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Original Article

Integrated use of boiler ash as organic fertilizer and soil conditioner with NPK in calcareous soil

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Abstract

Regular application of commercial fertilizers and increased crop yield, also degrade soils physically and chemically and increase the input cost. Sugar industry wastes can be used as soil amendments to improve crop yield, soil physico-chemical characteristics and provide a reasonable economic means to recycle these wastes in an environmentally friendly manner. To achieve this objective, sugar industry boiler ash was applied to wheat crop in pots having 20 kg soil @ 3, 12, 25, 50, 125 and 250 t ha^{-1} respectively, compared to the control. Same doses of boiler ash were also applied to wheat crop in the field experiment. A basal dose of NPK, 120, 90, and 60 kg ha^{-1} respectively, was also applied with boiler ash before sowing of wheat crop in both experiments. The soil under investigation was calcareous in nature, having a high pH (8.2), low in organic matter (8200 mg kg^{-1}), and deficient in N (300 mg kg^{-1}), P (7.5 mg kg^{-1}) and Zn (6.2 mg kg^{-1}). Boiler ash was rich in micronutrients like Fe, Mn, Zn and Cu and also contained sufficient amount of Ca, Mg, Na, S, K and P. Consequently, total porosity of soil, available P, S and K, Fe, Mn, Zn and Cu content in soil, increased with the levels of boiler ash application. On the other hand, dry bulk density declined which is a positive effect. EC_e and pH of the soil was minutely increased. Yields and most of the yield components of wheat crop in pots, as well as in the field experiment, also increased due to boiler ash application. It is recommended that application of boiler ash @ 50 t ha^{-1} will result in enhanced yield of wheat in calcareous soil.

Keywords: organic fertilizers, boiler ash, soil nutrients, soil characteristics, wheat yield

1. Introduction

Addition of organic material to agricultural fields was widely practiced in Asia for decades but due to intensive cropping and business oriented agriculture, the trend has shifted towards chemical fertilizers (Yaduvanshi, 2003). Chemical fertilizers were used in such high amounts that they deteriorated our soil health. Heightened environmental awareness has led to an organic revolution, with scientists turning to organic materials in search of a comprehensive strategy to save soils from further degradation and utilize organic wastes in an environmentally safe manner. Regular additions of organic materials such as sugar industry wastes, municipal biosolids, animal manures and crop residues are of utmost importance in maintaining the tilth, fertility and productivity of agricultural soils (Solaimalai *et al*., 2001). They can also be used as mulching material to protect the soils from wind and water erosion, thus preventing nutrient losses through runoff and leaching (Shuxun, 2000).

Boiler ash is one of the wastes obtained from sugar industries during the process of sugar manufacturing. After crushing and extracting juice from sugar cane, the remaining pulp (bagasse) is burnt under boilers for heating the juice. The material left behind after burning of bagasse is ash, which is of no use and poses a significant environmental problem. It is estimated that the sugar industry in Pakistan is producing about 2.0 million tonnes of boiler ash every year, which is a rich source of micronutrients (Nasir & Qureshi, 1999). At the moment these organic wastes are not used for

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fertilizing the fields by the farmers, rather, they are used in the manufacture of bricks or dumped as waste which cause environmental pollution as well as a loss of a considerable amount of nutrients. Boiler ash is one of the important organic wastes capable of supplying sufficient amount of plant nutrients such as, Mg, S, P, K, Fe, Mn, Zn and Cu to soil (Anguissola *et al*., 1999). When applied to fields as an organic amendment, its favorable effects on soil water holding capacity and aeration is also proven. Singh *et al*. (2002) has reported improved water use efficiency in soil and higher yield of wheat crop amended by fly ash. Along with luxurious amounts of important micronutrients like Zn, Cu, Fe and Mn, boiler ash also contains sufficient amount of some other useful nutrients like Mg, S, P, and K where as calcareous soils are deficient in these nutrients (Umar *et al*., 2003). Therefore, boiler ash is likely to improve the micronutrients distribution along with the physical properties of soil. The application of boiler ash, like other organic amendments, can also improve soil properties (Zende, 1995) and produce good results regarding yields of various crops, such as wheat and sugar cane (Hallmark *et al*., 1998). Mittra *et al*. (2005) also reported an increase in soil P, K, Ca, Mg, Cu, Zn and Co as a result of coal ash application besides improving soil physical and chemical properties. They also found it a useful practice for reducing the cost of fertilizer application and safe disposal of the waste.

The purpose of the present investigation is to observe the response of wheat crop to the application of boiler ash in a calcareous soil, deficient in N, P and trace elements. It is also intended to address the effect of different levels of boiler ash on physico-chemical characteristics of the soil and to recommend an appropriate dose for maximum yield of the crop and disposal of the waste in an environmentally friendly manner.

2. Materials and Methods

2.1 Experimental and management

2.1.1 Pot experiment

A pot culture experiment was conducted at the research area of the Department of Soil Science, Faculty of Agriculture, Gomal University, D.I Khan, Pakistan, during winter season 2001-2002. Bulk soil samples from 0-30 cm depth were collected, air dried, ground and passed through a 2mm sieve. Boiler ash was collected from the dumping site of Chashma Sugar Mills (Pvt) Ltd; Dera Ismail Khan, Pakistan, was air dried and passed through a 4mm sieve. Twenty kg of soil was added to the pots and mixed with boiler ash @ 3, 12, 25, 50, 125 and 250 t ha^{-1} along with the basal dose of NPK, @ 120, 90, and 60 kg ha^{-1} respectively, at the time of sowing in the form of Urea, K_2SO_4 and triple super phosphate. T_1 was kept as control. Ten seeds pot^{-1} of wheat variety "Fakhr-e-Sarhad" were sown in each pot. The experiment was laid out in a randomized complete design and each treatment was replicated four times. The crop was irrigated at appropriate times and weeds were controlled manually. After germination, thinning was done and only three plants were left in each pot. The recorded data were plant height, spike length, number of tillers $plant^{-1}$, number of productive tillers $plant^{-1}$, number of grains $spike^{-1}$, 1000-grain weight and grain and straw yield $plant^{-1}$.

2.1.2 Field experiment

The field experiment was also conducted at the research area of the Department of Soil Science, Faculty of Agriculture, Gomal University, D.I Khan, Pakistan, during 2002-2003. Bulk soil samples, before sowing and after harvesting, from 0-30 cm depth, were collected from the research area and analyzed for physico-chemical characteristics according to the methods described by Page *et al.* (1982) or otherwise mentioned in the methods section. Wheat variety Fakhr-e-Sarhad was sown on 20^{th} November 2002, in a randomized complete block design having four replications using a plot size of 2 x 5 m^2. Wheat was sown at a proper seed rate of 100kg ha^{-1}. Boiler ash was applied as organic fertilizer @ 3, 12, 25, 50, 125 and 250 t ha^{-1} along with the basal dose of NPK @ 120, 90, and 60 kg ha^{-1} respectively, at the time of sowing in the form of Urea, K_2SO_4 and TSP. The crop received four irrigations, timed appropriately to suit the crop requirements. Weeds were controlled manually. Plants were harvested at maturity and the parameters for recording crop data were kept the same as in the pot experiment.

2.2 Soil and boiler ash sampling and analysis

Bulk soil samples from 0-30 cm depth were collected before sowing. The samples were air dried, ground and passed through a 2mm sieve. Boiler ash samples were also air dried and passed through a 4mm sieve. Also after harvest of the crop, soil samples from the plots of field experiment were collected, air dried and passed through a 2mm sieve. All of the soil samples before sowing and after harvesting, and the boiler ash samples, were analyzed for various physico-chemical characteristics. Particle size in soil samples was analyzed by a hydrometer method as described by Day (1965). Filtrate from soil and boiler ash samples extracted by ammonium acetate solution was used for determination of Na by Flame Photometer (Richard 1954). Ca^{++} + Mg^{++} were determined by EDTA titration where NH_4Cl-NH_4OH buffer solution and eriochrome black T indicator was used (Richard, 1954). Organic matter content in the soil and boiler ash samples was determined by dichromate method recommended by MAFF (1986). Five ml of the sample water extract (1 : 5) diluted to 25 ml, was titrated with 0.1 N H_2SO_4 using phenolphthalein and methyl orange indicator for CO_3^{--} and HCO_3^- determination, respectively, as stated by Richard (1954). Sample water extract, titrated against 0.05 N $AgNO_3$ using potassium chromate as an indicator was used for Cl^- determination (Richard, 1954). Total N was determined by

Table 1. Physico-chemical characteristics of soil:

S. No	Characteristics	Units	Value
1.	Dry Bulk Density	gm cm^{-3}	1.34
2.	Total Porosity	%	51.00
3.	pH		8.2
4.	E C_e	dSm^{-1}	0.38
5.	Ca^{++} + Mg^{++}	mg kg^{-1}	94
6.	Cl^-	mg kg^{-1}	93
7.	CO_3^{--}	mg kg^{-1}	26
8.	HCO_3	mg kg^{-1}	100
9.	SO_4^{--}	mg kg^{-1}	27
10.	Textural Class		Sandy Clay Loam
11.	$CaCO_3$	mg kg^{-1}	63000
12.	Available K	mg kg^{-1}	172
13.	O.M	mg kg^{-1}	8200
14.	Total N	mg kg^{-1}	300
15.	Available P	mg kg^{-1}	7.5
16.	Fe	mg kg^{-1}	5.4
17.	Mn	mg kg^{-1}	11.0
18	Cu	mg kg^{-1}	6.5
19	Zn	mg kg^{-1}	6.2

Table 2. Physico-chemical characteristics of boiler ash.

S. No	Characteristics	Units	Value
1.	pH		9.2
2.	EC_e	dSm^{-1}	2.4
3.	Ca^{++} + Mg^{++}	mg kg^{-1}	773
4.	Cl^-	mg kg^{-1}	1808
5.	CO_3^{--}	mg kg^{-1}	36
6.	HCO_3	mg kg^{-1}	1525
7.	SO_4^{--}	mg kg^{-1}	8160
8.	Soluble Na	mg kg^{-1}	920
9.	Available K	mg kg^{-1}	210
10.	O.M	mg kg^{-1}	Nil
11.	Total N	mg kg^{-1}	Nil
12.	Available P	mg kg^{-1}	110
13.	Fe	mg kg^{-1}	267.0
14.	Mn	mg kg^{-1}	194.0
15.	Cu	mg kg^{-1}	55.0
16.	Zn	mg kg^{-1}	65

the Kjeldahl procedure (Jackson 1964). Available K was determined by ammonium acetate method (Black, 1965). S was determined in the extractant by 0.15% calcium chloride dihaydrate with spectrophotometer (Williams & Steinbergs, 1959). P was estimated by formation of a phosphomolybdate complex, which is reduced by using ascorbic acid to produce a blue color (Lennox, 1979). Zn, Cu, Fe and Mn determination was made in 0.005 M DTPA extractant (Lindsay & Norvell, 1978) by atomic absorption spectrophotometer.

2.3 Statistical analysis

Statistical analysis of all the data was done using Fisher Analysis of Variance Technique. A least significant difference test was applied at 5% probability level to determine the difference among treatment means (Steel & Torrie, 1984).

3. Results and Discussion

The soil under investigation was low in organic matter, calcareous in nature, having high pH value and deficient in N, P and Zn (Table 1). The boiler ash was, however, rich in Ca, Mg, P, S, K and all micronutrients (Table 2).

The effect of various levels of boiler ash on the physico-chemical characteristics of soil and yield and yield components of wheat can be explained as below:-

3.1 Impact of boiler ash on physico-chemical characteristics of the soil.

Table 3 contains the detailed laboratory analysis of soil receiving different doses of boiler ash during the field experiment. The analysis reveals that like other organic wastes, boiler ash also affects the physico-chemical characteristics of the soil positively. The dry bulk density of the soil decreased from 1.34 gm cm^{-3} to 1.27 gm cm^{-3} and the total porosity of the soil increased from 51.0 to 52.10%, while the textural class remained the same. There was also a slight increase in soil pH from 8.2 in control to 8.90 in the treatment receiving boiler ash @ 250 t ha^{-1}. An increase in exchangeable calcium and magnesium contents was observed due to boiler ash. Available micronutrients, EC_e, P and K also increased in comparison to the control. The highest amounts of Phosphorus (49 mg kg^{-1}) and Potassium (230 mg kg^{-1}) was found in the treatments amended with 250 t ha^{-1} bagasse ash. Maximum Zn (16 mg kg^{-1}), copper (15 mg kg^{-1}), iron (16 mg kg^{-1}) and manganese (24 mg kg^{-1}) contents were also recorded in the soil receiving boiler ash @ 250 t ha^{-1}. The values recorded for EC_e (1.50 dsm^{-1}) and Ca^{++} + Mg^{++} (284 mg kg^{-1}) were also highest in the treatments getting boiler ash @ 250 t ha^{-1}.

The decrease in dry bulk density and improvement in soil porosity positively affect the water retention and moisture availability in the root zone. This ultimately results in better availability of plant nutrients and enhances plant roots proliferation in the soil. The analysis also reveals that, along with improvement in soil physical properties, boiler ash also increases the Ca, Mg, K, P and Micronutrient content of the soil. Deshmukh *et al.* (2000), during their field experiments, reported that application of 10 t fly ash ha^{-1} alone and in combination with NPK (100:50:50 kg/ha) improved the nutrient status and physicochemical properties of the soil. Although the amendments had some effects on soil bulk density, CEC, available micronutrients and slight improvement in exchangeable Ca and Mg, they did not have an effect on soil pH, soil EC, organic C content and available N status of

Table 3. Impact of boiler ash on the physico-chemical characteristics of soil.

S. No	Characteristics	Units	Soil treated with boiler's ash (t ha^{-1})						
			T_1	T_2	T_3	T_4	T_5	T_6	T_7
			0	3.0	12.0	25.0	50.0	125.0	250.0
1	Textural Class		Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam
2	Dry Bulk Density	gm cm^{-3}	1.34	1.34	1.32	1.31	1.30	1.28	1.27
3	Total Porosity	%	51.00	51.00	51.32	51.50	51.70	51.94	52.10
4	pH		8.2	8.2	8.3	8.5	8.5	8.80	8.90
5	EC_e	dsm^{-1}	0.38	0.70	0.95	1.20	1.32	1.40	1.50
6	Exchangeable $Ca^{++} + Mg^{++}$	mg kg^{-1}	94	180	230	242	258	270	284
7	Cl^-	mg kg^{-1}	93	241	268	282	296	324	348
8	CO_3	mg kg^{-1}	26	26	26	26	26.5	27	27.6
9	HCO_3	mg kg^{-1}	100	288	340	382	412	438	467
10	SO_4	mg kg^{-1}	26	105	131	173	207	230	262
11	Soluble Na	mg kg^{-1}	69	120	153	172	194	214	231
12	Exchangeable K	mg kg^{-1}	172	182	194	202	210	221	230
13	O. M	mg kg^{-1}	8200	8300	8600	8780	8900	9190	9450
14	Total N	mg kg^{-1}	300	300	300	300	300	300	300
15	Available P	mg kg^{-1}	7.5	36	40	42	44	47	49
16	Fe	mg kg^{-1}	5.4	8	10	11	13	15	16
17	Mn	mg kg^{-1}	11.0	16	18	19	22	23	24
18	Cu	mg kg^{-1}	6.5	8	9	10	12	14	15
19	Zn	mg kg^{-1}	6.2	9	11	12	13	15	16

the soil. Grewal *et al.* (2001) also found that fly ash application also resulted in greater moisture storage in the plough layer of soil at all the stages of crop growth. Braman *et al.* (1999) observed during a wide range experiments that metal contents (Cd, Cu, Zn, Fe, Ni, Cr and Pb) in the soil samples having fly ash were higher than in the control soil. Kumar (2002) studied the possibility of fly ash application to agricultural soils. The result revealed that fly ash application, particularly in higher amount (8% w/w) increased the pH and electrical conductivity of the soils, however, the application of low amount (2% and 4% w/w) favored plant growth and improved yield. Although the element concentration was found more in fly ash amended soils than the control. Lee *et al.* (2006) also concluded that fly ash could be mixed as a supplement with other inorganic soil amendments to improve the nutrient balance in paddy soils.

3.2 Plant height and Spike length

The data shown in Table 4 indicates that the application of boiler ash along with NPK fertilizer to pots increases the plant height significantly over the control. The maximum plant height (87.75 cm) was obtained from the treatment getting 250 t ha^{-1} boiler ash, which is statistically at par with treatments receiving 125 and 25 t ha^{-1} of boiler ash. All of the remaining treatments, including the control, are also statistically at par with each other. Minimum plant height (81.42 cm) was obtained from the control. The field experiment data given in Table 6 also reveals that the application of boiler ash, along with fertilizer, increases the plant height significantly over the control. The maximum plant height (103.5 cm) was obtained from the treatments getting 125 and 250 t ha^{-1} boiler ash, which is statistically at par with treatments receiving 25 and 50 t ha^{-1} boiler ash.

The data from the pots given in Table 4 show that the increase in spike length due to the application of boiler ash is statistically non-significant at the 5% level of probability. Maximum spike length of 11.88 cm was recorded in the treatments receiving 50 t ha^{-1} boiler ash, followed by 11.20 cm from the treatment getting boiler ash @ 25 t ha^{-1}. Minimum spike length (9.97 cm) was obtained from the control. The field experiment data listed in Table 6 indicates an increase in spike length over control but is statistically non-significant. Maximum spike length (11.0 cm) was recorded in the treatment receiving 50 t ha^{-1} boiler ash, followed by 10.8 cm from the treatment getting 125 t ha^{-1} boiler ash. Minimum spike length (9.75 cm) was obtained from the control.

It can be concluded from the results that this increase in plant height and spike length is due to the improvement in the nutrient status and physicochemical properties of the soil as affected by different doses of boiler ash and mineral fertilizer. The plant height and spike length in pots and field experiment might have increased due to abundant S, K and micronutrients, and improved soil physical condition. Improvement in soil porosity also contributes to better crop growth, regarding roots and shoots development in the soil and better availability of essential nutrients. Hernandez (2000) also found the best growth (height, diameter and biomass production) of Hyeronima alchorneoides and Terminalia Amazonia due to the application of organic wastes (including bagasse ash). Upadhayay *et al*. (2001) reported an increase in plant height and biomass of three native forest species treated with bagasse ash. Stosio and Tomaszewicz, (1999) also found a significant increase in different yield parameters of four winter crop varieties, including wheat, due to fly ash application.

3.3 Number of tillers and productive tillers plant^{-1} / m^2

The data from the pot experiments given in Table 4 reveal that the application of different doses of boiler ash, along with mineral fertilizer, brought significant changes in the number of tillers plant^{-1} over the control. The maximum number of tillers plant^{-1} (5.75) was recorded in the treatment getting 250 t ha^{-1} boiler ash, followed by 5.50 from the treatments receiving boiler ash @ of 125 and 50 t ha^{-1}. Both of which are statistically at par with each other and all the other treatments except the control. A minimum value of 3.75 tillers plant^{-1} was recorded in the control. The statistical analysis of field experiment data given in Table 6 shows that application of different doses of boiler ash, along with fertilizer, brought significant changes in the number of tillers m^{-2} over the control. The maximum number of tillers m^{-2} (409.0) was recorded in the treatment getting 250 t ha^{-1} boiler ash, which is statistically at par with the treatments receiving 50 and 125 t ha^{-1} boiler ash. A minimum value of 301.0 tillers m^{-2} was recorded in the control.

The number of productive tillers plant^{-1} in the pot experiment wase also affected positively and the data given in Table 4 shows a significant increase over the control. The number of productive tillers plant^{-1} (4.50) is maximum in the treatments having 125 and 250 t ha^{-1} boiler ash, followed by (4.25) in the treatment receiving 50 t ha^{-1} boiler ash. All of these treatments are statistically at par with each other and with the remaining treatments, except the control. It is also evident from the analyzed means that the treatments amended with 3, 12, 25 and 50 t ha^{-1} boiler ash are statistically at par with each other and with the control. A minimum number of productive tillers plant^{-1} (3.25) was obtained from the control. The field experiment data given in Table 6 shows a significant increase in number of productive tillers m^{-2}. The number of productive tillers m^{-2} (333.5) was maximum, in the treatment having 50 t ha^{-1} boiler ash. However, it was statistically at par with treatment getting 12 t ha^{-1} of boiler ash. A minimum number of productive tillers m^{-2} (245.0) was obtained from the control.

This work suggests that the significant increase in the number of tillers and productive tillers could be attributed to the enhanced germination of crop, due to improvement in soil physical and chemical properties and abundance of different nutrients depending on the addition of fertilizer and organic amendments. Therefore, it is concluded from the results that a combination of boiler ash and mineral fertilizer in pots and in field experiments helped to increase the number of tillers and productive tillers because it effectively increased exchangeable Ca and Mg, lime potential and P, Ca and micronutrients in the soil. Pawar and Dubey (1988) also found an increase in the germination percentage of maize, sorghum, wheat and gram [Cicer arietinum] treated with up to 10% fly ash and decreased with higher fly ash doses except in gram, which tolerated a 30% fly ash dose. Singh (1992) also observed during his study that boiler ash, which caused the significant increase in number of productive tillers m^{-2}, increased available phosphorus and micronutrients in the soil. Chen and Li (2006) also concluded that utilization of fly ashes as container substrate amendments should represent a new market for the beneficial use of coal combustion byproducts for better crop yield and soil improvement.

3.4 No of grains spike^{-1} and 1000-grain weight

The data in Table 5, reveal a significant increase in the number of grains spike^{-1} with increasing doses of boiler ash over the control in pots. A maximum number of 42.75 grains spike^{-1} was found in the treatment receiving 50 t ha^{-1} boiler ash, followed by 41.00 grains spike^{-1} recorded in the treatment receiving 25 t ha^{-1} boiler ash, both of which are statistically at par with each other and with the remaining treatments, except the control. It was also obvious from the data that all of the treatments getting different doses of boiler ash are statistically at par with each other and with the untreated control except the treatment receiving boiler ash @ 50 t ha^{-1}. The field experiment data presented in Table 7 also reveals a significant increase in the number of grains spike^{-1} with increasing doses of boiler ash over the control. A maximum number of 49.5 grains spike^{-1} were found in the treatment receiving 50 t ha^{-1} of boiler ash, followed by 48.5 grains spike^{-1} recorded in the treatment receiving boiler ash @ 125 t ha^{-1}. The treatments receiving 25, 50, 125 and 250 t ha^{-1} boiler ash are statistically at par with each other. A minimum number of grains spike^{-1} (40.8) was recorded in the non-treated control.

The pot experiment data on 1000-grain weight are given in Table 5. Means of the analyzed data show that the 1000-grain weight significantly increased with different doses of boiler ash. Maximum 1000-grain weight (41.35 g) was recorded in the treatment receiving 50 t ha^{-1} boiler ash followed by the treatment (40.78 g) having 25 t ha^{-1} boiler ash, both of which are statistically at par with each other. However, the treatment receiving boiler ash @ 25 t ha^{-1} is also statistically at par with the treatments receiving boiler ash @ 125 and 250 t ha^{-1}. The means of analysed data on

Table 4. Effect of different levels of boiler ash on plant height, spike length, no of tillers and productive tillers plant^{-1} (Pot experiment).

Treatments	Plant height (cm) *	Spike length (cm) *	No of Tillers plant^{-1} *	No of Productive Tillers plant^{-1} *
T_1	81.42 b	10.98 a	3.75 b	3.25 b
T_2	82.50 b	10.56 a	5.00 a	4.00 ab
T_3	84.00 b	10.91 a	4.75 ab	4.00 ab
T_4	84.83 ab	11.20 a	5.00 a	3.75 ab
T_5	84.16 b	11.88 a	5.50 a	4.25 ab
T_6	84.83 ab	10.95 a	5.50 a	4.50 a
T_7	87.75 a	10.49 a	5.75 a	4.50 a

* = Values followed by the same letters are not significantly different at μ = 0.05.

Table 5. Effect of different levels of boiler ash on the number of grains spike^{-1}, 1000-grain weight, grain and straw yield plant^{-1}

Treatments	Number of grains spike^{-1} *	1000-grain weight (g) *	Grain yield (g) palnt^{-1} *	Straw yield (g) plant^{-1} *
T_1	37.75 b	38.50 e	3.61 b	8.93 b
T_2	39.75 ab	39.28 d	4.50 a	11.04 ab
T_3	40.50 ab	40.08 c	5.07 a	11.05 ab
T_4	41.00 ab	40.78 ab	5.09 a	12.53 a
T_5	42.75 a	41.35 a	5.22 a	12.69 a
T_6	40.50 ab	40.75 b	5.10 a	12.65 a
T_7	40.75 ab	40.55 bc	5.03 a	13.57 a

* = Values followed by the same letters are not significantly different at μ = 0.05.

1000-grain weight from the field experiments are given in Table 7. Different doses of boiler ash produce a significant increase in the 1000-grain weight over the control. The maximum 1000-grain weight (41.2 g) was recorded in the treatment receiving 25 t ha^{-1} boiler ash followed by the treatment (40.9 g) having 50 t ha^{-1} boiler ash. Both of which are statistically at par with each other.

Improvement in soil porosity and abundant supply of micronutrients like Zn, Cu, Fe and Mn, along with Ca, Mg, P and K is recorded in the soil samples having different doses of boiler ash. Therefore, an increase in the number of grains spike^{-1} and the 1000-grain weight might be the effect of boiler ash application. The results also show that the combination of commercial NPK fertilizer with the boiler ash has affected the crop yield positively. Selvakumari *et al.* (1999) inferred that integration of fly ash alone and with other components of the nutrient supply system, because of synergistic effects, resulted in better nutrient uptake, higher yield and improved maintenance of soil fertility. Kalra *et al.* (1998) also reported that the 1000-grain weight in bagasse ash treatments increased significantly over the control due to the improvement in soil fertility, especially due to the availability of P and micronutrients like Zn and Cu. During their experiments, Kumar *et al.* (1999) found that the grain yield of wheat increased due to the favorable effects of fly ash on the soil structure, moisture retention and essential nutrients availabile in the soil. Sharma *et al.* (2001) also reported increased crop yield and improvements in the soil nutrient status due to the application of fly ash to the soil.

3.5 Grain and straw yield plant^{-1} / tones ha^{-1}

Grain yield, especially in cereal crops, is an important factor in determining the fertility and productivity of a certain soil. The results of statistically analyzed data recorded on grain yield (Table 5) reveal that all the different doses of boiler ash in pot experiments increase the grain yield significantly over the control. A maximum grain yield of 5.22 g was obtained from the treatment receiving 50 t ha^{-1} boiler ash followed by 5.10 g from the treatment receiving 125 t ha^{-1} boiler ash, both of which are statistically at par with each other and all of the remaining treatments, except the control. A minimum grain yield was recorded in the control (3.61 g). The field data recorded on grain yield m^{-2} presented in Table 7 also reveals a significant increase. A maximum grain yield (5.2 t ha^{-1}) was obtained from the treatment receiving 50 t ha^{-1} boiler ash followed by 5.1 t ha^{-1}, from the treatment receiving 125 t ha^{-1} boiler ash, both of which are statistically

Table 6. Effect of different levels of boiler ash on plant height, spike length, no of tillers and productive tillers m^{-2} (Field experiment).

Treatments	Plant height (cm) *	Spike length (cm) *	No of Tillers m^{-2} *	No of Productive m^{-2}*
T_1	83.3 d	9.8 b	301.0 e	245.0 f
T_2	86.0 c	10.0 ab	330.3 d	263.5 e
T_3	91.3 b	10.3 ab	354.5 c	289.0 d
T_4	102.5 a	10.5 ab	385.5 b	312.0 bc
T_5	102.8 a	11.0 a	400.0 a	333.5 a
T_6	103.5 a	10.8 ab	406.0 a	325.0 ab
T_7	103.5 a	10.5 ab	409.0 a	310.5 c

* = Values followed by the same letters are not significantly different at $\mu = 0.05$.

Table 7. Effect of different levels of boiler ash on the number of grains $spike^{-1}$, 1000-grain weight, grain and straw yield tones ha^{-1}

Treatments	Number of grains $spike^{-1}$ *	1000-grain weight (g) *	Grain yield tones ha^{-1}*	Straw yield tones ha^{-1}*
T_1	40.8 d	36.17 e	3.2 f	5.8 d
T_2	42.8 cd	37.2 d	3.7 e	6.1 d
T_3	45.0 bc	37.7 d	4.3 d	6.8 c
T_4	47.0 ab	41.2 a	4.6 c	7.5 b
T_5	49.5 a	40.9 ab	5.2 a	7.8 ab
T_6	48.5 a	40.2 bc	5.1 ab	7.9 a
T_7	47.0 ab	39.9 c	4.8 bc	8.0 a

* = Values followed by the same letters are not significantly different at $\mu = 0.05$.

at par with each other. A minimum grain yield (3.2 tones ha^{-1}) was recorded in the control.

The statistically analyzed data from pots, regarding straw yield, is given in Table 5. A maximum straw yield (13.57 g) $plant^{-1}$ was obtained from the treatment, receiving 250 t ha^{-1} boiler ash, followed by 12.69 g $plant^{-1}$ from the treatment receiving 250 t ha^{-1} boiler ash. Both of the treatments were statistically at par with each other and with all other treatments getting different doses of boiler ash except the control. Control gave minimum straw yield (8.93 g) $plant^{-1}$ followed by 11.04 g and 11.05 g $plant^{-1}$ from the treatments receiving 3 and 12 t ha^{-1} boiler ash respectively. All of these three treatments were statistically at par with each other. Statistical analysis of the data from field experiment (Table 5) showed significant increase in straw yield. Maximum straw yield (7.97 t ha^{-1}) was obtained from the treatment which was added 250 t ha^{-1} boiler ash followed by 7.89 t ha^{-1} from the treatment getting 125 t ha^{-1} boiler ash. The control gave a minimum straw yield (5.80 t ha^{-1}).

This significant increase in grain and straw yield of wheat in both experiments was possible due to the availability of better nutrients and improved development of the plants, along with greater proliferation of roots and tillers due to the favorable effects of boiler ash on soil physical characteristics. It is also evident from the study that bagasse ash application, along with mineral fertilizer, positively changed the Ca, Mg and K availability and micro nutrient contents of the soil. Therefore, it might have significantly affected the grain and straw yield in wheat crop. As boiler ash increased the exchangeable calcium, and magnesium contents, this may be recognized as a positive influence on the structure-forming capacity of the soil and a favorable factor for higher crop yield. Malewar *et al.* (1999) reported a significant increase in dry matter weight of wheat crop treated with fly ash. Mlynkowiak *et a*l. (2001) observed during their experiments that application of different doses of fly ash increased the grain yield in wheat crop. Singh and Siddiqui (2003) also found increased grain yield in wheat crop due to dusting of different doses of fly ash. Dee *et al.* (2003) applied sugar industry wastes, including boiler ash, and found it also increased grain yield in maize crop.

4. Conclusion

Boiler ash is generally considered a waste product, however, the present findings show it is rich in micronutrients and also contains sufficient amounts of Ca, Mg and other macro-nutrients like P and K. Different levels of boiler ash positively influence the physico-chemical properties of soil, and most of the yield parameters of wheat crop improved in response to its favorable effects on the soil characteristics. Utilization of boiler ash as organic fertilizer can also save the cost of chemical fertilizer along with minimizing environmental pollution. By comparing the levels of bagasse ash application, 50 t ha^{-1} was found to be the optimal dose regarding important yield parameters, such as, the number of productive tillers $plant^{-1}$, the number of grains $spike^{-1}$, the 1000-grain weight and the grain yield of wheat crop in calcareous soil.

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