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REVIEW

Use of sugarcane industrial by-products for improving sugarcane productivity and soil health

M. L. Dotaniya[1] · S. C. Datta[2] · D. R. Biswas[2] · C. K. Dotaniya[3] · B. L. Meena[4] · S. Rajendiran[1] · K. L. Regar[5] · Manju Lata[6]

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Abstract
Purpose Sugarcane industries are age-old industrial practices in India which contribute a significant amount of by-products as waste. Handling and management of these by-products are huge task, because those require lot of space for storage. However, it provides opportunity to utilize these by-products in agricultural crop production as organic nutrient source. Therefore, it is attempted to review the potential of sugar industries by-products, their availability, and use in agricultural production.
Methods A large number of research experiments and literatures have been surveyed and critically analyzed for the effect of sugarcane by-products on crop productivity and soil properties.
Results Application of sugar industries by-products, such as press mud and bagasse, to soil improves the soil chemical, physical, and biological properties and enhanced the crop quality and yield. A huge possibility of sugarcane industries by-products can be used in agriculture to cut down the chemical fertilizer requirement. If all the press mud is recycled through agriculture about 32,464, 28,077, 14,038, 3434, 393, 1030, and 240 tonnes (t) of N, P, K, Fe, Zn, Mn, and Cu, respectively, can be available and that helps in saving of costly chemical fertilizers.
Conclusions Application of sugarcane industries by-products reduces the recommended dose of fertilizers and improves organic matter of soil during the crop production. It can also be used in combination with inorganic chemical fertilizers and can be packed and marketed along with commercial fertilizer for a particular cropping system. That helps in reduce the storage problem of sugarcane industries by-products across the India.

Keywords Bagasse · Nutrient management · Sugar industry · Press mud · Soil quality

✉ M. L. Dotaniya
mohan30682@gmail.com

1 ICAR-Indian Institute of Soil Science, Nabibagh, Berasia Road, Bhopal 462 038, India

2 Division of Soil Science & Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

3 Department of Soil Science & Agricultural Chemistry, College of Agriculture, SKRAU, Bikaner 334 006, India

4 ICAR-Central Soil Salinity Research Institute, Karnal 132 001, India

5 Department of Soil Science and Agricultural Chemistry, BHU, Varanasi 221 005, India

6 University of Rajasthan, Jaipur 302 004, India

Introduction

Sugarcane is one of the world's largest crops (Tiwari and Nema 1999; Dotaniya and Datta 2014; Choudhary et al. 2016). It is cultivated on about 26.9 million hectares (M ha), in more than 109 countries, with a worldwide harvest of 1.91 billion tonnes (bt) (Factfish 2015). Sugarcane is a long-duration cash crop categorized under exhaustive crop (Paul et al. 2005). It requires larger amounts of macro- as well as micro-plant nutrients. It has been measured that sugarcane of 100 t that produced from 1 ha land removes 140, 34 and 332 kg NPK ha^{-1}, respectively, from soil (Bokhtiar et al. 2001). High requirement of plant nutrient limits the crop yield due to scarcity of fertilizers (Gholve et al. 2001). Similarly, spiralling prices coupled with a short availability of fertilizers in peak season (Khandagave 2003) cause depletion of plant nutrients from the soil (Kumar and Verma

2002; Ibrahim et al. 2008; Sarwar et al. 2008). Brazil is a large producer of sugarcane in the world. The next five major producers, in decreasing amounts of production, are India, China, Thailand, Pakistan, and Mexico (Sarwar et al. 2010). In 2013, about 1.91 billion tonnes of sugarcane was produced worldwide; its 50 % was produced by Brazil and India (Factfish 2015). More than 45 million sugarcane growers in India, and about 65 % of the rural population depend on this agro-based industry. These industries are struggling for energy with high cost of production. It needs lower cost input and use of by-products as a fertilizer (Dotaniya et al. 2015). The sugar industry is the second largest agricultural industry in the country after the textile industry. Its importance in day-to-day life adds its value. In this respect, it has the lot of importance in Indian agriculture. Maharashtra sugar industry is one of the most notable and large-scale sugar manufacturing sectors in the country. In India, between the sixth and fourth centuries BC, the Persians, followed by the Greeks, discovered the famous "reeds that produce honey without bees". They adopted and then spread sugar and sugarcane agriculture (Mintz 1986). This crop grown like cotton and other crops at vast levels, during 19th and 20th century revolution, it had stands in front row of agricultural cash crops. The world demand for sugar is the primary driver of sugarcane agriculture. Sugarcane accounts for 80 % of sugar produced; the rest is made from sugar beets. New innovations and accelerated mechanization enhanced the sugarcane productivity in a quantum jump.

In India, many industries are consuming agricultural produce as their raw material and generate various types of wastes. In which, sugarcane industries are one of them, generating huge amount of by-products, such as bagasse and press mud, which are creating the storage problem across the country. There is a growing concern among the scientific community, policy maker, industrialist, and environmentalist for its safe disposal without compromising the ecosystem.

Sugarcane products

Sugarcane is a rich source of carbohydrates; it used as a food for human; fodder for animal in various forms and used as a fertilizer in crop production across the globe.

(a) Food: sucrose, fructose, syrups, and jaggery.
(b) Fiber: cellulitic materials.
(c) Fodder: green leaves, top portion.
(d) Fuel: residue/waste materials.
(e) Chemicals: alcohol, bagasse, and press mud.

All above products are very important, but here, it is mainly focused on sugarcane press mud, bagasse, and molasses and their economic value in crop production.

Press mud

Organic waste, such as press mud or filter cake, is generated as a by-product of sugarcane industries and characterized as a soft, spongy, amorphous, and dark brown to brownish material depicted in Fig. 1 (Ghulam et al. 2012). It is generated during the purification of sugar by carbonation or sulphitation process. Both the processes separated clear juice on top and mud at the bottom. In general, when 100 t of sugarcane is crushed, about 3 t of press mud are produced as a by-product (Gupta et al. 2011). It is considered as rejected waste material of sugarcane industries that cause problem of storage and pollution to surrounding of sugar mills on its accumulation (Bhosale et al. 2012). It contains sugar enhanced its decomposition in soil (Dotaniya et al. 2013c, d). Press mud supplies a good amount of organic manure (Bokhtiar et al. 2001) and can be an alternate source of plant nutrient and act as a soil ameliorates (Razzaq 2001). The amount of sugar press mud (SPM) production depends upon the carbonation and sulphitation process; it is 7–9 and 3–5 % of the total weight of sugar cane from above the process, respectively (Table 1) (Sardar et al. 2013). It contents 50–70 % moisture, which is most favorable for soil micro-organisms, especially earthworms (Dominguez 1997). The composition of SPM is also affected by variety, fertility status of soil, and also the recovery process of industries. It contains significant amounts of iron, manganese, calcium, magnesium, silicon, and phosphorus, and enhanced the suitability of SPM as a source of nutrient (Yadav and Solomon 2006). Press mud, an end product of the sugar industry, is used as one of the substrates in bio-composting (Chand et al. 2011). The SPM is also generated from the alcohol distillation originating from the fermentation of sugarcane molasses; it contains a huge volume of water and plant nutrients. Therefore, it is a necessity of treating SPM to a valuable bio-fertilizer for agricultural crop production (Patil et al. 2013).

The integrated use of SPM with nitrogen fertilizers has enhanced the dry matter, cane, and sugar yield (Bangar

Fig. 1 Bagasse and press mud

Table 1 Composition of press mud

Constituents	%
Moisture	50–65
Fiber	20–30
Crude wax	7–15
Sugar	5–12
Crude protein	5–10
Nitrogen	2–2.5

et al. 2000). In 2002, Sharma et al. reported that use of press mud with urea in the 1:1 ratio increased the number of millable cane and yield of sugarcane. Due to application of press mud, the availability of macro- and micro-nutrients in soil increases. It also supplies carbon-to-soil micro-organism, which helps during decomposition and nutrient transformation reactions. Application of press mud along with inorganic fertilizers resulted higher cane yield in Uitic haplustalf (red soil) (Venkatakrishnan and Ravichandran 2013). Therefore, recycling organic waste by applying into agriculture land seems to be a good option, to short out the waste storage problem and shortage of plant nutrient (Zaman et al. 2002, 2004). Application of 25 t ha^{-1} SPM significantly improved sugarcane yield and yield attributes, i.e., number of millable canes and individual cane weight in sandy loam soil (Venkatakrishnan and Ravichandran 2013).

Application of bagasse and press mud improved the physical condition of soil by reducing bulk density and enhanced macro-spore for a better root growth, and ultimate enhanced the cane yield (Patil and Shingate 1981). Application of filter cake increase soil CEC and residual effects remained after 4 years (Rodella et al. 1990; Viator et al. 2002). Press mud contains 21 % organic carbon along with macro- and micro-nutrients, which promote microbe's growth, improve cation exchange capacity (CEC), and nutrient supply in the soil (Dey et al. 1997). Incorporation of press mud in crop field enhanced the soil quality parameters and sugarcane yield and cane juice quality (Sarwar et al. 2010). The press mud reported as a valuable plant nutrient and may affect physical, chemical, and biological properties of soil (Kumar and Verma 2002; Nehra and Hooda 2002; Rangaraj et al. 2007). Application of press mud in sugarcane cultivation is attributed in various growth and yield parameters, such as weight and number of millable cane at harvest (Indirajith 1995; Srivastava et al. 2006). Razzaq (2001) reported that continuous land application of SPM for agricultural crop production, build up a significant amount of organic carbon in soil and in 5–6 years is likely to improve soil health by adding sulfur (S) and organic matter to soil. Therefore, its positive effect on soil properties land application of press mud is becoming a common farm practice in the sub-continent countries of Pakistan and India (Ghulam et al. 2012).

Bagasse

It is the by-product of sugarcane industries during the extraction of juice from cane. It is dry pulpy residue and fibrous in nature. In summer seasons, in local markets, we can see bagasse heaps at sugarcane juice corner. It is used as a bio-fuels or in industrial level; it is used as a binding material. In general, bagasse contains major portion as cellulose, hemicellulose, and lignin are 47–52, 25–28, and 20–21 %, respectively. Apart from this 0.8–3 %, other compounds and ashes are pre-dominantly found (Rocha et al. 2011). It contains sugar, which is responsible for fast bio-degradable within 3 months. The application of bagasse in agricultural crop production system can be reduced the application rate of fertilizers. It produced organic acids, which mobilized the insoluble P from soil to soil solution in labile form. During application, it is suggested that these bagasse properly chopped; and applied one month prior to seed sowing in the field for proper decomposition. Rate of decomposition is also affected by temperature, moisture, and population and diversity of soil micro-organisms. At industrial level, it is using for energy generation; in Brazil, 19.3 % energy generation contributed from bagasse (Hofsetz and Silva 2012).

Molasses

It is produced during sugar production from raw juice. It is a viscous liquid which can be separated by massecuite. It contains higher microbial activities used for the production of alcohol and/or ethanol, or fuel for ethanol. An average of 1 t sugarcane produces 23 L of molasses. Composition of molasses variable depending upon classification method, variety of cane, and soil type (Sardar et al. 2013) is described in Table 2.

Table 2 Composition of molasses

Constituents	%
Sucrose	30–35
Glucose and fructose	10–25
Moisture	23–23.5
Ash	16–16.5
Calcium and potassium	4.8–5
Non-sugar compounds	2–3
Other mineral contents	1–2

Molasses is one of the most economically important by-products of sugar industries. This has many industrial uses, viz., generation of alcohol, preparation of animal feeds, and food stuffs. Molasses containing large fractions of fermentable sugars which is diluted (three times) with good water and allowed to ferment in the presence of yeast culture (*Saccharomyces cerevisae*) either by batch or continuous process of fermentation. The fermentable sugars are recovered by the action of yeast as an alcohol (rectified spirit)/ethanol, leaving unfermented lower order sugars (such as dioses, trioses, tetroses, pentoses, etc.), water soluble amino acids, lignins, and other organic fractions, etc., in spentwash. The organic constituents present in higher concentration undergo reduction generating unpleasant odour.

Spentwash

The raw spentwash generated after fermentation and distillation is acidic in nature, having dark brown color with unpleasant odour, high COD, and BOD (1,00,000 and 45,000 mg L^{-1}). Bio-methanation is one of the options to treat such organically rich raw spentwash. With the adoption of primary treatment, 1100 million cubic feet of methane gas per annum is generated in India which is used for steam generation and to run the boilers. The primary-treated spentwash has high suspended/dissolved solids, chemical oxygen demand (COD) (32,800–43,200 mg L^{-1}), and biological oxygen demand (BOD) (12,472–17,576 mg L^{-1}) (Ghosh et al. 2004). Bio-methanated spentwash, a plant extracts and microbial residue, is rich in plant nutrients, and can be utilized in agriculture as liquid manure. The nutrient potential of post-methanated spentwash is 2,44,000 t of potassium, 12,200 t nitrogen and 2000 t of phosphorus per annum with appreciable amounts of secondary and micronutrients (Kulkarni et al. 1987). Spentwash, press mud, and other agro-based industrial bio-resources can be bio-composted into nutrient rich organic products, which can serve as one of the components in integrated nutrient management (INM).

Availability of press mud and bagasse in India

India is the largest producer and consumer of sugar in the world. Among the several industries, sugar industry is the most important which not only contributes substantially to the economic development of the country, but also provides ample employment opportunities directly or indirectly. The more than 600 sugar factories are in the country and estimated that the production would go up to 26 Mt in 2015–16 (Business Standard 2015). At the same time, annual by-product production through these industries is more than 8 Mt of press mud, 7.5 Mt of molasses, 43.8 Mt of bagasse, and 7.4 Mt bagasse ash (FAI 2011) mentioned in Table 3. Government of India has solved the problem of disposal of molasses by encouraging the industries to set up distilleries to manufacture alcohol using molasses as raw material, while the press mud can be used for compost making and bagasse for power generation.

Table 3 Sugarcane by-products produced by the sugar mills in India (Mt) (Fertilizer Statistics 2011)

States	Press mud	Bagasse	Bagasse ash
Punjab	0.111	0.555	0.094
Haryana	0.160	0.801	0.136
Uttar Pradesh	3.516	17.571	2.987
Karnataka	0.913	4.566	0.773
Maharashtra	1.925	9.624	1.630
All India	8.774	43.845	7.454

Why sugarcane waste used for nutrient requirement of sugarcane?

Sugarcane pre-dominantly grows in the tropical and subtropical regions, and sugar beet predominantly grows in colder temperate regions of the world. Other than sugar, products derived from sugarcane include falernum, molasses, rum, *cachaça* (a traditional spirit from Brazil), bagasse, and ethanol. Several workers throughout the world have characterized these bio-resources from the point of their utilization in agriculture, and reported that these bio-resources could be used in agriculture for improving the soil fertility and productivity, growth, and yield of crops. Under the present trend of exploitative agriculture, inherent soil fertility can no longer be maintained on a sustainable basis. The nutrient supplying capacity of soil declines steadily under continuous and intensive cropping (Shukla et al. 2016). The use of optimum levels of N, P, and K has failed to maintain yield levels, probably due to increasing secondary and micronutrient deficiencies and also unfavorable alterations in the physical and chemical properties of soil. Apart from the fertility and productivity issues, the use of chemical fertilizers is also becoming increasingly difficult due to their high costs and scarcity during peak season. Alternative means of providing nutrients needs to be explored. In this context, the utilization of by-products and industries wastes serves as sources of macro-, secondary, and micro-nutrients. Sugarcane is a heavy feeder; it required higher amount of nitrogenous, phosphatic, and potassic fertilizers for a better healthy crop. For healthier food products, people using organic fertilizer are heaving negligible amount of chemical fertilizers. It is gaining more attention, nowadays, than chemical fertilizers. It enhanced the soil organic matter and supply plant nutrient in a long way, by the significant improvement in soil physio-chemical properties.

Sugarcane residues, such as bagasse and press mud, both are by-product of sugar industries and their disposal and management is very difficult. Use of these by-products in agriculture field will solve disposal problem. These residues may produce different types of organic acids during microbial decomposition (Bhattacharyya et al. 2003). Sugar content in the organic residues may enhance organic acid production in the soil. These organic acids may enhance phosphorus use efficiency (PUE) and indirectly improve crop yield and quality. Use of these sugarcane by-products also play a crucial role in phosphorus availability, because it produces various ions on decomposition, which compete with phosphate for binding sites in soils, and ultimately reduces the phosphorus fixation. Organic sources have traditionally played an important role in maintaining soil productivity. Among the organic sources, crop residues are most easily available for recycling of the macro- and micro-nutrients (Dotaniya 2013; Dotaniya and Kushwah 2013). Incorporation of these materials in soil could be a good source of nutrients and would influence agricultural sustainability by improving physical, chemical, and biological properties of soil (Mitani and Ma 2005). The addition of organic acids to soils increases the plant uptake of phosphorus from water-soluble phosphorus fertilizers (Shukla et al. 2013). The researchers were identified three possible mechanisms for the effect of organic acids on P adsorption. These include: (1) competition for P adsorption sites"; (2) dissolution of adsorbents; and (3) change in the surface charge on adsorbents. Solubilization of phosphorus compounds by organic acids is achieved by complex formation between organic acids/anions and metal ion, such as Fe, Al, and Ca. Complex formation depends on the number and position of carboxyl (–COOH) and phenolic (–OH) functional groups in the organic acids (Dotaniya et al. 2014a, b).

Use of sugar industries waste for sugarcane production

Organic wastes, i.e., press mud having a significant amount of plant nutrient nitrogen and phosphorus, and easily decomposable sugar content (Dotaniya et al. 2013a, b, c, d). Apart from plant nutrients, its C:N ratio is wider (Table 4), that creating immobilization, which can be remedied by application of inorganic fertilizers. Korndorfer and Anderson (1997), studied the use and impact of vinasse and filter cake for sugarcane production in Brazil. Vinasse has been used primarily on ratoon cane and filter cake on plant cane and increased sugarcane yield resulted from the application of either finance or filter cake without detrimental effects on cane quality or the environment. Shinde et al. (1994) reported the effect of organic residue application on nitrate production. It can be generalized from their studies that residue with wide C:N ratio initially immobilizes nitrogen from the soil and releases nitrate later when mineralization sets in. Dhull et al. (1998) reported that nitrogen mineralization of press mud increased with increase in the incubation period. The nitrogen mineralization potential differed markedly depending upon organic material and soil type. It ranged from 52 to 107 mg kg^{-1} for press mud. Press mud supplies a good amount of organic matter (Bokhtiar et al. 2001) and also crop nutrients and acts as a soil ameliorates (Razzaq 2001). It acts as a food material for soil biota and generated bio-chemicals after decomposition in soil (Sharma et al. 2014).

Table 4 Some crop residues and their composition

Material	C:N	N (%)	P (%)
Rice straw	60	0.58	0.10
Corn stover	55	0.59	0.31
Cotton stover	–	0.88	0.15
Peanut hulls	–	1.75	0.20
Sugarcane	116	0.35	0.04

Application of nitrogen and press mud cake increased dry matter, and cane and sugar yields (Bangar et al. 2000). Some researcher reported that use of press mud along with chemical fertilizers enhanced the yield of sugarcane. The integrated use of press mud with urea 1:1 ratio at 180 kg ha^{-1} is beneficial due to producing higher amounts of organic acids in calcareous soil, modified the physio-chemical properties of soil and enhanced the cane yield (Sharma et al. 2002). Application of press mud at 6 t ha^{-1} increased cane and sugar yields, while its application at 4 t ha^{-1} with 5 kg *Azotobacter* ha^{-1} produced similar results to 6 t press mud alone (Tiwari and Nema 1999). Furthermore, Sharma et al. (2002) recorded integrated use of press mud with urea in 1:1 ratio compared to press mud alone an increase in the number of millable canes. Singh and Aulakh (2001) revealed that immobilization of mineral N with the incorporation of wide C/N ratio crop residue would enhance substantially if incorporated along with fertilizer N. However, re-mineralization would initiate after about 3-week period with a faster immobilization–mineralization turn over. These results suggest that some initial starter N would be needed when wide C/N ratio crop residues are incorporated, whereas incorporation of narrow C/N ratio crop residues would supply sufficient N to the growing plants. Oblisamy (1991) observed an increase in plant nutrients, viz., N, P, K, and S, because of the incorporation of distillery effluent to the press mud. Effluent added to press mud harbored more bacteria, fungi, and actinomycetes, indicating the more microbial activity.

Kulkarni et al. (1987) stated that spentwash was a major pollutant, because of its high organic load. However, over a period researcher finds out, it uses as fertilizers in crop production. They considered spentwash as dilute liquid organic fertilizer with high K content and further reported that it contained about 90–93 % water and 7–9 % solids. Apart from it 75 % of solids were organic and 25 % were inorganic. The most important thing is that its N content was mostly in colloidal form which behaves as a slow release fertilizer and it was better than the other inorganic N source. It also contains other macro- and micro-nutrient in organic and inorganic states. The two-thirds of P were in organic form and the metabolic availability of which was more than any other important elements, such as Ca, S, and Mg as well as Cu, Mn, and Zn. Joshi et al. (1996) found that the distillery effluent contained large amounts of organic matter, N, P, K, S, and Ca besides high salt load, sulfates, and chlorides of K, Na, and Ca. Its use for nutrient purpose is required technology and regular monitoring of soil properties (Dotaniya et al. 2014c). Rajukannu and Manickam (1996) reported that spentwash was highly acidic having a pH range of 3.8–4.0, can be use as an amendment in alkaline soils. It carried a huge organic load, i.e., BOD (45,000–55,000 mg L^{-1}), COD (90,000–110,000 mg L^{-1}), and total solids (80,000–90,000 mg L^{-1}), which act as organic source that improve soil properties. The distillery effluent contains N, P, K, Ca, Mg, and SO_4 (Devarajan et al. 1996), and it is, thus, a valuable fertilizer when applied to soil through irrigation water.

Use of sugarcane by-products as bio-compost

Bio-compost is prepared by mixing press mud and distillery spentwash in the ratio of 1:2.5. A consortium of efficient microbial decomposers, viz., *Phanerocheate chrysosporium*, *Trichurus spiralis*, *Pacelomyces fusisporus*, *Trichoderma* spp., etc., are sprayed on the press mud and mixed thoroughly using aerotiller which makes the press mud aerable and hastens the process of decomposition. After 8 weeks, the windrows are allowed for curing for a month to make the process complete. The end product obtained is usually enriched with $FeSO_4$, $ZnSO_4$ and bio-fertilizers (N fixers and P solubilizers) to get a valuable product. Considering spentwash from the point of view of its organic matter and nutrient content, it could be a valuable source as a fertilizer and a source of organic compounds. However, the direct application of concentrated spentwash on agricultural lands may lead to nutritional and environmental problems due to high salinity, low P content, and high density (Murillo et al. 1993); therefore, it should be properly treated before application. Composting of spentwash with other solid agricultural residues could be used to overcome these disadvantages and compost obtained is easy to handle, with a higher P content and lower salinity. Composting can be regarded as the most usual method for recycling the organic fraction of the bioresources, since it provides an agricultural amendment capable of mitigating the serious deficit of organic materials in the fertilization programmes of crops (Haug 1993). Spentwash is usually considered a highly polluting waste, as it is produced in a very large amount during a short season. Moreover, spentwash presents two main environmental problems, a high organic load and high salinity (Diaz 1998). Nakajima-Kambe et al. (1999) reported the micro-organisms that have ability to decolorize molasses wastewater under thermophilic and anaerobic conditions, and it can be used for bio-composting. Isolation and identification of *Pseudomonas, Enterobacter, Stenotrophomonas, Aeromonas, Acinetobacter,* and *Klebsiella* have more efficiency in reducing the chemical oxygen demand of spent wash (Ghosh et al. 2004). Use of selected strain of plant growth promoting Rhizobacteria (PGPR) beneficial soil organism adapted to the SPM in laboratory and enriched with SPM; SPM used as nutrient as well as carrier material. They can be used either for seed treatment or soil application; these bio-fertilizers generate plant nutrients. As a suitable carrier, SPM plays a major role in formulating microbial inoculants. It is a good delivery medium which is used to transfer live micro-organism from an agar slant of laboratory to a rhizosphere, where it can work properly and helps in plant nutrient transformation. In SPM carrier-based inoculants, bacteria have a lower tolerance particularly for temperature variations. This also provides organic material for plant growth. It also helps to reduce unwanted contamination that can reduce the shelf life of the inoculants. Use of bio-fertilizers in combination with SPM enhanced the macro- and micro-nutrient status in soil (Patil et al. 2013).

Impact of application of press mud and bagasse on soil properties

Sugarcane industries generated wastes are organic in nature, and it has been tried to meet the nutrient requirements of various crops and cropping system as well as soil amendments. They contains significant amount of plant nutrients and organic matter improve soil properties (Jamil et al. 2008). There are two types of press mud, i.e., produced from

Table 5 pH, organic carbon, available P, and K of soil as influenced by the type and dose of press mud (Kumar and Mishra 1991)

Press mud type	Press mud dose (t ha^{-1})						Mean
	0	5	10	15	20	25	
Soil pH (1:2)							
Carbonation	–	8.0	8.1	8.3	8.4	8.5	8.3
Sulphitation	–	7.6	7.6	7.5	7.6	7.6	7.6
Mean	7.6	7.8	7.9	7.9	8.0	8.0	
CD ($P = 0.05$): press mud type = 0.01; dose = 0.1; interaction = 0.1							
Organic carbon (%)							
Carbonation	–	1.16	1.18	1.21	1.24	1.27	1.21
Sulphitation	–	1.18	1.24	1.30	1.36	1.42	1.30
Mean	1.13	1.17	1.21	1.26	1.30	1.35	
CD ($P = 0.05$): press mud type = 0.01; dose = 0.01; interaction = 0.01							
Available P (mg kg^{-1})							
Carbonation	–	22.4	25.9	24.2	23.4	21.2	23.8
Sulphitation	–	26.9	28.7	30.3	31.7	32.1	29.9
Mean	24.6	24.7	27.3	27.3	27.6	27.7	
CD ($P = 0.05$): press mud type = 0.3; dose = NS; interaction = 0.6							
Available K (mg kg^{-1})							
Carbonation	–	169	174	180	188	192	181
Sulphitation	–	179	184	189	192	196	188
Mean	144	174	179	184	190	194	
CD ($P = 0.05$): press mud type = 1.0; dose = 2.0; interaction = 2.0							

sulphitation process, and another one is produced from carbonation process; they have different impacts on soil properties (Table 5). In sulphitation process, press mud contains nutrient and $CaSO_4$, which is acting as a soil amendment in alkaline soils (Tiwari et al. 1998). Yaduvanshi and Yadav (1990) reported that application of sulphitation press mud not only resulted in increased crop yields, but also improved soil chemical properties. Later on, Kumar and Mishra (1991) compared the carbonation and sulphitation type of press mud on the chemical composition of soil after the harvest of rice and maize crop.

Singh et al. (1986) compared the effectiveness of pyrite and press mud in reclaiming the sodic soils. The soils pH, EC, and ESP were decreased by the application of pyrites as well as sulphitation press mud. Application of 20 t press mud ha^{-1} was an effective as 4–5 t ha^{-1} pyrites. However, press mud enhanced the P availability in soil and more economical over pyrites. The P availability in soil enhanced by the effects of organic residues, i.e., bagasse and press mud, and hence, carboxylates can be grouped into direct and indirect effects. The direct effects generally result in an immediate P release (Datta and Gupta 1983a). During the decomposition of organic residues, a range of organic acids are produced (Dotaniya and Meena 2013), which mobilize the P from fixed sites and are easily available to plants (Dotaniya et al. 2013a, b). They refer to the blocking of P adsorption sites (ligand exchange), oxide dissolution by complexing Al or Fe held in minerals, or mobilization of P held in metal–humic substances (Staunton and Leprince 1996; Dotaniya 2014). In the case of carbonation processed, press mud contains about 60 % $CaCO_3$ and can be exploited as an amendment for acid soils (Datta and Gupta 1983b; Tiwari et al. 1998). Application of bagasse and press mud in combination with rice straw enhanced the P availability and reduced the P fixation capacity in soil (Dotaniya and Datta 2014). It enhanced P availability by 68 % over the control in soil solution and reduced P fixation capacity from 43 % (control) to 32 % by addition of bagasse and press mud (5 g kg^{-1} of soil) (Fig. 2).

Addition of organic residue enhanced the soil organic carbon in soil and accelerated the microbial activities in soil (Dotaniya et al. 2013d). Soil microbial diversity as well as microbial population enhanced due to easily available carbon as a food material (Singh et al. 2009). Application of filter cake increased the cation exchange capacity for 30 months after its application (Rodella et al. 1990) and residual effect remains up to four years in soil (Viator et al. 2002).

Major challenges and opportunities

Sugar mills in the country are producing large amount wastes as their by-products, being its disposal and management are the major tasks. It can be used in agriculture

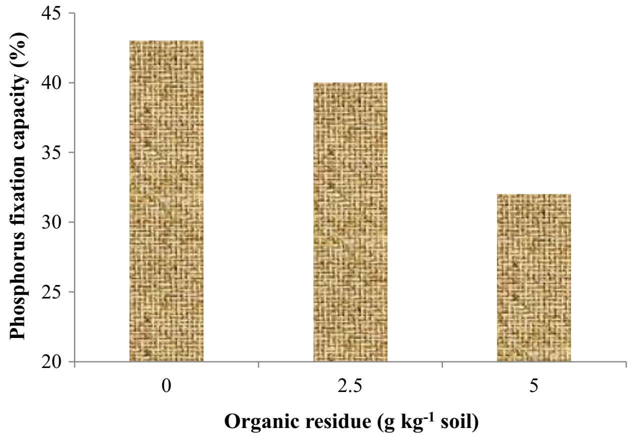

Fig. 2 Effect of organic residue on phosphorus fixation capacity of soil

for crop production as soil ameliorant, organic source of nutrients to plants, medium for microbial inoculants for producing bio-fertilizer, bio-compost, etc. Though these wastes are largely available, due to their bulky nature, their transportation to application site involves lot of expenditure. Therefore, suitable technologies could be developed to reduce their voluminous to cheaper concentrated end products. The composting process is suitable option for reduce the volume, and after composting, it can be used in fertilizer industries as carrier of nutrients. Customized organic–inorganic fertilizers can be developed using these composted waste along with inorganic fertilizers for particular cropping system or region. Further spentwash produced from the industry can be used as liquid fertilizer after proper treatment. Due to its acidic nature with high organic matter, it can be used as soil ameliorant in sodic soils. The nutrients present in these materials are recycled through adopting suitable technology to improve their availability to plants. Apart from all the above process, packaging and marketing of these wastes into fine products will popularize and accelerate its usage.

Conclusions

The time when cost of chemical fertilizer is skyrocketing and not affordable by farmers, press mud has promise as a source of plant nutrient and as a medium for raising sugarcane seedlings and leguminous inoculants. Wastes produced from sugarcane industries are organic in nature, and it augmented the soil chemical, physical, and biological properties as well as improves crop yield and quality. It can be encouraged to use these wastes with inorganic chemical fertilizers under various cropping systems to enhance nutrient availability to plants. An economical viable technology has to be developed for the complete package of sugarcane waste for a particular crop. Use of these byproducts as a fertilizer should be spread through a pilot project, regarding creating awareness and continuous evaluation of their effect on soil. It can be a best option for minimizing fertilizer shortage for crop production, especially heavy nutrient feeder crop like sugarcane.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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