiency and cost effective treatments was opted to process vinasse

starting by anaerobic treatments for high BOD, COD and total solid content, followed by some aerobic methods (Orendain et al., 2006). Bio-gas produced in the anaerobic methods could certain to substitute some extend fuel needs of industrial operation and same time it avoids the high load sludge problems to the subsequent aerobic method (Kumar and Chandra, 2006). Even after the anaerobic treatment, some organic compounds in the vinasses causes dark colour and it is removed to some extent by aerobic digestion with biological and/or physico-chemical treatments namely lagooning, coagulation, filtration, adsorption, ozonation, ion exchange, reverse osmosis, electro-flocculation, chemical oxidation, precipitation and incineration (Melamane et al., 2007).

Even though biological treatments are environmental friendly and cost effective, there are some chemicals which are toxic to microbes that

**Table 3.** Vinasse treatment methods and their pollutants removal efficiency.

Countries	Treatments	Process	Kind of vinasses	BOD removal (%)	COD removal (%)	Color removal (%)	References
South Africa		Upflow Anaerobic Sludge Blanket (UASB) reactor	Distillery waste water	na	90	na	Wolmarans and Villiers (2002)
Germany		Continuous Stirred Tank Reactor (CSTR).	Tequila vinasse	na	90-95	na	Mendez-Acosta,(2010)
China	Anaerobic treatments	Anaerobic Sequencing Batch (ASB) Reactor	Cassava stillage	na	90	na	Luo et al. (2009)
Jappan		Kubota Submerged Anaerobic Membrane Bioreactor (KSAMBR)	Distillery waste water from barely and potato	na	92	na	Kanai et al. (2010)
Colombia		USBF Reactor	winery effluent	na	96	na	Molina et al. (2007)
India		electro-chemical methods	Vinasse	na	56	na	Krishna et al. (2010)
		Ozonation	aerobically treated vinass	na	21.5		Benitez et al. (2000)
India	Aerobic treatments	Pseudomonas sp.	Vinasse-sugarcane molasses	na	63	56	Chavan et al. (2006)
India		Pseudomonas putida and Aeromoas sp	Vinasse-sugarcane molasses	na	44	60	Ghosh et al. (2002)
UK		Phanerochaete chrysosporium	Vinasse-sugarcane molasses	85.4		85	Coulibaly et al. (2003) and Fahy et al. (1997)
India		Double coagulation by ferrous sulfate		na	46.4	82.5	Chauhan and Kumar (2012)
India		Calcium Hydroxide		na	32.1	46.4	Chauhan and Kumar (2012)
France		Anaerobic treatment-Aerobic treatment	Wine vinasse	na	99.5	na	Moletta (2005)
Brazil	Combined treatments	Anaerobic Sequencing batch reactor – Aerobic (SBR)	Domestic wate water	na	94	na	Callado and Foresti (2001)
		UASB-SBR	Domestic waste water	98	92	na	Guimaraes et al. (2003)
South Africa		USAB-Activated sludge treatment	Winery effluent	na	96.5	na	Musee et al. (2007)

need to be treated by physic-chemical methods (Fahy et al., 1997). Therefore, combination of anaerobic and aerobic methods is recommended and most commonly followed contemporary practices and their efficiency in pollutant removal given in Table 3.

#### UTILIZATION OF SPENT WASH IN AGRICULTURE

Beyond the limitation, it is utilized in agriculture for organic fertilizer as complement to mineral fertilizers, irrigation by mixing with good quality water, reclamation agents, neutralizing materials to compost preparation, feeding materials to

animals and production of microbial protein (Linda et al., 2005; Kumari and Phogat, 2010; Rodrigo and Araujo, 2011).

With an advancement of knowledge in vinasse, handling and utilization improved an environmental quality over the past open to soil and water (Table 4) (Chhonkar et al., 2000). In India, reclamation of sodic soils by spent wash is considered for economical practice than gypsum for poor and marginal farmers (Haroon and Bose, 2004; Mahendra et al., 2010).

Therefore, vinasse rather waste, is considered as win-win situation in agriculture for safe disposal and quality improvement of soils, plants and animals (Kulkarni et al., 1987; Mahimairaja and Bolan, 2004).

#### SIGNIFICANCE OF VINASSE APPLICATION AND ITS MECHANISM FOR SOIL QUALITY IMPROVEMENT

Vinasse is known for high organic matter, potassium, nitrogen, calcium and micronutrients; and decades ago it was substituted for fertilizer in agriculture. In tropical countries, it is a material in agriculture for soil carbon sequestration where most of the soils are poorly fertile and has low soil organic matter content (Biswas et al., 2009). Across the world, vinasse application in agriculture have been reported positive feedback to soil properties for bulk density, porosity, water retention, stable aggregates and structure formation, infiltration, hydraulic conductivity, soil

**Table 4.** Vinasse practice in agriculture and major crop yield.

Countries	Crop/Cropping system	Recommended practices	Remarks	Yield increase (%)	References
Cuba	Sugar cane	Irrigation (300 m <sup>3</sup> /ha) as 1/5th dilution of vinasses about 2 irrigation per cycle + 60:25:80 kg of N, P <sub>2</sub> O <sub>5</sub> and K <sub>2</sub> O per ha.	Main	64.4	Armengol et al. (2003)
			Ratoon-2	51.4	
Mauritius	Sugar cane	Application of vinasse at 100 m <sup>3</sup> /ha just prior to planting	Average yield for 4 years in 3 places	9.81	Soobadar and Kwong (2013)
India	Sugarcane	Application of PMSW* at 1 KL up to 3 months of planting + 100% N, P and K	-	63.3	Janaki and Velu (2010)
Venezuela	Sugar cane	Vinasse application at 50 m <sup>3</sup> /ha + 80 kg N + 45 kg P <sub>2</sub> O <sub>5</sub> /ha	Main crop	43	Gomez and Rodríguez (2000)
			Ratoon-1	13	
			Ratoon-2	12	
India	Rice	GLM (6.5 t/ha.+ PMSW at 125 m <sup>3</sup> /ha.	-	102.8	Das et al. (2010)
Spain	Wheat	Beet vinasse fresh 6 t/ha + 150 kg of N as NH <sub>4</sub> NO <sub>3</sub>	-	6.1	Tejada and Gonzalez (2005)
Spain	Maize	Vinasse at 2000 l/ha+ 200:80:120 kg NP and K kg/ha	-	13.8	Tejada and Gonzalez (2006)
India	Sweet sorghum	150 kg of N through spent wash one month prior to sowing	-	61.1	Mallikarjun (2010)
India	Soybean-Wheat cropping systems	Application of molasses spent wash at 5 cm to soybean and 2.5 cm to wheat	Soybean	60.3	Biswas et al. (2009)
			Wheat	94.7	
Egypt	Wheat	Foliar spray of vinasse at 10% with 2% N, P <sub>2</sub> O <sub>5</sub> and K <sub>2</sub> O for every 10 days	-	50	Tejada and Gonzalez (2005)
India	Fodder sorghum	Rock phosphate and SW(1:20)	-	31.3	Kumari and Phogat (2012)
Spain	Corn	Grape marc 40 + 10% vinasse at 1500 kg/ha.	In comparison to farmer practices	25	Benitez et al. (2000)

\*Post methanated spent wash.

reaction, nutrient availability, improved nutrient use efficiency and soil biochemical properties eventually on crop growth and developments (Pathak et al., 1999; Armengol et al., 2003). In Cuba, 40 years of irrigation practices in sugarcane crops with vinasse contained 11 to 15% of dissolved organic carbon and increased the soil organic carbon to about 40 to 500% in ultisols and similar observation have been obtained for different soils, crops and cropping

systems across the countries (Ao et al., 2009; Escobar et al., 1966; Tejada and Gonzalez, 2007; Gupta and Khan, 2009). In short as well as long-term, vinasses application improved aggregate formation and its stability across the soil orders (Hati et al., 2006; Cunha et al., 1987). Increased microbial population and their activities to its soil application caused five times more in decomposition rate than farm yard manure (FYM) that enhanced the production of more structural

carbohydrate and humified materials (Patil et al., 1984; Nayamangra et al., 2001). Application of vinasse by 5 cm soil depth, increased the mean weight diameter of the soil aggregates and aggregate stability more than farmer recommendation (FYM + 100% NPK) in soybean-wheat cropping system on vertisols in India (Hati et al., 2007). In China, it is found that application of vinasse at the rate of 75 t/ha increased the macro aggregates over farmer practices and had

more of larger size (>1 mm) aggregates with high amount of biodegradable carbon and nitrogen that has more significance to soil fertility (Jiang et al., 2012; Elliott, 1986). In short-term (<5 years), use of both treated and non-treated sugarcane vinasse application, significantly decreased bulk density and increased hydraulic conductivity of reclaimed sodic soils in India (Mahendra et al., 2010). Increased soil organic matter content from vinasse practices made changes in pore size distribution for capillary porosity and eventually increased the soil water content (Aggelides and Londra, 2000). Water retention is getting increased at field capacity state rather at permanent wilting point for increased micro pores in soils and it also reduced the soil penetration resistance (Webber, 1978; Weil and Kroontje, 1979). It increased soil humified materials at clay minerals interface and eventually soil external surface area for water and nutrient adsorption (Khaleel et al., 1981). Humified materials in vinasse binds the clay particles that had interfered in soil particles size content where the sand and silt size particles get increased over the clay content in the experiments conducted in China and Cuba (Rosabal et al., 2007; Jiang et al., 2012).

Raw vinasse application in soils, initially decreased soil pH for high content of free hydrogen ions but later stage of 30 or 45 days after the application increased to optimum level for organic matter oxidation ( $H^+$  act as electron acceptor), soil saturation by exchangeable base, reduction of exchangeable Al, high buffering capacity of the clays, nominal presence of any weak salts namely carbonates or bicarbonates and release of free cations (Gemtos et al., 1999; Jiang et al., 2012; Hati et al., 2007; Aggelides and Londra, 2000). Increased total soil salt content as consequence of application is big concern for long-term disposal in agriculture (Madejon et al., 1995; Gemtos et al., 1995). However, the soil salinity content on post-harvest soil was not increased beyond the critical value of crops and rather it was observed only in laboratory condition (Gemtos et al., 1995). Short-term vinasse application on soil salinity on wetlands observed the minimum and well below to crop threshold value of many crops. It was due to regular irrigation practice that leached out the salt beyond the crops root zone (Rhoades and Loveday, 1990; Raverkar et al., 2000). For example in India, application of vinasse at increasing levels (10 to 40% Post metahated spent wash) reported less increase of electrical conductivity (EC) in plough layers of wheat-rice cropping system than wheat-maize cropping system and in sugarcane field of Mauritius (Chhonkar et al., 2000; Jain et al., 2005).

For vinasse dose optimization, land basic character such as land slope, salinity level, soil permeability etc., term continuous disposal in agriculture are need to be considered for long-term eco-friendly utilization (Chhonkar et al., 2000). Vinasses recommendation on the basis of soil permeability worked well in Brazil where sugarcane cultivation in normal soils and highly

permeable soils have recommendation of 400  $m^3/ha$  or below and 300  $m^3/ha$  or lower, respectively (Pexioto and Coelho, 1981; Rodella and Ferrari, 1977). Application of vinasse by increasing rate (0, 150 and 300  $m^3 ha^{-1}$ ) increased the variable net negative charges and decreased the value of zero point charge in oxisols than ultisols that moderated soil flocculation and dispersion behaviour (Musee et al., 2007). Das et al. (2010) reported for increasing trend of Ca, Mg, Na and K content for the spentwash ascending rate (40 to 160  $m^3/ha$ ) application in red lateritic soils and it is indicative for resilient character and plant nutrition. In Spain, application of sugarbeet vinasse compost at moderate rate in calcareous sandy loamy soils has positive effect on soil organic matter, humic substance, Kjeldahl-N contents, cation exchange capacity and has residual effect to the subsequent crops (Madejon et al., 2001). Fertilization of soil nitrogen in excess of crop demand tends to be lost by leaching, volatilization etc. and causes water pollution to eventually affect the environmental quality (Jackson and Smith, 1997; Thomsen, 2004). Dutil and Muller (1979) and Bustamante et al. (2010) reported from vinasse application for reduced available nitrogen at the beginning and 40% of the organic N was mineralized after 48 weeks to meet pace of the crop demand. For increased plant nitrogen utilization, application of vinasse recommended 1 month before to planting or sowing to avoid the potential leaching losses otherwise it would cause nitrate pollution in ground water (Delin and Engstrom, 2010). Rock phosphate and spent wash blended application (1:20) improved the phosphorous uptake and had residual effect to succeeding crops (Kumari and Phogat, 2012). This significant increase in soil available phosphorous is due to moderate content in spent wash and production of organic acids upon decomposition of vinasse in soils reduced the soil phosphorous fixation and increased the native phosphorous availability by solubilisation action on native phosphorous (Mahimairaja and Bolan, 2004). With high potassium content in vinasse, it is applied to meet out the 100% potassium requirement of wheat crop in Egypt (Arafat and Yassen, 2002). As ameliorating agents, treated spent wash application by 100  $km/hac$  and 100% recommended dose of NPK regarded for highest exchange of Na by calcium that attributed from spent wash source (Deshpande et al., 2012). In India as per observation from Valliappan (1998), one time application of 150  $m^3 ha^{-1}$  followed by two leaching and transplanting of rice on 40<sup>th</sup> day is recommended practice for its cheaper and better in efficiency than gypsum application to sodic soils reclamation. Soil microbial properties are influenced by pH, organic matter, C/N ratio, humidity and temperature (Stotzky and Norman, 1961). High organic matter and C:N ratio of vinasse materials mediated the microbial population and it is classified into two stages (Parnaudeau et al., 2008). One is carbonic stage where

up to 45 days, the increased microbial population is due to oxidation of organic matter and beyond the days, the blooms would have been by mineralized nutrients. In Brazil, application of vinasse by  $800 \text{ m}^3 \text{ ha}^{-1}$  as irrigation to sugarcane at 30 days interval found the fungi domination to first 15 days and later up to 45 days (Casarini et al., 1987). In contrast, domination of actinomycetes population over others was found in sugarcane field of China where it had been irrigated with vinasse of  $120 \text{ m}^3/\text{ha}$  as 1:5 ratio dilutions. It is concluded for advantage of soil microbial properties, where it is major component for nutrient cycling and sustainability of ecosystem (Flanagan and Cleve, 1983). Increase of microbial biomass C and N about 75% over farmer practices as well as increased microbial induced enzyme activities such as cellulase, aminopeptidase and phosphatase in China and also other countries are reported well (Shang-Dong et al., 2013; Su et al., 2009).

In India, split dose application of post methanated sugarcane spent wash about  $187.5 \text{ m}^3 \text{ ha}^{-1}$  in sugarcane has increased the microbial population and enzymatic activities of urease, phosphatase and dehydrogenase (Selvamurugan et al., 2001). Observation of spent wash impact over nitrogen fixing bacteria paved the way for alternative mode of spent wash management (as 1:1 ratio) to pulses crops (Purushottam et al., 1986; Juwarkar and Dutta, 2003). However, over all the utilization of distillery spent wash alone or combination with other water materials (biocompost etc.) increased the activities of soil microbes and enzymes thus enhancing the soil fertility status besides an eco-friendly disposal. With these studies from different countries, it is concluded that appropriate application of vinasse with consideration of all local factors optimized for improved soil health of degraded lands sodic soils and crop production without polluting the environment (Chhonkar et al., 2000; Saliha, 2005). It is being considered as analogous to salty water for ionic composition, need to verify for cyclic and mixed mode approach on different cropping system with modern irrigation system for increased utilization in agriculture and better eco-friendly disposal in agriculture.

### **SIGNIFICANCE OF VINASSE UTILIZATION IN AGRICULTURE AND CROP QUALITY**

Crop improvements are usually appreciated in terms of quality and quantity parameters; in vinasse it is about its nutritional value and optimization of soil properties to crops (Tejada and Gonzalez, 2006; Osman, 2010). Most of the countries have recommended vinasse application for high content of major nutrients to crops. Gomez and Rodríguez (1996) gave recommendation to substitute 55% N, 72% P and 100% K to sugarcane crop in Venezuela. Similarly, vinasse irrigation of about 5 ml/L in sandy soil has substituted 62% P and 100% K to wheat crops in Egypt (Arafat and Yassen, 2002) and once again

Gemtos et al. (1999) came out with recommendation to central part of Greece that vinasse by 7 t/ha for every 4 years can substitute for N requirement of wheat crops and given the significant yield increase over the farmer practices. As per meta-analysis of vinasse nutrition potential data, America can be able to derive the complete requirement of potassium and 68% phosphorus consumption for crop production. Absolute production and nutrient content of vinasse would have been to substitute significant fraction on nutrient consumption of countries particularly, America, Europe, China and India (Table 1).

Application of methanated sugarcane spent wash between  $125$  to  $250 \text{ m}^3 \text{ ha}^{-1}$  has not affected the dry land crops rather it improved the germination, growth and yield of crops (Mahimairaja and Bolan, 2004). In Greece, vinasse practice  $20 \text{ tha}^{-1}$ , while sowing was not affected by the seed germination of cotton, bean and corn crops (Assimakopoulos, 2000). The vinasse application increased significantly N, P, K, S and Ca uptake as well as yield of sugarcane, wheat, pigeon pea and maize yield over the countries (Komdorfer and Anderson, 1993). Vegetable crops are sensitive to vinasse and irrigation by 33% dilution increased the fruit size and weight (Chidankumar et al., 2009). Application of spent wash along with rock phosphate (1:20) to fodder sorghum increased the phosphorous uptake by 30 and 26% on yield than sole rock phosphate or spent wash application (Kumari and Phogat, 2010). Application of raw spent wash at 50% dilution as irrigation in sugarcane has significance over plant height, length and girth of stem, leaves breadth, number of leaves and number of tillers per plant, leaf area index and total chlorophyll content than usual prevailing fertilizer recommendation in India (Rath et al., 2011). Application of vinasse of about  $120 \text{ m}^3/\text{ha}$  is considered as optimum recommendation to rice cultivation in low fertile red and lateritic soils where 25% of yield is increased over farmer practices (Das et al., 2010). In Mauritius, vinasse application of  $100 \text{ m}^3 \text{ ha}^{-1}$  for 10 years to sugarcane crops produces additionally cane yield of 80 to 90 tonnes that is equivalent to one more crop season (Soobadar and KeeKwong, 2012). Vinasse practice of  $80 \text{ m}^3 \text{ ha}^{-1}$  in entisols to sugarcane crops is better than trash management and farmers practice by yield, soil C and nitrogen stocks improvement (Alexander et al., 2006; Soobadar and KeeKwong, 2012). Similarly, different mode of vinasse practices and significant increase in crops yield over major countries are given in Table 4.

### **STILLAGE SIGNIFICANCE ON ANIMAL QUALITY**

Grains vinasses are called stillage, used as feeding materials to animals where these residues contain  $\frac{3}{4}$ <sup>th</sup> of non-starch component as broken grains and soluble. The soluble are concentrated to around 30 to 35% dry matter and used to feed the animals as such or along with

**Table 5.** Kinds of stillage and their composition for animal feeds.

Particulars (%)	Wheat	Barley	Maize	Potato	Sorghum	Corn
Dry matter	12	28.9	6.2	6.0	5.8	Na
Crude protein	3.8	15.4	1.3	1.45	1.7	16.8
Fat	2.3	na	1.3	0.05	Nd	8.1
Crude fibre	0.12	na	0.1	0.7	1.51	Na
Sugars	6	na	2.8	3.1	2.6	Na
Starch	na	11.0	0.5	Nd	1.01	22
Ash	0.156	4.15	0.8	0.7	3.77	5.9

Adopted from Krzywonos et al. (2009)

coarse grains before the dehydration and they referred by wet distiller's grains (WDG), distiller's dried grains (DDG), distiller's dried soluble (DDS) and distillers dried grains with soluble (DDGS). It contains degraded yeast cells, soluble proteins rich in exogenous amino acids, large amounts of vitamin-B and minerals that are characterized by very high nutritive value to animals (Linda et al., 2005; Mustafa et al., 2000). These compositions are varied with kinds of grains used in the process and their original composition, fermentation process and their ethanol conversion efficiency (Table 5). In Australia, substantial proportion are recommended in diet ration to nursery pigs, boars, broilers, Layers, cattles and fishes as 25, 50, 10, 15, 20 and 5 - 20% of feeding materials, respectively (Bonnardeaux, 2007) and studies found the stillage significance over the diet digestibility and performance of the animals like normal feed (Gibb et al., 2008). It could be supplementary of water and feed materials to the ruminants in lean season of dry land regions where usually feed shortage experienced. Storability of WDG is increased by addition of corn or hay and lactic bacterial inoculants to WDG (Garcia and Kalscheur, 2004). By and large, stillage played significant role by improved animal survivability in the lean season, animal health and yield however, studies on technology development over processing vinasses materials for storage as well as nutrient enrichment is needed.

#### IMPLICATION OF VINASSE APPLICATION IN AGRICULTURE AND GROUND WATER QUALITY

As consequence of vinasse application in agriculture, the underground and surface water quality depends on land characters such as slope, soil depth, clay content and hydraulic properties and vinasse properties like chemical composition, time and rate of application and depth of ground water table (Jain et al., 2005). High EC, potassium, chloride, sulphate and melanoidine as colorant are potential components in vinasse to cause the pollution (Kumar and Gopal, 2001; Filho, 1996). Studies in many countries concluded for faulty management practices of vinasse caused the underground water pollution (Schoor, 2004). Indiscriminate application in

agriculture to the areas of shallow water table (<15 m) associated with sandy soils of high infiltration rate are highly prone to pollution and that could not been recommended.

However, continuous application of vinasse 600 m<sup>3</sup>/ha in sandy soils of sugarcane field could not cause the ground water pollution (Muhammad et al., 2012; Filho, 1996). Generalized rate of application in agriculture is normally not beyond the 500 m<sup>3</sup>/ha and it has meagre probability for ground water pollution due to their absorptivity and microbial mediated oxidation of vinasse, filter mechanism of soils and low mobility rate constants of nitrate and other major anions in the soils (Allred et al., 2007; Karanam and Joshi, 2010). In Brazil, continuous application of vinasse about 300 m<sup>3</sup>/ha in clay loam soils for 15 years have not altered the ground water quality and leach out studies found the decreased amounts of nitrate and other pollutant at water front with depth where rate of anions mobility in soils are very low (Allred et al., 2007; Cruz et al., 1991). It is well supported by studies in India where field irrigation by 40% of treated spent wash application to sandy loam soils (Ustochrept) found decreased spent wash concentration and chloride with soils depth (Karanam, 2001). Application at rainy seasons particularly areas near moderate sloppy lands are highly subject to surface run-off and leaching that pollute the flowing waters and these are against the normal recommendation (Shenbagavalli et al., 2011). Over the countries, ground water near industrial areas are highly polluted for continuous storage in lagoon ponds that leached into water tables and therefore need felt amendments was made for structural modification (Chaudhary and Mahima, 2011). For continuous monitoring of water quality in the sensitive areas of degraded soils where vinasse have been practiced as irrigation or basal application in agriculture (salt affected soils) have recommended 15 m length permanent pores in four numbers per 10 hac (EPA, 2012). In water quality aspect, India already made safety measures and given the following recommendation: (1) For ferti-irrigation, waste water is required to be treated up to BOD of 100 mg/L and total dissolved solids (TDS) of 2100 mg/L, (2) Fertigation, composting and land application options



should not be taken up in rainy season (Central Pollution Control Board, 2008). Indiscriminate direct disposal of waste water from distilleries to water bodies of Ganga and Gomati River in India caused the dissolved oxygen content less than 2.25 mg/L and lethal concentration 50 (LC<sub>50</sub>) value of 0.5% are critical for fingerling mortalities (Joshi, 1988). Approach of ground water monitoring, optimized time and space application with mixing of good quality water and judicious application of vinasse in agriculture need to be considered against ensured water quality (Chhonkar et al., 2000). Therefore, appropriate time and space in judicious application of vinasse in agriculture is not merely environmental friendly way of utilization, but might be a component to enhance the environmental quality.

### Final consideration

Appropriate time, space and rate of vinasse application in agriculture has added significant amount of nutrients, improved the soil quality of degraded land and increased of crop yields. Crop yield increment is varied for soil fertility status, spent wash composition, methods of application and inherent ability of crops. Starch based vinnase material used as ration in animal feeds increased animal quality and survival ability in the off-season period. However, water quality of many parts of the world affected severely by indiscriminate and inappropriate application and storage for treatments in surrounding areas of distillery industries possess biggest challenge in handling of increased production of spent wash.

### Conflict of Interest

The authors have not declared any conflict of interest.

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