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ORIGINAL RESEARCH

Effects of sugarcane pressmud on agronomical characteristics of hybrid cultivar of eggplant (*Solanum melongena* L.) under field conditions

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Abstract
Purpose The field experiments were conducted to utilize the sugarcane pressmud in the farming of *Solanum melongena* as an organic fertilizer.
Methods For growing of *S. melongena*, six agricultural fields were selected for the six amendments of sugarcane pressmud, viz., 0 % (garden soil as control), 20 % (20 % sugarcane pressmud + 80 % garden soil), 40 % (40 % sugarcane pressmud + 60 % garden soil), 60 % (60 % sugarcane pressmud + 40 % garden soil), 80 % (80 % sugarcane pressmud + 20 % garden soil) and 100 % (100 % sugarcane pressmud). *S. melongena* was grown in sugarcane pressmud-amended soil till harvest and impact of sugarcane pressmud on the soil and agronomical characteristics of *S. melongena* were determined.
Results The results showed that the sugarcane pressmud was rich in various nutrients and produced significant ($P < 0.05/P < 0.01$) changes in the soil characteristics in both seasons. Among various treatments, the maximum agronomic performance of *S. melongena* was observed due to 40 % treatment in both the growing seasons. The contamination factor (Cf) of various metals were recorded in order of Zn > Mn > Cd > Cu > Fe > Cr for the soil and Fe > Mn > Cu > Zn > Cd > Cr for *S. melongena* in both growing seasons after treatment with sugarcane pressmud.
Conclusions This study concluded that application of sugarcane pressmud treatments increased the soil fertility and as a result agronomical performance of *S. melongena*. Therefore, it can be used for the soil amendments in the lower proportion (up to 40 %) to improve the yield of *S. melongena*.

Keywords *Solanum melongena* · Sugarcane pressmud · Soil amendment · Heavy metals · Rainy and summer season

Introduction

Sugarcane pressmud is the solid residue produced after filtration of sugarcane juice. The purification process separates the juice into a clear juice that rises to the top and goes for manufacture of sugar, and a mud that collects at the bottom (Gaikwad et al. 1996; Bokhtiar et al. 2001; Sharma et al. 2002). The mud is then filtered to separate the suspended matter, which includes insoluble salts and fine bagasse (Partha and Sivasubramanian 2006; Jamil et al. 2008). The yield of filter cake or pressmud is changeable, from 1 to 7 kg (wet basis) per 100 kg of sugarcane (Singh et al. 2005). With a conventional yield of 2 % and a total manufacture of 1700 million tons in 2009, the world production of fresh filter pressmud can be estimated to be about 30 million tons (Tompe and More 1996a, b; Yaduvanshi and Swarup 2005).

India is being one of the major producers of sugar in the world and presently has about 650 sugar mills (Ezhilvannan et al. 2011; Kumar and Chopra 2014a). Sugarcane pressmud is generated in sugarcane mills and its sharing follows that of cane sugar production, with Brazil, India and China representing 75 % of the world manufacture (Rodella et al. 1990; Zaman et al. 2002). Huge quantities of pressmud are liberated by the sugarcane industry and the

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discarding of this by-product is a major concern. In many cases pressmud is burnt in brick kilns, resulting in the loss and wastage of millions of tons of nutrients, which ultimately degrades the environment. A most common use of pressmud is for fertilizer, in both the unprocessed or processed form. Processes used to recover its fertilizer value include composting, treatment with microorganisms and mixing with distillery effluents (Yaduvanshi and Swarup 2005; Kumar and Chopra 2014c, d). This industrial waste is mostly used as soil conditioner, soil fertilizer and for wax production (Ibrahim et al. 2008; Baskaran et al. 2009; Kumar and Chopra 2013a, b). Sugarcane pressmud has been used as feed component, notably for ruminants because of its sugar and mineral content and as a compacting agent for ensiling (Tompe and More 1996b; Yaduvanshi and Swarup 2005).

Pressmud is a solid waste by-product of sugar mill and rich in phosphorus, organic carbon, NPK and other micronutrients (Rakkiyappan et al. 2001). Thus, pressmud can serve as an excellent source of organic fertilizer (Juwarkar et al. 1993; Bangar et al. 2000), an alternate source of crop nutrients and soil ameliorates (Razzaq 2001). Several studies have been conducted on pressmud for its suitability to use in crop production and for energy generation (Yaduvanshi and Swarup 2005; Partha and Sivasubramanian 2006; Ibrahim et al. 2008). The integrated use of pressmud and urea 1:1 ratio at 180 kg ha^{-1} has been found to be beneficial for cane crop in calcareous soil (Sharma et al. 2002; Khandagave 2003).

Sugarcane pressmud is reported to be a precious resource of plant nutrients and may, therefore, influence physical, chemical and biological properties of a soil (Rakkiyappan et al. 2001; Sharma et al. 2002; Shah et al. 2015). Razzaq (2001) reported that incessant land application of sugarcane filter cake to farming crops for 5–6 years is likely to improve soil health by adding sulfur (S) and organic matter to soil. Therefore, land application of pressmud is becoming a common farm practice in the sub-continent of India (Sharma et al. 2002; Naik and Rao 2004).

In India, some organic wastes such as farm waste, city waste (sewage and sludge), poultry litter and industrial wastes (food, sugar, cotton and rice industry) are recycled by applying back to agricultural land (Baskaran et al. 2009; Kumar and Chopra 2012, 2013a, c; Moyin-Jesu 2015) but a significant amount of organic wastes is still disposed through other means such as burning which is associated with other environmental problems such as emission of particulates, heavy metals (e.g., Cd, Cr, Cu, Fe, Mn, Hg, Pb and Zn), and acidic gases (e.g., hydrogen chloride and sulfur dioxide) (Chopra et al. 2012). Therefore, recycling organic wastes using into agricultural land seems to be the only best alternative in such circumstances (Zaman et al. 2002; Muhammad and Khattak 2009). However, soil may not be regarded as a dumping place for organic wastes (Sarwar et al. 2008a, b; Najafi et al. 2015).

Among the organic sources of nourishment, pressmud occupies unique position as a by-product of sugar industry. Pressmud can serve as a good source of organic matter (Bokhtiar et al. 2001), an alternate source of crop nutrients and soil ameliorant (Razzaq 2001). It is also known as filter cake or filter mud and used as manure in soils (Raman et al. 1999; Sharma et al. 2002). The pressmud is rich in fiber, crude protein, sugar, crude wax and fats and ash comprising oxides of Si, Ca, P, Mg and K (Partha and Sivasubramanian 2006). This organic matter is extremely soluble and readily available to the microbial activity and so to the soil (Gaikwad et al. 1996; Rangaraj et al. 2007). In addition to that, some traceable amount of heavy metals such as zinc, copper and lead are usually present in the sugarcane pressmud (Ramaswamy 1999; Rangaraj et al. 2007; Kumar and Chopra 2015). The presence of these chemicals in large proportion in sugarcane pressmud not only affects plant growth but also collapses the soil properties when used for amendment (El-Keltawi et al. 2003; El-Naggar 2005; Sarwar et al. 2008a).

Eggplant (*Solanum melongena* L.) is one of the most precious veggies packed with indispensable nutrients (Mukhopadhyay and Mandal 1994; Nunome et al. 2001). It is being extensively cultivated throughout the world in tropical and subtropical climates (Prabhu et al. 2009; Saxena and Diwakar 2012). Nutritionally, eggplant is low in fat, protein, and carbohydrates. It is rich in dietary fiber, sugar, sodium and potassium (Fukuoka et al. 2010; Hirakawa et al. 2014). It also contains important vitamins like A, B_6, C and D, calcium, iron and magnesium. Eggplant is used in the cuisine of many countries (Dar et al. 2014). It is widely used in its native Indian cuisine, like vegetable, chutney, curry, and pickle. Eggplant, due to its texture and bulk, can be used as a meat substitute in vegan and vegetarian cuisine. The juice of eggplant significantly reduces weight, plasma cholesterol levels, and aortic cholesterol content (Saxena and Diwakar 2012; Dar et al. 2014).

In some reports, properties of the sugarcane pressmud and agronomic characteristics of diverse crop plants have been determined (Kim and Kim 1999; Ferguson 1990; Elsayed et al. 2008; Kumar and Chopra 2012, 2015). But most studies were conducted on few agronomic stages with limited parameters in various crops, but there are few reports on comprehensive agronomic studies at various agronomic stages of these plants (Kaushik et al. 2004; Naik and Rao 2004; Saxena and Diwakar 2012). Use of sugarcane pressmud on farming of *S. melongena* is receiving attention but additional information is required on how this crop responds to various treatments of sugarcane pressmud (Paul et al. 2005; Togay et al. 2008; Zhou et al. 2012;

Kumar and Chopra 2015). Keeping in view the significance of sugarcane pressmud in the present scenario of agriculture and availability of nutrients, this investigation was conducted to study the effects of sugarcane pressmud on the agronomical traits of eggplant (*S. melongena* L.) under field conditions.

Materials and methods

Experimental design

The field trials were carried out in the multipurpose experimental area of the Department of Zoology and Environmental Sciences, Gurukula Kangri University Haridwar, India (29°55′10.81″N and 78°07′08.12″E), to study the agronomical performance of *S. melongena* grown in sugarcane pressmud-amended soil. The crops were cultivated in the rainy and summer seasons during the years 2013 and 2014. Six agricultural fields (each field had an area of $9 \times 9\ m^2$) were selected for the farming of *S. melongena.* Six treatments of sugarcane pressmud, viz, 0 % (Garden soil as control), 20 % (20 % sugarcane pressmud + 80 % garden soil), 40 % (40 % sugarcane pressmud + 60 % garden soil), 60 % (60 % sugarcane pressmud + 40 % garden soil), 80 % (80 % sugarcane pressmud + 20 % garden soil) and 100 % (100 % sugarcane pressmud) were used for the experiments. The garden soil (0–20 cm) was collected from the experimental garden to prepare various treatments of sugarcane pressmud. All the six treatments were placed within each of the six fields in a randomized complete block design.

Collection of sugarcane pressmud and analysis

The sugarcane pressmud samples were procured from effluent treatment plant of the R.B.N.S. Sugar Mill, Laksar, Haridwar (29°44′46″N 78°1′46″E). The sugarcane pressmud was filled in the plastic bags from pressmud beds located in the vicinity of the sugar mill. It was brought to the laboratory and used for the soil amendment. The pressmud and soil was analyzed for pH using pH meter (pH System 362 Systronics, India), electrical conductivity (EC) using conductivity meter (Conductivity meter 306 Systronics, India), respectively. Na^+ and K^+ were measured by Stanford and English method (1949) using the flame photometry (Flame photometer 128, Systronics, India) while Ca^{2+} and Mg^{2+} were analyzed using versenate titration method. Organic carbon (OC) was determined using chromic acid titration method while total Kjeldahl nitrogen (TKN) was estimated using digestion block and nitrogen distillation method. Phosphate (PO_4^{3-}) was analyzed by Olsen method while sulfate (SO_4^{2-}) was determined by chemical precipitation method with barium chloride using spectrophotometer. Heavy metals Cd, Cr, Cu, Fe, Mn and Zn were determined using atomic absorption spectrophotometer. Standard plate count (SPC) was estimated using Petri plate method and most probable number (MPN) was determined using culture tube method cited in Chaturvedi and Sankar (2006).

Preparation of nursery of *S. melongena*

Seeds of a high yield variety of *S. melongena*, cv. Pusa Purple Long Hybrid-F_1, were obtained from Indian Council of Agriculture Research (ICAR), Pusa, New Delhi, and sterilized with 0.01 % Thiram. The nursery was prepared before 1 month of transplantation of *S. melongena* in each season. For the nursery preparation, 0.6 g seeds of eggplant were sown in the six fields in the rows 5 cm apart on 6–12 mm raised nursery beds (sugarcane pressmud treatments + farm yard manure mixed control soil). The nursery beds were covered with plastic or straw mulch till seeds germinate. The plants were watered as per requirement and other agronomical practices like weeding and hoeing were performed till the plants were transplanted into the field.

Transplantation and farming practices of *S. melongena*

Four-week-old plants of *S. melongena* were planted at the end of July 2013 and 2014 for the rainy season crop and at the end of April 2013 and 2014 for the summer season crop. Plants of *S. melongena* were transplanted in 6 rows with a distance of 60 × 60 cm between plants (Saxena and Diwakar 2012). The plants in each field were irrigated twice in a month with 400 L of bore well water and necessary agronomical practices were performed. The insecticide Chlorax 20 (Chlorpyrifos 20 % EC) was applied (1 ml/L water) to control the pests on *S. melongena* during the experiments. The soil was analyzed prior to planting and after harvest for various physico-chemical parameters like soil texture, bulk density (BD), water holding capacity (WHC), EC, pH, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, PO_4^{3-}, SO_4^{2-}, TKN, Cd, Cr, Cu, Fe, Mn and Zn determined following standard methods (Chaturvedi and Sankar 2006).

Study of crop parameters

The agronomic parameters of *S. melongena* at different stages (0–120 days) were determined following standard methods for seed germination, plant height, root length and crop yield (Saxena and Diwakar 2012), dry weight (Denison and Russotti 1997), chlorophyll content (Porra 2002) and leaf area index (LAI) (Milner and Hughes 1968). The biochemical parameters like crude protein, dietary fiber, total carbohydrate and total sugar in *S. melongena* were determined following standard methods (Anonymous 1980; Chaturvedi and Sankar 2006).

Extraction of heavy metals and their analysis

For the heavy metals analysis, 1.0 g of air-dried sugarcane pressmud, soil or plants were taken in digestion tubes separately. For each sample 3 ml of concentrate HNO_3 was added and digested in an electrically heated block for 1 h at 145 °C. To this mixture 4 ml of $HClO_4$ was added and heated to 240 °C for 1 h. The mixture was cooled and filtered through Whatman # 42 filter paper. The volume was made to 50 ml by adding double-distilled water and used for analysis. Metals were analyzed using an atomic absorption spectrophotometer (PerkinElmer, Analyst 800 AAS, GenTech Scientific Inc., Arcade, NY) following the methods of Chaturvedi and Sankar (2006). In this field study, the contamination factor (Cf) was used to determine the contamination of metals in the soil and *S. melongena* amended with sugarcane pressmud. The Cf was calculated following formula (Håkanson 1980).

Data analysis

Data were analyzed with SPSS (ver. 14.0, SPSS Inc., Chicago, Ill.). Data were subjected to one-way analysis of variance (ANOVA). Mean standard deviation and coefficient of correlation (*r* value) of soil and crop parameters with sugarcane pressmud treatments were calculated with MS Excel (ver. 2013, Microsoft Redmond Campus, Redmond, WA) and graphs produced with Sigma plot (ver. 12.3, Systat Software, Inc., Chicago, IL, USA).

Results and discussion

Characteristics of sugarcane pressmud

Table 1 demonstrates the physico-chemical and microbiological characteristics of sugarcane pressmud. The ANOVA data indicated that the values of parameters were found to be significantly ($P < 0.05/P < 0.01$) different over the treatments of sugarcane pressmud. The most values of EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, PO_4^{3-}, SO_4^2, OC, TKN, Cd, Cr, Cu, Fe, Mn, Zn, SPC and MPN were recorded with absolute (100 % treatment) sugarcane pressmud. The sugarcane pressmud was highly alkaline (pH 8.78). The higher value of EC (6.34 dS m^{-1}) in the sugarcane pressmud might be due to more ionic species like Na^+ (138.75 mg Kg^{-1}), K^+ (248.50 mg Kg^{-1}), Ca^{2+} (610.06 mg Kg^{-1}), Mg^{2+} (184.25 mg Kg^{-1}), PO_4^{3-} (105.68 mg Kg^{-1}) and SO_4^2 (568.50 mg Kg^{-1}) present in the sugarcane pressmud. The higher number of SPC (8.76×10^{14} SPC g^{-1}) and MPN (9.24×10^{12} MPN100 g^{-1}) in the sugarcane pressmud is likely due to higher OC (6.45 mg Kg^{-1}) and TKN (165.40 mg

Table 1 Physico-chemical and microbiological characteristics of sugarcane pressmud

Parameter	0 (garden soil)	Sugarcane pressmud treatment (%)				
		20	40	60	80	100
EC (dS m^{-1})	0.12	1.26*	2.52*	3.78**	5.07**	6.34***
pH	7.18	7.24 ns	7.36 ns	7.45 ns	8.12 ns	8.78 ns
Na^+ (mg Kg^{-1})	10.23	28.20*	57.10*	86.65**	115.90**	138.75***
K^+ (mg Kg^{-1})	18.55	48.30*	98.40*	148.86**	194.77**	248.50***
Ca^{2+} (mg Kg^{-1})	40.10	120.50	240.20*	362.97**	480.50**	610.06***
Mg^{2+} (mg Kg^{-1})	18.34	35.80*	72.60*	108.58**	150.12**	184.25***
OC (mg Kg^{-1})	0.35	1.20*	2.42*	3.69**	4.88**	6.45***
TKN (mg Kg^{-1})	25.60	32.45*	45.80*	78.96**	126.34**	165.40***
PO_4^{3-} (mg Kg^{-1})	0.06	16.50*	34.12*	52.66**	88.42**	105.68***
SO_4^{2-} (mg Kg^{-1})	85.00	110.24*	224.56*	336.78**	454.70**	568.50***
Fe (mg Kg^{-1})	2.34	3.70*	7.14*	12.20**	15.80**	19.45***
Cd (mg Kg^{-1})	0.80	1.45**	2.92**	4.38**	5.86**	7.28***
Cr (mg Kg^{-1})	0.01	0.25*	0.52**	0.76**	1.15**	1.42***
Cu (mg Kg^{-1})	1.38	1.64*	3.18*	4.84**	6.38**	8.05***
Mn (mg Kg^{-1})	1.12	1.25*	2.56*	3.79**	5.18**	6.42***
Zn (mg Kg^{-1})	1.68	1.98*	4.37*	6.78**	8.56**	10.34***
SPC (SPC g^{-1})	5.80×10^3	6.90×10^6**	7.25×10^8**	8.45×10^{10}***	9.12×10^{12}***	8.76×10^{14}***
MPN (MPN100 g^{-1})	4.32×10^2	6.34×10^4**	8.56×10^6**	7.55×10^8***	8.12×10^{10}***	9.24×10^{12}***

ns, *, **, *** non-significant, significant at $P \leq 0.05$, $P \leq 0.01$, $P < 0.001$ level of ANOVA, respectively; least squares means

Kg^{-1}) in the sugarcane pressmud. Gaikwad et al. (1996) reported that higher numbers of SPC (7.34 × 10^{18} SPC g^{-1}) and MPN (5.85 × 10^{16} MPN100 g^{-1}) in the sewage sludge are due to the occurrence of more dissolved solids and organic matter in the sewage sludge. Moreover, higher content of OC in the sugarcane pressmud supports higher contents of Cd (7.28 mg Kg^{-1}), Cr (1.42 mg Kg^{-1}), Cu (8.05 mg Kg^{-1}), Fe (19.45 mg Kg^{-1}), Mn (6.42 mg Kg^{-1}) and Zn (10.34 mg Kg^{-1}) in the sugarcane pressmud. Bokhtiar et al. (2001) also reported higher contents of Cd (10.50 mg Kg^{-1}), Cr (3.80 mg Kg^{-1}), Cu (14.75 mg Kg^{-1}), Fe (22.85 mg Kg^{-1}), Mn (6.00 mg Kg^{-1}) and Zn (16.40 mg Kg^{-1}) in the sugarcane pressmud.

Effects of sugarcane pressmud on soil characteristics

During the present study, at harvest of *S. melongena* (120 days after sowing), 100 % treatment of sugarcane pressmud showed the most increase in the soil characteristics like EC, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, TKN, PO_4^{3-}, SO_4^{2-}, Cd, Cr, Cu, Fe, Mn and Zn in both seasons (Table 2). The values of WHC and BD of the sugarcane pressmud-treated soil were insignificantly changed with different treatments of the sugarcane pressmud in both seasons. The WHC and BD of the soil were reduced from their control values 42.50 % and 1.40 gm cm^{-3} to 40.20, 40.05 % and 1.39 gm cm^{-3}, respectively, due to the

Table 2 Effects of sugarcane pressmud treatment and season interaction on physico-chemical characteristics of soil used in the cultivation of *S. melongena* in both seasons

Season × %SPM	EC (dS m^{-1})	pH	OC (mg kg^{-1})	Na^+ (mg kg^{-1})	K^+ (mg kg^{-1})	Ca^{2+} (mg kg^{-1})	Mg^{2+} (mg kg^{-1})
Rainy							
0	1.21	7.52	0.45	22.48	150.36	45.98	38.60
20	1.67 ns	7.64 ns	2.69*	28.94*	166.74 ns	55.67*	48.64*
40	3.68*	7.84 ns	5.78**	54.77*	195.68**	75.94**	65.72**
60	5.48*	7.98*	7.94**	68.95*	244.80**	86.94**	86.30**
80	7.66*	8.12*	9.67**	82.48**	275.94*	136.85**	102.14*
100	9.86**	8.58*	12.94**	90.26**	298.64*	186.95**	125.94*
Summer							
0	1.23	7.54	0.48	23.48	155.36	46.80	40.36
20	1.86 ns	7.75 ns	2.95*	30.25*	175.40 ns	62.40*	58.64*
40	4.52*	7.94 ns	6.15**	56.84*	182.69*	86.37**	75.94**
60	6.32*	8.15*	8.56**	78.48*	230.84*	115.61**	98.45**
80	9.47*	8.38*	10.36***	85.49**	264.84**	152.69***	124.60***
100	11.20**	8.80*	14.58***	95.48**	305.90**	205.64***	138.95***

	TKN (mg kg^{-1})	PO_4^{3-} (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	Cd (mg kg^{-1})	Cr (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Rainy									
0	32.60	24.50	60.20	0.42	0.32	1.18	1.69	0.52	0.63
20	74.85**	38.60*	86.94*	1.05*	0.68*	3.69*	5.58*	2.15*	1.95*
40	162.40**	58.90*	142.63**	2.75*	1.06**	5.94*	7.84**	4.60*	3.94*
60	280.20**	84.75**	170.64**	4.64**	1.44**	8.67**	9.68**	6.91*	7.09**
80	340.70**	115.64**	206.94**	5.96**	2.64**	10.94***	12.94**	7.94**	10.95***
100	428.96*	137.83**	234.80**	7.33**	2.96**	12.88***	16.94**	10.62***	13.94***
Summer									
0	34.26	25.64	62.32	0.43	0.32	1.19	1.72	0.53	0.64
20	82.94**	46.50*	92.67*	1.14*	1.12*	3.95*	6.88*	2.85*	2.26*
40	195.75**	70.94*	156.39**	2.96*	1.65**	6.42*	8.67**	5.38*	5.64*
60	296.80**	102.60**	185.94**	5.12**	1.95**	9.68**	10.64**	7.61**	9.67**
80	368.88***	130.48***	226.55***	6.44***	2.75***	12.94***	14.69***	10.26***	13.54**
100	445.80***	154.66***	243.80***	8.15***	3.15***	14.20**	18.85***	12.39**	15.32***

SPM sugarcane pressmud

ns, *, **, *** non-significant, significant at $P \leq 0.05$, $P \leq 0.01$, $P < 0.001$ level of ANOVA, respectively; least squares means analysis

100 % treatment of the sugarcane pressmud. The WHC is related to the number and size distribution of soil pores, soil moisture content, textural class and structure, salt content and organic matter. The BD of soil changes with the application of organic manure to soil that substantially modifies and lowers the soil bulk density. It is used to determine the amount of pore space and water storage capacity of the soil. The organic matter applied through the sugarcane pressmud can lower the BD and WHC as earlier reported by Juwarkar et al. (1993). The findings of the present study are also in accordance with Nehra and Hooda (2002) who reported that higher contents of OC in sewage sludge lowered the BD and WHC of the soil.

During the present study, the results showed that 40 % to 100 % treatments of the sugarcane pressmud significantly ($P < 0.05/P < 0.01/P < 0.001$) changed EC, OC, TKN, cations Na^+, K^+, Ca^{2+}, Mg^{2+}, anions PO_4^{3-}, SO_4^{2} and heavy metals Cd, Cr, Cu Fe, Mn and Zn of the soil used for the farming of *S. melongena* in both seasons (Table 2). The pH (8.58 and 8.80) of the soil was found to be more alkaline with 100 % treatment of the sugarcane pressmud and it is likely due to the alkaline nature (pH 8.78) of the sugarcane pressmud. The higher values of EC of the sugarcane pressmud-treated soil might be due to the occurrence of more cations and anions in the soil suspension. Moreover, the EC, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, TKN, PO_4^{3-}, SO_4^{2-}, Cd, Cr, Cu, Fe, Mn and Zn of the soil were noted to be positively correlated with different treatments of the sugarcane pressmud in both seasons (Table 3). Thus, there was gradual build up of EC, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, TKN, PO_4^{3-}, SO_4^{2-}, Cd, Cr, Cu, Fe, Mn and Zn of the soil due to the treatments of the sugarcane pressmud. Paul et al. (2005) reported that sugarcane pressmud amendments increased EC, pH, total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and available phosphorus, exchangeable Na, K, Ca and Mg in soil. The soil pH is an important parameter as many nutrients are available to plants only within a particular pH range. A pH range of 6.0–9.4 increases nutrient accessibility for plants, and a pH below 6.0 and above 8.8 inhibits the availability of nutrients for plants (Charman and Murphy 1991; Kumar and Chopra 2015). During the present study, pH of the soil ranged 8.58–8.80 with 100 % treatment of the sugarcane pressmud which makes the diverse soil nutrients obtainable to the plants.

The contents of TKN and OC in the soil treated with sugarcane pressmud were recorded greater than the control soil. The more organic carbon in sugarcane pressmud-amended soil might be due to the high organic nature of the sugarcane pressmud. Kumar and Chopra (2013b) found higher organic content in the soil treated with sewage sludge. The higher values of Na^+, K^+, Ca^{2+}, Mg^{2+}, PO_4^{3-} and SO_4^{2-} in the soil treated with sugarcane pressmud

Table 3 Coefficient of correlation (*r*) between sugarcane pressmud and soil characteristics in both seasons

Sugarcane pressmud/soil characteristics	Season	*r* value
Sugarcane pressmud versus soil EC	Rainy	+0.94
	Summer	+0.95
Sugarcane pressmud versus soil pH	Rainy	−0.90
	Summer	-0.92
Sugarcane pressmud versus soil OC	Rainy	+0.97
	Summer	+0.98
Sugarcane pressmud versus soil Na^+	Rainy	+0.92
	Summer	+0.94
Sugarcane pressmud versus soil K^+	Rainy	+0.88
	Summer	+0.90
Sugarcane pressmud versus soil Ca^{2+}	Rainy	+0.94
	Summer	+0.96
Sugarcane pressmud versus soil Mg^{2+}	Rainy	+0.82
	Summer	+0.84
Sugarcane pressmud versus soil TKN	Rainy	+0.96
	Summer	+0.98
Sugarcane pressmud versus soil PO_4^{3-}	Rainy	+0.95
	Summer	+0.96
Sugarcane pressmud versus soil SO_4^{2-}	Rainy	+0.92
	Summer	+0.94
Sugarcane pressmud versus soil Cd	Rainy	+0.95
	Summer	+0.96
Sugarcane pressmud versus soil Cr	Rainy	+0.90
	Summer	+0.92
Sugarcane pressmud versus soil Cu	Rainy	+0.86
	Summer	+0.88
Sugarcane pressmud versus soil Fe	Rainy	+0.96
	Summer	+0.98
Sugarcane pressmud versus soil Mn	Rainy	+0.94
	Summer	+0.95
Sugarcane pressmud versus soil Zn	Rainy	+0.96
	Summer	+0.98

were probable due to high amounts of Na^+, K^+, Ca^{2+}, Mg^{2+}, PO_4^{3-} and SO_4^{2-} in the sugarcane pressmud. The varied accumulation of the Na ($_3s^1$), K ($_4s^1$), Ca ($_4s^2$), Mg ($_3s^2$), P ($_3p^3$), S ($_3p^4$), Fe ($_3d^6$), Cd ($_4d^{10}$), Cr ($_3d^5$), Cu ($_3d^{10}$), Mn ($_3d^5$) and Zn ($_3d^{10}$) in the soil after treatments with sugarcane pressmud is possibly due to the electrons present in their s, p and d orbitals which determine their stability, reactivity, oxidation and reduction in the aqueous environment (Chopra et al. 2012).

The contents of heavy metals, Cd, Cr, Cu, Fe, Mn and Zn in the soil were increased with the increase in the treatments of the sugarcane pressmud (Table 2). The contamination factor (Cf) of the heavy metals indicated that Zn (22.13 and 23.94) was highest while Cr (9.25 and 9.84) was lower in both seasons with 100 % treatment of the

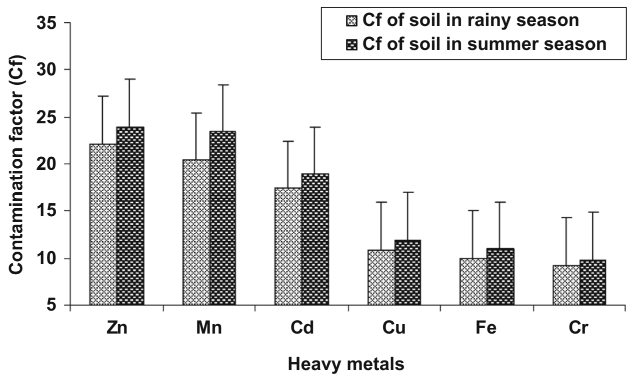

Fig. 1 Contamination factor of different heavy metals in soil treated with sugarcane pressmud. *Error bars* are standard error of the mean. *Error bars* are standard error of the mean

sugarcane pressmud. The Cf of heavy metals were in the order of Zn > Mn > Cd > Cu > Fe > Cr after treatment with sugarcane pressmud in both seasons (Fig. 1). Thus, treatments with sugarcane pressmud increased the nutrients in the soil used for the farming of *S. melongena*.

Effect of sugarcane pressmud on seed germination of *S. melongena*

The percent seed germination of *S. melongena* after treatment with sugarcane pressmud is shown in Fig. 2. During this investigation, most seed germination (84 and 86 %) of *S. melongena* was observed with 40 % treatment of the sugarcane pressmud, while the least seed germination (74 and 78 %) was noted with 100 % treatment of the sugarcane pressmud (Fig. 2). The seed germination of *S. melongena* was noted to be negatively correlated ($r = -0.51$ and -0.53) with different treatments of the sugarcane pressmud in both seasons. At germination stage, ANOVA indicated that seasons showed insignificant ($P > 0.05$) effect on the seed germination of *S. melongena* while sugarcane pressmud treatments and their interaction with seasons showed significant ($P < 0.05$) effect on the seed germination of *S. melongena* (Table 4). The findings are in agreement with Elsayed et al. (2008) who reported that the germination of sugarcane decreased with the increase in the concentrations of sugarcane pressmud. In the present study, the higher treatments (60–100 %) of the sugarcane pressmud did not support the seed germination of *S. melongena*. Yaduvanshi and Swarup (2005) also reported that the germination of rice and wheat decreased when the concentrations of pressmud increased. The higher treatments of sugarcane pressmud lowered the seed germination of *S. melongena*. It may be likely due to the occurrence of more contents of salts and heavy metals in the sugarcane pressmud at higher treatments of sugarcane pressmud.

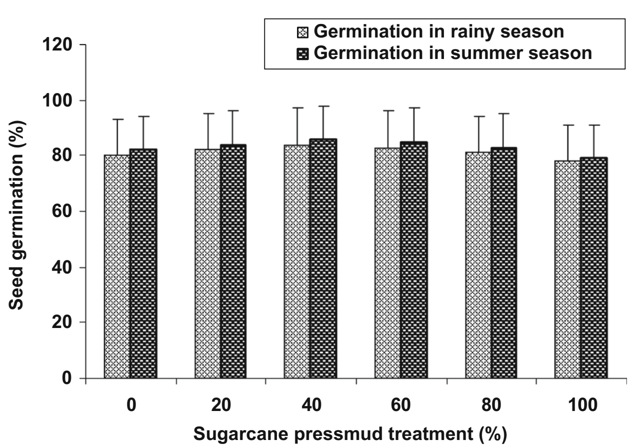

Fig. 2 Seed germination of *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

Table 4 ANOVA for effects of sugarcane pressmud on different parameters of *S. melongena*

Source	Season (*S*)	SPM treatment (*T*)	Interaction $S \times T$
Seed germination	ns	*	*
Plant height	ns	*	*
Root length	ns	ns	ns
Chlorophyll content	ns	*	*
LAI	ns	*	*
Dry weight	ns	ns	ns
CY/plant	ns	*	*
Crude proteins	*	*	*
Dietary fiber	*	**	**
Total carbohydrates	*	**	**
Total sugar	*	**	**
Cd	*	*	*
Cr	*	*	*
Cu	*	**	**
Fe	*	**	**
Mn	*	*	*
Zn	*	**	**

SPM Sugarcane pressmud

ns, *, non-significant or significant at $P \leq 0.05$ level of ANOVA, respectively

Effect of sugarcane pressmud on vegetative growth of *S. melongena*

Table 4 shows the ANOVA data for the effects of season, treatments of the sugarcane pressmud and their interaction on the attributes of the vegetative growth stage (75 day after planting) of *S. melongena*. The ANOVA indicated that treatments of the sugarcane pressmud and their interaction with season significantly ($P < 0.05$) affected the

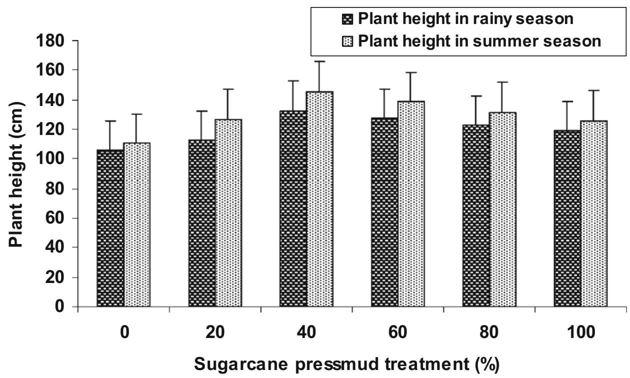

Fig. 3 Plant height of *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

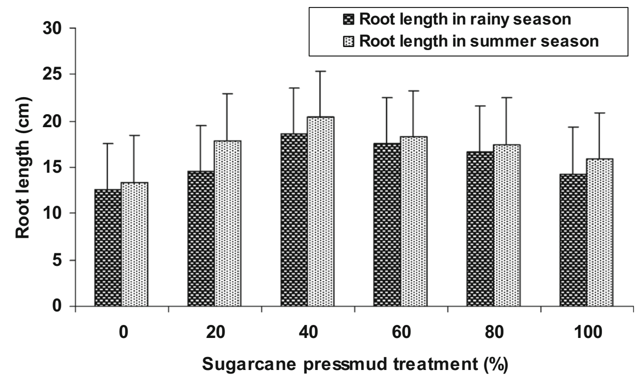

Fig. 4 Root length of *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

plant height, chlorophyll content, and LAI of *S. melongena* in both the growing seasons. The season showed insignificant effect ($P > 0.05$) on these vegetative growth attributes of *S. melongena*. Furthermore, season, treatments of the sugarcane pressmud and their interaction did not show significant ($P > 0.05$) effect on the root length of *S. melongena*.

In the present study, at vegetative growth the minimum plant height (105.64 and 110.23 cm), root length (12.54 and 13.42 cm), dry weight (875.48 and 895.60 g), chlorophyll content (3.05 and 3.12 mg/g f wt) and LAI/plant (3.21 and 3.28) of *S. melongena* were observed with control, while the moderate plant height (118.62 and 125.84 cm), root length (14.30 and 15.86 cm), dry weight (945.68 and 968.52 g), chlorophyll content (3.24 and 3.32 mg/g f wt) and LAI/plant (3.18 and 3.45) of *S. melongena* were noted with 100 % treatment of the sugarcane pressmud in both seasons. The maximum plant height (132.50 and 145.64 cm), root length (18.56 and 20.36 cm), dry weight (1256.60 and 1298.55 g), chlorophyll content (3.82 and 4.08 mg/g f wt) and LAI/plant (3.52 and 3.75) of *S. melongena* were observed with 40 % treatment of the sugarcane pressmud in both seasons (Figs. 3, 4, 5, 6, 7).

During the investigation, plant height, root length, dry weight, chlorophyll content and LAI/plant of *S. melongena* were noted to be positively correlated with different treatments of the sugarcane pressmud in both seasons (Table 5). Togay et al. (2008) reported that the growth of dry bean (*Phaseolus vulgaris* L.) decreased when the doses of municipal sewage sludge increased. Likewise, Naik and Rao (2004) reported that the greatest vegetative growth characteristics like plant height, root length, dry weight, chlorophyll content and leaf area index of sunflower (*Helianthus annuus* L.) were noted with lower treatments of organic manures (farm yard manure and pressmud). Furthermore, the growth of *H. annuus* decreased with increase in the doses of organic manures. The findings were

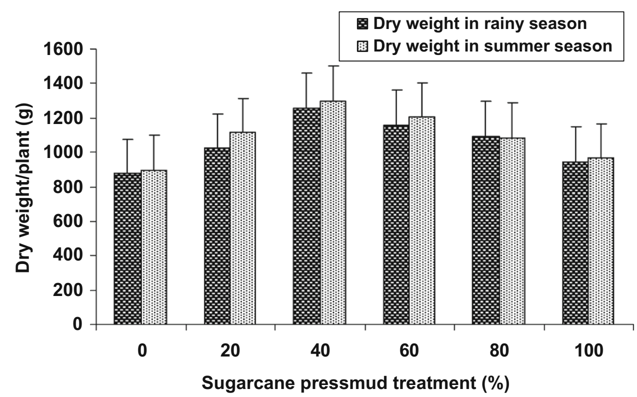

Fig. 5 Dry weight of *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

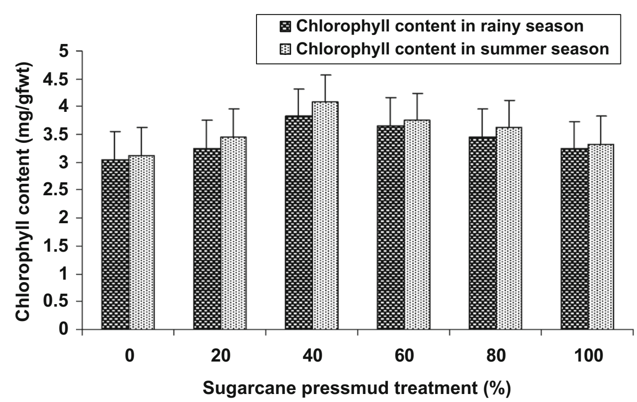

Fig. 6 Chlorophyll content of *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

also supported by Naeem et al. (2006) who reported that the growth of mung bean (*Vigna radiata* L.) decreased due to the application of high concentrations of organic manures.

The results showed that the vegetative growth of *S. melongena* decreased at higher treatments (i.e., 60–100 %)

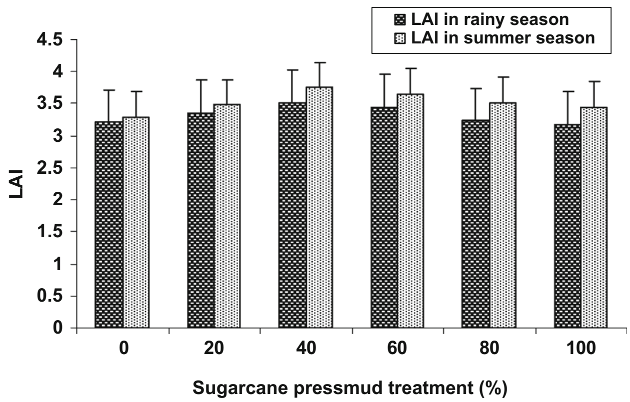

Fig. 7 LAI of *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

of the sugarcane pressmud. It might be due to the existence of additional contents of the heavy metals in the higher treatments of sugarcane pressmud, which lowered the plant height, root length, dry weight, chlorophyll content and LAI/plant of *S. melongena*. Vegetative growth is concerned with the expansion of new shoots, leaves and leaf area (Kumar and Chopra 2012). The maximum plant height, root length, dry weight and LAI/plant of *S. melongena* were noted with 40 % treatment of the sugarcane pressmud and it may be possibly due to the maximum uptake of nitrogen (N), phosphorus (P) and potassium (K) by *S. melongena* plants. The enhancement of vegetative growth may be attributed to the role of K in the nutrient and sugar translocation in the plants and turgor pressure in the plant cells. It is also involved in the cell enlargement and in triggering young tissue or meristematic growth (Porra 2002; Kumar and Chopra 2012). The chlorophyll content was found to be higher due to the use of 40 % treatment of the sugarcane pressmud in both seasons and is likely due to Fe, Mg and Mn contents in the sugarcane pressmud, which are associated with chlorophyll synthesis (Saxena and Diwakar 2012; Zhou et al. 2012). Thus, 40 % treatment of the pressmud contains optimum contents of nutrients required for the highest vegetative growth of *S. melongena*.

Effect of sugarcane pressmud on fruiting of *S. melongena*

The ANOVA data indicated that the crop yield/plant of *S. melongena* was not affected by seasons, sugarcane pressmud treatments and their interaction (Table 4). In addition, the crop yield/plant of *S. melongena* was found to be positively correlated with all treatments of the sugarcane pressmud in both the growing seasons (Table 5). At fruiting stage (120 days after planting), the maximum yield/plant (1460.30 and 1520.50 g) at I harvest (1840.30 and 1880.95 g) at II harvest and (1285.50 and 1360.90 g) at III harvest of *S. melongena* were recorded with 40 % treatment of the sugarcane pressmud in both the growing seasons. The least crop yield/plant (1010.20 and 1050.64 g) at I harvest, (1125.30 and 1185.47 g) at II harvest and (1095.35 and 1105.78 g) at III harvest of *S. melongena* were recorded with the control while moderate crop yield/plant (1225.60 and 1295.48 g) at I harvest, (1560.36 and 1645.58 g) at II harvest and (1164.95 and 1250.68 g) of *S. melongena* at III harvest were recorded with 100 % treatment of the sugarcane pressmud in both the growing seasons (Fig. 8). At fruiting stage the 40 % treatment of the sugarcane pressmud favored crop yield of *S. melongena.* This is possibly due to the existence of optimal contents of K, Fe, Mg and Mn in 40 % treatment of the sugarcane pressmud. Moreover, the high treatment (i.e., 60–100 %)

Table 5 Coefficient of correlation (*r*) between sugarcane pressmud and *S. melongena* in both seasons

Sugarcane pressmud/*S. melongena*	Season	*r* value
Sugarcane pressmud versus plant height	Rainy	+0.45
	Summer	+0.48
Sugarcane pressmud versus root length	Rainy	+0.27
	Summer	+0.28
Sugarcane pressmud versus dry weight	Rainy	+0.36
	Summer	+0.39
Sugarcane pressmud versus chlorophyll content	Rainy	+0.54
	Summer	+0.56
Sugarcane pressmud versus LAI	Rainy	+0.52
	Summer	+0.54
Sugarcane pressmud versus crop yield/plant	Rainy	+0.42
	Summer	−0.44
Sugarcane pressmud versus Cd	Rainy	+0.90
	Summer	+0.92
Sugarcane pressmud versus Cr	Rainy	+0.74
	Summer	+0.76
Sugarcane pressmud versus Cu	Rainy	+0.96
	Summer	+0.98
Sugarcane pressmud versus Fe	Rainy	+0.94
	Summer	+0.96
Sugarcane pressmud versus Mn	Rainy	+0.92
	Summer	+0.94
Sugarcane pressmud versus Zn	Rainy	+0.96
	Summer	+0.98
Sugarcane pressmud versus crude proteins	Rainy	+0.54
	Summer	+0.56
Sugarcane pressmud versus dietary fiber	Rainy	+0.78
	Summer	+0.80
Sugarcane pressmud versus total carbohydrates	Rainy	+0.64
	Summer	+0.66
Sugarcane pressmud versus total sugar	Rainy	+0.56
	Summer	+0.58

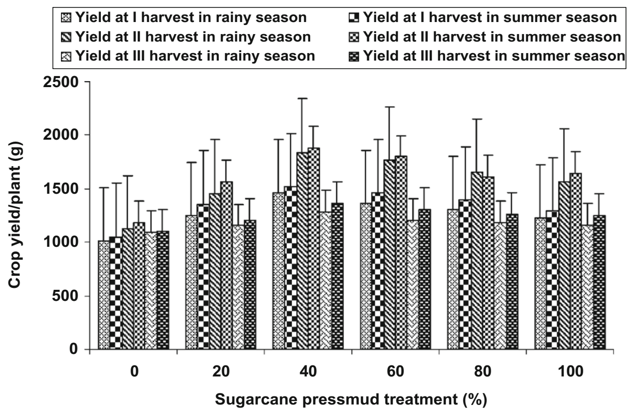

Fig. 8 Crop yield of *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

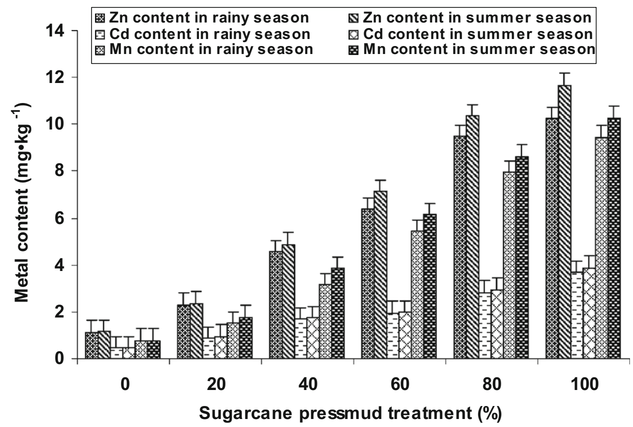

Fig. 9 Contents of Zn, Cd and Mn in *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

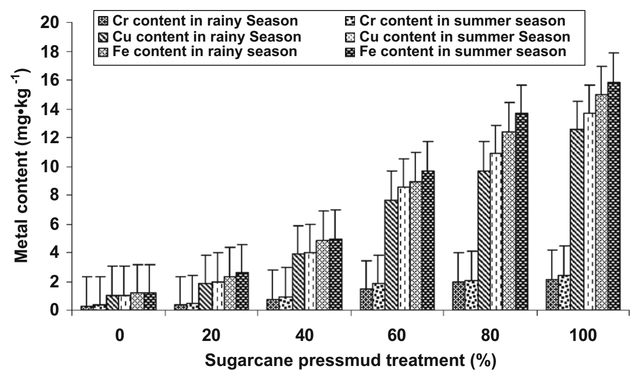

Fig. 10 Contents of Cr, Cu and Fe in *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

of the sugarcane pressmud lowered the crop yield of *S. melongena.*

The function of K, Fe, Mg and Mn at fruiting is essential and associated with production of chlorophyll and enhances the crop yield (Naeem et al. 2006; Kumar and Chopra 2012). The K, Fe, Mg and Mn contents could improve the yield of eggplants (*S. melongena*) as reported by Fukuoka et al. (2010) and Hirakawa et al. (2014). Kumar and Chopra (2013b) reported that the maximum crop yield of French bean (*Phaseolus vulgaris* L.) was noted with 40 % treatment of sewage sludge. Moreover, the crop yield of *P. vulgaris* decreased with the increase in sewage sludge treatments from 60 to 100 %.

Effect on heavy metals and biochemical components in *S. melongena*

Table 4 shows the ANOVA data for the effects of season, treatments of the sugarcane pressmud and their interaction on the contents of Cd, Cr, Cu, Mn and Zn and biochemical components, viz, crude proteins, dietary fiber, total carbohydrates and total sugar in *S. melongena*. The ANOVA indicated that season, treatments of the sugarcane pressmud and their interaction significantly affected the contents of heavy metals and biochemical components in *S. melongena*. The 20–100 % treatments of the sugarcane pressmud produced significant ($P < 0.05/P < 0.01$) effect on Cd, Cr, Cu, Fe, Mn and Zn, crude protein, dietary fiber, total carbohydrate and total sugar in *S. melongena.* The contents of diverse metals Cd, Cr, Cu, Fe, Mn, Zn, crude proteins, dietary fiber, total carbohydrates and total sugar were noted to be positively correlated with all treatments of sugarcane pressmud in both seasons (Table 5).

The higher contents of Cd, Cr, Cu, Mn and Zn in *S. melongena* were observed with 100 % treatment of the sugarcane pressmud (Figs. 9, 10). It might be due to the occurrence of additional heavy metals in 100 % treatment of the sugarcane pressmud, which added extra metals in the soil environment. The contamination factor (Cf) of heavy metals was affected in both seasons. The Cf of various metals was in the order of Fe > Mn > Cu > Zn > Cd > Cr in *S. melongena* after application of sugarcane pressmud (Fig. 11). The highest contamination factor was noted for Fe (12.68 and 13.33), while the least was found for Cr (6.72 and 7.42) in *S. melongena* with 100 % treatment of the sugarcane pressmud in both the growing seasons. The buildup of the Cr, Cu, Mn and Zn except Cd in the *S. melongena* was noted below the permissible limit of the FAO/WHO standards for the Cd (0.20 mg Kg^{-1}), Cr (2.30 mg Kg^{-1}), Cu (40.00 mg Kg^{-1}) and Zn (60.00 mg Kg^{-1}) (FAO/WHO 2011). The content of Cd in *S. melongena* may be caused by garden soil used for the experiment having higher content of Cd. The diverse accumulation of these metals might be due to the number of electrons in the d-levels of the atom. Although, metals with completely filled d orbitals such as $3d^{10}$ of Cu and Zn and $4d^{10}$ of Cd may be least incorporated compared to $3d^{5}$

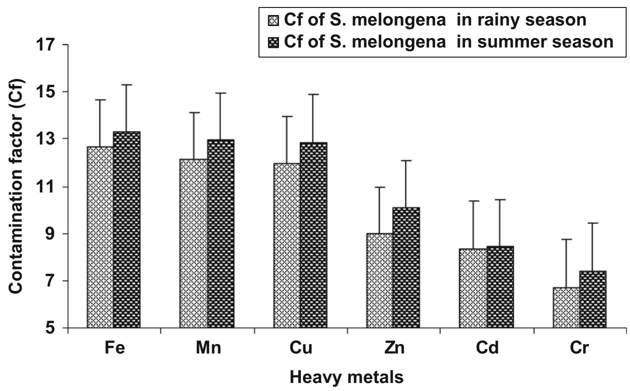

Fig. 11 Contamination factor of different heavy metals in *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

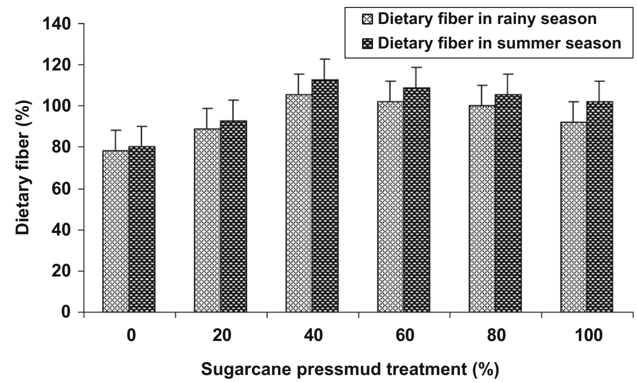

Fig. 13 Dietary fiber in *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

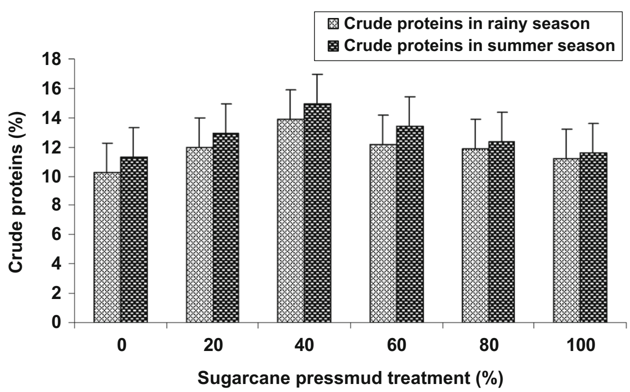

Fig. 12 Crude proteins in *S. melongena* treated with sugarcane pressmud

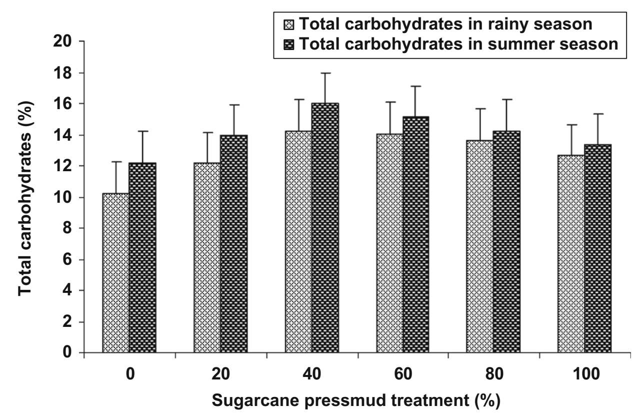

Fig. 14 Total carbohydrates in *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

of Cr and Mn into the plants due to their lower reactivity and more stability imparted by the completely filled d orbitals, the lower reactivity and stability of these metals reduce the rate of various reactions such as absorption, ionic exchange, redox reactions, precipitation and dissolution through which plants take metals from soils. However, the bioavailability of these metals might be increased due to the ionization in the aqueous phase in the soil which increases their reactivity and instability as earlier reported by Kumar and Chopra (2014c).

The results showed that the contents of Cd, Cr, Cu, Fe, Mn and Zn were more at 60–100 % treatments of the sugarcane pressmud and likely inhibited growth of *S. melongena*. The 40 % treatment of the sugarcane pressmud favored vegetative enlargement and fruiting of *S. melongena*. This is likely due to optimal uptake of these metals by crop plants, which supports various biochemical and physiological processes. The results are in conformity of Kumar and Chopra (2013b) who reported that the accumulation of metals in French bean (*Phaseolus vulgaris*) was noted in the order of Fe > Zn > Cd > Cu > Cr > Pb after amending with sewage sludge. Nunome et al. (2001) also reported the contamination of Cd, Cu, Cr, Zn and Pb in soil and *S. melongena* subsequent to application of sugarcane pressmud and effluent. During the present study, maximum contents of crude proteins, dietary fiber, total carbohydrates and total sugar were noted with 40 % treatment of the sugarcane pressmud (Figs. 12, 13, 14, 15). The contents of crude proteins, dietary fiber, total carbohydrates and total sugar were decreased from 60 to 100 % treatments of sugarcane pressmud. The findings are in agreement with Kumar and Chopra (2014b, 2015) who reported that the contents of total carbohydrate, crude protein and crude fiber in French bean (*Phaseolus vulgaris*) and spinach (*Spinacia oleracea* L.) were decreased with the increase in the concentration of sugar mill and paper mill effluent, respectively, when these effluents were used for fertigation.

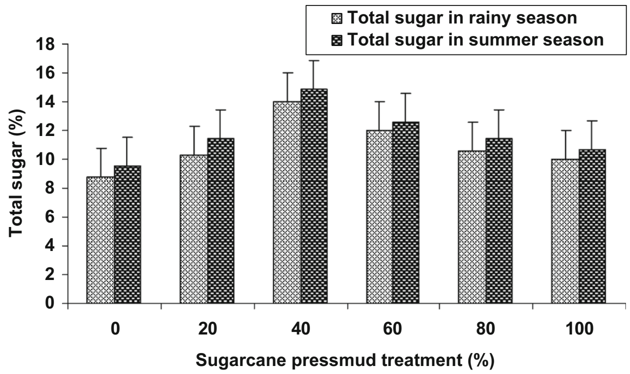

Fig. 15 Total sugar in *S. melongena* treated with sugarcane pressmud. *Error bars* are standard error of the mean

Conclusions

This study concluded that sugarcane pressmud increased nutrients in the soil and affected the agronomical attributes of *S. melongena* in both the growing seasons. The maximum agronomical performance of *S. melongena* was observed with 40 % treatment of the sugarcane pressmud. The maximum contents of heavy metals Cd, Cr, Cu, Fe, Mn and Zn in *S. melongena* were noted with 100 % treatment while biochemical components like crude proteins, dietary fiber, total carbohydrates and total sugar in *S. melongena* were found maximum with 40 % treatment of the sugarcane pressmud in both the growing seasons. The contamination factor (Cf) of various metals were in order of Zn > Mn > Cd > Cu > Fe > Cr for soil and Fe > Mn > Cu > Zn > Cd > Cr for *S. melongena* in both the seasons after treatments with sugarcane pressmud. Thus, sugarcane pressmud can be used as a biofertilizer in lower proportion (up to 40 %) to improve yield of this crop. Further studies on the agronomic growth and changes in biochemical composition of *S. melongena* after sugarcane pressmud treatments are required using different field conditions.

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