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Phosphorus fertilizing potential of biomass ashes and their effect on bioavailability of micronutrients in wheat (*Triticum aestivum*. L)

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Abstract: Ashes from agricultural biomass in agro-based industries have been found to have most of the plant nutrients except nitrogen and sulphur but are treated as waste material. The present study was conducted to evaluate the potential of biomass ashes as source of P and their effect on bioavailability of micronutrients in wheat crop. We conducted the pot experiment at glass house of the Department of Soil Science, Punjab Agricultural University, Ludhiana, India. The experiment consisted of combinations of four P sources [bagasse ash (BA), rice husk ash (RHA), rice straw ash (RSA), fertilizer P (Fert-P)] supplying P at three levels (10, 20 and 30 $\mu g\ g^{-1}$) along with one zero-P control. This experiment was laid out in completely randomized design (CRD) having three replications. Application of P through RSA produced significantly higher grain yield (14.3 g pot^{-1}) than BA (12.8 g pot^{-1}) and RHA (12.9 g pot^{-1}) but statistically at par with Fert-P (13.5 g pot^{-1}). Grain Zn content decreased maximum than other micronutrients with application of P from all sources, hence maximum increased P/Zn ratio. Phosphorus applied from all the biomass ashes significantly increased biomass and yield over control. With increase in P application, micronutrients content in grain was significantly decreased, hence decreased bioavailability of micronutrients in wheat grain.

Keywords: Bagasse ash, Micronutrients, Phosphorus fractions, Rice husk ash, Rice straw ash

INTRODUCTION

The search for alternative fertilizer sources has become increasingly important due to drastic rise of prices for commercial fertilizers. Moreover, yield of many crops such as rice and wheat are now showing signs of fatigue and no longer exhibiting increased production with increased chemical fertilizer use. The stagnation or decline in wheat production raises concerns about the sustainability of such chemical inputs driven production system and the food security of the region (Ladha *et al*., 2003). The possible reasons for such yield stagnation are non-judicious use of nutrients in relation to amount, timing and balance, and less use of organics (Ladha *et al*., 2005). In such cases, repeated application of organic manures is often recommended to maintain soil fertility. However, the use of organic manures is generally decreasing because of farm mechanization and a decrease in the size of livestock. Because commercial fertilizer prices continue to rise, organic manures including agricultural waste biomass ashes remain a valuable alternative to commercial fertilizers (Bolan *et al*., 2004).

Bagasse and rice husk are important agro-industrial by-product wastes which are generally used as fuel in sugar and rice mill industry, respectively. In India,

about 7.63 mt of bagasse ash (BA) and 6.37 mt of rice husk ash (RHA) are produced every year (Beri and Gupta, 2003). Large quantities of rice straw are converted to ash during various processes involved in its utilization for bioenergy. The disposal of these ashes has become a serious problem for mill owners, municipal administration and environmental organizations. These ashes contain nearly all the nutrients except N and S, which are lost to the atmosphere during burning due to their conversion into gaseous form. These materials are cheap, easily available and can be effectively used as amendment in agriculture for soil fertility improvement; otherwise they will pollute the environment and encroach upon vast areas of productive land in their present mode of disposal. The use of wood ash as a soil amendment has been well documented in the United States (Vance 1996; Mitchell and Black 1997; Patterson *et al*., 2004). The lack of research on use of agricultural waste biomass ashes has resulted in regulators being reluctant to classify rice husk ash and bagasse ash as soil amendments until benefits resulting from its application have been demonstrated. Ashes as amendment have been found to increase soil pH, availability of nutrients and improved physical properties of soils (Giovannini *et al*., 1993; Demeyer *et al*., 2001;

Saarsalmi *et al.*, 2001). Earlier studies showed increases in maize yield with the application of cocoa husk ash and alfalfa ash (Onwuka *et al.*, 2007) and of rice yield with the application of rice husk ash (Prakash *et al.*, 2007; Nwite *et al.*, 2011). Ayeni *et al.* (2008) observed the direct application of cocoa pod husk ash at 10 t ha^{-1} increased grain yield of maize by 31 % on a sandy loam Alfisol. Mozaffari *et al.* (2002) have observed an increase in maize yield accompanied by significant increase in P and K uptake with the application of alfalfa ash. Talashilkar and Chavan (1996) reported an increase in rice grain yield as well as P uptake with the application of RHA. Thind *et al.* (2012) also reported that the application of RHA and BA to wheat at the rate of 10 t ha^{-1} along with recommended fertilizers resulted in 25 and 24 % increase in mean grain yield of wheat and 10 and 11 % in subsequent rice crop in rice-wheat system, respectively. It is established that wheat responds more to P than rice in rice-wheat system (Yadvinder-Singh *et al.*, 2009). Nutrient composition and other properties of ashes are affected by different factors. Firstly, the kind of biomass combusted influences the quality and the nutrient values of ashes. For example, P concentrations range from 0.01 % in bagasse ash (Jamil *et al.*, 2004) to about 0.5 % P in cocoa husk ash (Onwuka *et al.*, 2007) and 0.09 % in alfalfa stem fly ash (Mozaffari *et al.*, 2002).

Fertilization with P increases cereal crop yields which help to meet growing food demand. These yield increases, have led to declines in concentration of micronutrients such as Fe, Zn, Mn and Cu in cereal grain (Fan *et al.*, 2008; Murphy *et al.*, 2008), which are often critical sources of micronutrients for humans (Cakmak 2008). Phosphorus applications have been reported to negatively affect the shoot and even grain Zn concentration in cereal crops (Stukenholtz *et al.*, 1966; Ryan *et al.*, 2008). In addition, complex interactions of P with cations such as Mn, Fe and especially Zn are known to occur. Although the bioavailability of micronutrients in foods is difficult to determine, it can be predicted by the molar ratio of P to micronutrients (P/Zn) (Bohn *et al.*, 2008; Ryan *et al.*, 2008). The molar ratio of grain P to micronutrients, therefore, could be also used as a simple indicator of micronutrients bioavailability (Zhang *et al.*, 2010; Kutman *et al.*, 2011). Furthermore, crop biomass ashes (rape meal ash, cereal ash and wheat straw ash) have been reported as an efficient P source comparable to commercial fertilizers (Schiemenz and Eichler-Lobermann, 2010). Therefore, this study was undertaken to evaluate the potential of biomass ashes as a source of P for wheat and their effect on bioavailability of micronutrients.

MATERIALS AND METHODS

Site of study: The pot experiment was conducted using wheat crop at glass house of the department of Soil Science, Punjab Agricultural University, Ludhiana, India. At the initiation of the experiment, soil studied had sandy loam texture, pH of 7.23(1:2 soil water suspension), electrical conductivity was 0.21ds m^{-1}. Contents of soil organic carbon (4.20 g kg^{-1}) and available K (226 kg ha^{-1}) were medium and Olsen-P (13.15 kg ha^{-1}) (Olsen *et al.*, 1954) was medium.

Experimental details: The soil was ground, passed through 2 mm sieve and was treated with four level of P from different four sources of P including three different ashes and one fertilizer. The experiment consisted of treatment combinations of four different phosphorus sources [bagasse ash (BA), rice husk ash (RHA), rice straw ash (RSA), fertilizer P (Fert-P)] and three P levels (10, 20 and 30 µg g^{-1}) designated as P_{10}, P_{20} and P_{30}, respectively along with one P_0 control. The screen house experiment was laid out in a completely randomized design with three replications. The P content of different biomass ashes (BA-0.137 %, RHA -0.082 %, RSA-0.103 %) was determined and the rate of application of different biomass ashes was as per the P levels. Single superphosphate was used in P fertilizer treatment.

Six kg soil was filled in polythene lined earthen pots. The required amounts of different ashes were applied in each pot and mixed thoroughly. The soil in the pots was subjected to alternate wetting and drying cycles for 10 days to attain equilibrium. The double of recommended dose of N and K_2O (100:24 kg ha^{-1}) were applied to wheat. Eight seeds of wheat were sown in each pot. After germination, plants were thinned to maintain 4 plants per pot. The soil in the pots was irrigated as and when required with distilled water.

Soil and plant analysis: Plants were harvested at two stages, half at maximum tillering stage (49 days after sowing) and remaining half at maturity stage. At maximum tillering stage the shoot samples were harvested with the help of steel blade. For collection of roots the polythene bags were taken out from the pots. The soil was washed gently with tap water from each polythene bag. The roots were separated and put in the stainless steel sieve and washed with tap water, water jet, acidified water and finally with double distilled water. The harvested shoot samples were also washed with acidified water, distilled water and double distilled water. The washed shoot and root samples were air dried in paper bags and then in oven at 65±2 ^{0}C. Thereafter, the shoot and root biomass was weighted for dry matter yield. Shoot and root samples were ground and stored in polythene bags for chemical analysis. At maturity, plants were harvested and weighed for total biomass (grain+straw) from each pot. Samples were threshed manually by beating against hard surface. After threshing, grain and straw samples were collected and weighted from each pot. The grain

samples were counted for each pot. Representative soil sample from each pot was taken with steel tube auger. These samples were air dried, ground, sieved and stored in polythene bags for further chemical analysis. Olsen-P and available K in soil samples were determined using 0.5N NaHCO$_3$ extractable P method (Olsen *et al.*, 1954) and ammonium acetate extractable K using flame photometer (Jackson, 1973), respectively. Grain and straw samples were analyzed for total P and K content using Vanado-Molybdo-Phosphoric yellow colour method in nitric acid (Jackson, 1973) and flame photometer, respectively. For micronutrients 0.5 gm of grounded sample taken in test tube and added 10 ml of di-acid (distilled HNO$_3$ and HClO$_4$ in the ratio of 3:1) and determined using atomic absorption spectrophotometer.

Statistical analysis: Analysis of variance (ANOVA) was carried out using CPCS1 and LSD at 0.05 level of probability was used to test the significance of differences among treatment means. MS EXCEL (Microsoft Corporation, Red-land, CA, USA) was used for graphical representation of the results.

RESULTS AND DISCUSSION

Plant biomass, grain yield and straw yield: The application of P$_{10}$ from RSA and Fert-P caused significant (p=0.05) increase in shoot biomass over the P$_0$ which further increased significantly at P$_{20}$ (Table 1). However, BA as source of P caused significant increase only at P$_{20}$ but RHA failed to cause significant increase at all the P levels applied. Irrespective of P levels, shoot biomass was significantly higher when P was applied through RSA and Fert-P than BA which was significantly higher than RHA. Application of P, irrespective of sources, caused significant increase in

shoot biomass with increase from P$_{10}$ to P$_{20}$ and also with further increase to P$_{30}$. In all the sources, significant increase was resulted in root biomass at P$_{10}$ over the P$_0$ except RHA which caused significant increase at P$_{30}$. With application of BA and RSA root biomass was further increased significantly when P was from P$_{10}$ to P$_{30}$. Irrespective of P levels, RHA produced minimum root biomass which was significantly increased in BA and RSA which further increased significantly in Fert-P. Irrespective of P sources, there was significantly increased in root biomass with increase in P level from P$_{10}$ to P$_{20}$.

Application of P$_{10}$ caused significant increase in grain and straw yield over P$_0$ in all sources except RHA which caused significant increase at P$_{20}$. The application of P$_{10}$ from RSA produced significantly higher grain yield than P$_{10}$ from RHA. The application of P through RSA, irrespective of P levels, produced significantly higher grain yield as compared with P applied through BA and RHA, but yield was statistically at par with Fert-P. The application of P$_{20}$, irrespective of P sources, increased the grain yield significantly as compared to P$_{10}$. At the highest rate of P applied (P$_{30}$), the increase in the grain yield was 43, 37, 29 and 27 % in RSA, Fert-P, RHA and BA, respectively, over P$_0$. The straw yield produced with application of RHA as source of P was significantly lower than all other P sources which were at par among themselves.

Yield attributing characters: The application of P$_{10}$ from RSA and Fert-P; while P$_{20}$ applied from BA and RHA caused significant (p=0.05) increase in plant height over P$_0$ (Table 1). The application of P$_{10}$ through RSA caused significantly higher plant height than P$_{10}$ using BA and RHA. The plant height with application of RSA and Fert-P as source of P, irrespective of P

Table 1. Plant biomass, grain, straw yield (g pot^{-1}) and yield attributing characters of wheat as influenced by various levels of phosphorus applied through different sources.

P sources	P levels (µg g^{-1})	Shoot biomass	Root biomass	Grain yield	Straw yield	Plant height (cm)	Effective tiller count plant^{-1}	No of grains pot^{-1}	1000 grain weight
P sources	BA	4.69	1.93	12.8	20.4	84.8	4.91	412	31.0
	RHA	3.69	1.51	12.9	17.9	85.3	4.89	413	31.1
	RSA	5.39	1.96	14.3	22.1	91.2	5.08	460	31.1
	Fert-P	5.27	2.26	13.5	21.1	90.1	5.10	440	30.6
	LSD(0.05)	0.579	0.224	0.90	2.17	4.45	NS	21.6	NS
Levels	10	4.06	1.69	12.5	19.4	77.4	4.60	405	30.9
	20	4.82	1.93	13.7	21.1	87.2	5.13	432	31.6
	30	5.40	2.12	13.9	20.7	99.0	5.27	457	30.3
	LSD(0.05)	0.501	0.194	0.78	NS	3.85	0.267	18.7	NS
Control vs Treatments									
	Treatments	4.76	1.91	13.3	20.4	87.8	5.00	431	30.9
	Control	2.85	1.15	10.4	13.7	70.3	4.14	343	30.3
	LSD(0.05)	0.738	0.286	1.14	2.77	5.67	0.393	27.4	NS

Table 2. Phosphorus content (%) and uptake (mg pot^{-1}) in wheat as influenced by various levels of phosphorus applied through different sources.

P sources	P levels (µg g^{-1})	P content				P uptake			
		shoot	Root	grain	straw	shoot	root	grain	straw
P sources	BA	0.301	0.162	0.245	0.052	14.1	3.15	31.2	10.3
	RHA	0.309	0.177	0.241	0.051	11.4	2.66	31.1	9.10
	RSA	0.291	0.180	0.251	0.046	15.6	3.53	35.9	10.2
	Fert-P	0.253	0.183	0.267	0.055	13.5	4.12	36.1	11.6
	LSD(0.05)	0.0340	NS	0.0205	NS	2.12	0.467	3.33	1.40
Levels	10	0.278	0.166	0.236	0.045	11.3	2.79	30.0	8.73
	20	0.291	0.178	0.252	0.051	13.8	3.43	36.1	10.6
	30	0.298	0.183	0.265	0.056	15.9	3.87	39.6	11.6
	LSD(0.05)	NS	NS	0.0177	0.0065	1.83	0.404	2.30	1.21
Control vs Treatments									
	Treatments	0.289	0.175	0.251	0.051	13.7	3.36	33.6	9.97
	Control	0.266	0.190	0.221	0.038	7.7	2.16	23.3	4.07
	LSD(0.05)	NS	NS	0.0261	0.0097	2.70	0.595	4.25	1.200

Table 3. Zinc and iron content (mg kg^{-1}) in wheat as influenced by various levels of phosphorus applied through different sources.

P sources	P levels (µg g^{-1})	Zn content				Fe content			
		Shoot	root	grain	straw	shoot	root	grain	straw
P sources	BA	71.2	64.0	39.4	9.51	426	693	71.0	190
	RHA	71.5	68.5	36.9	8.68	411	685	62.0	172
	RSA	70.9	49.4	36.6	9.79	526	667	47.7	237
	Fert-P	70.9	54.2	36.6	9.63	471	656	55.7	210
	LSD(0.05)	NS	4.6	2.28	NS	37.0	NS	8.25	5.5
Levels	10	74.3	61.7	40.2	10.37	427	614	61.3	187
	20	71.2	59.3	36.8	8.96	464	660	58.1	206
	30	67.9	56.1	35.1	8.89	484	751	57.8	213
	LSD(0.05)	4.17	3.98	1.98	0.748	32.1	54.9	NS	4.8
Control vs Treatments									
	Treatments	71.1	59.0	37.4	9.40	459	675	59.1	202
	Control	82.0	84.1	46.2	13.05	404	666	81.4	185
	LSD(0.05)	6.14	5.86	2.91	1.101	47.2	NS	10.51	7.0

levels, was significantly higher than BA and RHA. Irrespective of P sources, the P levels increased plant height significantly with increase in P level from P_{10} to P_{20} and further to P_{30}. Application of Fert-P at P_{10} resulted significant increase in effective tiller count over P_0 which was further increased significantly at P_{20} however biomass ashes caused significant increase only at P_{20}. Application of P, irrespective of sources, increased effective tiller count significantly with increase in P level from P_{10} to P_{20}. Application of P_{10} from all the sources caused significant increase in grain number over P_0 which further increased significantly at P_{30}. Among the all P sources RSA resulted maximum grain number which was at par with Fert-P and significantly higher than BA and RHA. Thousand grain weight was not significantly affected with different P sources and levels.

P content: Among the P sources, irrespective of P levels, the P content in shoot biomass was significantly (p=0.05) lower with application of Fert-P than all other P sources which were statistically at par among themselves (Table 2). Application of different P sources at different levels failed to cause significant effect in root P content. Application of P_{30} caused significant increase in P content in grain over the P_0 in all sources except Fert-P which caused significant increase at P_{20}. The application of P_{20} through Fert-P caused significantly higher P content in grain than P_{20} using RHA. Application of Fert-P, irrespective of P levels, caused significantly higher grain P content than BA and RHA. The application of P_{20} caused significant increase in P content in straw over the P_0 in all sources except RSA which caused significant increase at P_{30}. Different P levels, irrespective of P sources, increased

Table 4. Copper and manganese content (mg kg^{-1}) in wheat as influenced by various levels of phosphorus applied through different sources.

P sources	P levels (µg g^{-1})	Cu content				Mn content			
		shoot	Root	grain	Straw	shoot	root	grain	straw
P sources	BA	8.68	19.7	7.90	2.76	17.5	140	20.0	9.91
	RHA	8.06	19.5	8.16	2.59	15.9	137	18.0	8.53
	RSA	7.47	18.9	7.82	2.37	17.9	139	16.4	9.94
	Fert-P	8.48	19.5	8.44	2.66	16.5	138	17.0	9.55
	LSD(0.05)	NS	NS	0.468	NS	1.46	NS	1.20	0.438
Levels	10	8.95	21.4	8.58	2.84	17.4	130	18.1	10.3
	20	7.80	18.9	7.87	2.40	17.0	141	17.7	9.46
	30	7.77	18.0	7.79	2.55	16.4	146	17.7	8.69
	LSD(0.05)	0.986	0.97	0.406	0.275	NS	6.8	NS	0.379
Control vs Treatments									
	Treatments	8.17	19.4	8.08	2.59	16.9	139	17.9	9.48
	Control	9.98	25.5	9.18	3.17	14.6	114	24.3	8.18
	LSD(0.05)	1.452	1.43	0.597	0.405	1.86	10.1	1.53	0.558

Table 5. P/Zn and P/Fe ratio in wheat as influenced by various levels of phosphorus applied through different sources.

P sources	P levels (µg g^{-1})	P/Zn				P/Fe			
		shoot	root	grain	straw	shoot	root	grain	straw
P sources	BA	42.5	25.6	59.1	48.5	7.08	2.39	27.0	2.87
	RHA	43.6	26.2	58.2	48.0	7.64	2.63	26.6	2.84
	RSA	41.1	37.3	60.6	43.2	5.55	2.75	27.7	2.55
	Fert-P	35.7	34.1	64.4	51.7	5.47	2.82	29.4	3.05
	LSD(0.05)	4.81	4.73	NS	NS	0.971	NS	NS	NS
Levels	10	37.4	27.7	57.0	42.5	6.65	2.78	26.0	2.51
	20	40.9	30.7	60.8	48.2	6.44	2.73	27.8	2.85
	30	43.8	34.0	63.9	53.0	6.22	2.44	29.2	3.13
	LSD(0.05)	4.17	4.10	4.28	6.18	NS	NS	1.96	0.365
Control vs Treatments									
	Treatments	40.7	30.8	60.6	47.9	6.43	2.65	27.7	2.83
	Control	32.9	22.6	53.3	35.5	6.6	2.86	24.4	2.10
	LSD(0.05)	6.14	6.04	6.31	9.10	NS	NS	2.88	0.538

P content in straw significantly with increase in P level from P_{10} to P_{30}.

P uptake: Application of P_{20} from all sources caused significant (p=0.05) increase in P uptake in shoot over the P_0 except RSA which caused significant increase at P_{10} (Table 2). The application of P_{20} using RSA caused significantly higher P uptake in shoot than P_{20} from RHA. Irrespective of P levels, the P uptake in shoot with application of RHA as source of P was significantly lower than BA and RSA and statistically at par in Fert-P. There was significant increase in shoot P uptake with increase in P level from P_{10} to P_{20} which further increased to P_{30}. Application of P_{10} from Fert-P while P_{20} applied through BA and RSA caused significant increase in P uptake in root over the P_0 but RHA

caused significant increase at P_{30}. Application of P_{30} from Fert-P caused significantly higher P uptake in root than P_{30} from BA and RHA. The lowest P uptake in root was recorded in RHA, irrespective of P levels, which increased significantly in BA and RSA which further significantly increased in Fert-P.

Grain P uptake was significantly increased with P_{10} applied from RSA and Fert-P over the P_0 but BA and RHA caused significant increase only at P_{20}. Application of Fert-P, irrespective of P levels, caused significantly higher P uptake in grain than BA and RHA. Application of P_{10} resulted significant increase in straw P uptake over P_0 in all sources except RHA which caused significant increase at P_{20}. With increase in P level from P_{10} to P_{20} with application of RSA and

Table 6. P/Cu and P/Mn ratio in wheat as influenced by various levels of phosphorus applied through different sources.

P sources	P levels (μg g^{-1})	P/Cu				P/Mn			
		shoot	root	grain	straw	shoot	root	grain	Straw
P sources	BA	358	82.4	310	147	174	11.6	129	44.8
	RHA	393	92.5	305	146	197	12.8	127	44.3
	RSA	396	96.7	318	131	164	13.0	132	39.9
	Fert-P	304	94.7	338	157	155	13.3	140	47.7
	LSD(0.05)	64.3	NS	NS	NS	25.7	NS	NS	NS
Levels	10	320	78.2	299	129	160	12.8	124	39.2
	20	379	93.9	319	146	173	12.7	133	44.5
	30	389	103	335	161	184	12.5	139	48.9
	LSD(0.05)	55.7	10.3	22.5	18.8	NS	NS	9.3	5.71
Control vs Treatments									
	Treatments	363	91.6	318	145	172	12.7	132	44.2
	Control	270	74.6	280	108	183	16.9	116	32.8
	LSD(0.05)	82.0	15.2	33.1	27.6	NS	2.36	13.8	8.40

Table 7. Soil pH, EC (dSm^{-1}), Olsen-P (kg ha^{-1}) and P fractions (μg g^{-1}) as influenced by various levels of phosphorus applied through different sources.

P sources	P levels (μg g^{-1})	Parameters			P fractions			
		pH	EC	Olsen-P	Al-P	Fe-P	Ca-P	Org-P
P sources	BA	7.47	0.229	7.53	14.4	43.5	547	77.8
	RHA	7.53	0.228	7.55	14.0	42.4	556	77.7
	RSA	7.65	0.231	7.74	14.3	47.2	570	80.1
	Fert-P	7.19	0.230	7.60	14.3	44.0	577	79.4
	LSD(0.05)	0.06	NS	NS	NS	NS	NS	NS
Levels	10	7.39	0.228	7.12	13.4	41.6	482	74.6
	20	7.47	0.230	7.57	14.4	44.9	571	79.1
	30	7.52	0.230	8.12	14.9	46.4	635	82.5
	LSD(0.05)	0.052	NS	0.197	1.11	NS	40.1	4.63
Control vs Treatments								
	Treatments	7.46	0.230	7.60	14.3	44.3	562	78.7
	Control	7.23	0.228	6.74	12.2	37.1	388	67.7
	LSD(0.05)	0.076	NS	0.289	1.64	6.96	59.1	6.82

from P_{10} to P_{30} with application of Fert-P resulted significant increase in straw P uptake. Application of P_{10} through BA caused significantly higher P uptake in straw than P_{10} using RHA. The application of P_{30} from Fert-P caused significant higher P uptake in straw than with P_{30} from BA and RHA. The P uptake in straw with application of RHA caused significantly lower than all other P sources which were at par among themselves.

Micronutrients content: Zinc content was significantly (p=0.05) decreased with increase in P levels, irrespective of P sources in shoot, root, grain and straw (Table 3). Grain Zn content was significantly decreased with increase in P level from P_{10} to P_{20} with application of RHA and RSA and from P_{10} to P_{30} using Fert-P. The application of P_{30} caused decrease in the grain Zn content which was 28, 25, 25 and 18 % in Fert-P, RHA, RSA and BA, respectively, over P_0. The results

revealed that shoot, root and straw Fe and Mn content were significantly increased with increasing P levels (Table 3, 4). But grain Fe content was significantly decreased with increase in P application. Application of P_{10} from RSA and Fert-P while P_{20} applied from BA and RHA caused significant decrease in grain Fe content over the P_0. Within application of different biomass ashes, the lowest Fe content in grain was recorded in RSA which significantly increased in RHA which further increased significantly in BA. Application of P_{10} caused significant decrease in Mn content in grain in all the sources over the P_0 which was further significantly increased with increase in P level from P_{20} to P_{30} with application of Fert-P. Root, grain and straw Cu content showed significant decrease with increasing P levels, however, maximum decrease was with application of RSA (Table 4). Application of P_{10} from BA while P_{20} applied from RHA and RSA caused

significant decrease in grain Cu content over the P_0 but Fert-P caused significant decrease at P_{30}. There was significant increase in Cu content in grain with increase in P level from P_{20} to P_{30} through RSA. Application of Fert-P, irrespective of P levels, caused significant higher Cu content in grain than BA and RSA.

Molar ratio of P to micronutrients: Molar ratio is the concentration ratio with one nutrient to other nutrient which gives the idea how one nutrient concentration effects other. Molar ratio of P/Zn in shoot, root, grain and straw was significantly (p=0.05) increased by as much as 1.5 to 2 fold with increasing P levels which showed with increase in P concentration in biomass decreased the Zn concentration due to antagonistic effect (Table 5). P/Cu in biomass, grain and straw was also significantly increased with P applied from different sources (Table 6). Application of P_{20} from Fert-P while P_{30} from BA and RSA caused significant increase in grain P/Cu over the P_0 while RHA was failed to cause significant affect. The P/Fe and P/Mn in shoot and root resulted no significant effect with P application, however, grain and straw molar ratio significantly increased with P applied.

Soil pH, electrical conductivity and Olsen-P: The application of P at different rates from different sources significantly (p=0.05) affected the soil pH (Table 7). Application of P_{10} caused significant increase in soil pH over the P_0 in all sources except Fert-P which failed to cause significant affect in soil pH. There was further significant increase in soil pH with increase in P level from P_{10} to P_{20} with application of BA, RHA and RSA. The application of P_{10} and P_{20} through RSA caused significantly higher soil pH than P_{10} and P_{20} using all other sources. Irrespective of P levels, application of RSA caused significant increase in soil pH than P from BA and RHA which were statistically at par among themselves. Application of P from different sources failed to cause significant effect on soil EC. Phosphorus applied from different sources significantly increased Olsen- extractable P (Table 7). Olsen-P was significantly increased with increase in P level from P_{20} to P_{30} with application of BA and from P_{10} to P_{30} with application of RHA, RSA and Fert-P.

P fractions: Phosphorus applied through different biomass ashes failed to cause significant effect in all the P fractions. But with increase in P levels, significant (p=0.05) increase was showed in Al-P, Ca-P and Org-P content. The application of P_{10} caused significant increase in Ca-P content over the P_0 using all sources except BA which caused significant increase at P_{20}. There was further significant increase in Ca-P content with increase in P level from P_{10} to P_{30} with application of Fert-P and from P_{10} to P_{20} using RHA and RSA.

The results of the present study showed that wheat grain and straw yield increased with addition of biomass ashes, which is in accordance with the results of Thind *et al.* (2012) who reported that the application of RHA

and BA to wheat at the rate 10 t ha^{-1} along with recommended fertilizer resulted in 25 and 24 % increase in mean grain yield of wheat. The significant (p=0.05) increase in grain yield with the application of RHA and BA seems to be attributed to the increased availability of nutrients and favorable effects of ashes on soil physical conditions and microbial processes (Demeyer *et al.*, 2001). Nwite *et al.* (2011) reported that RHA produced significantly higher maize yield (5.75 t ha^{-1}) than wood ash (1.51 t ha^{-1}) and leaf ash (0.60 t ha^{-1}) when these ashes were applied at the rate of 3 t ha^{-1}. Lopez *et al.* (2009) reported that sugarcane ash produced significantly higher lettuce yield and P uptake over control. They also observed that application of rape meal ash produced significantly higher yield of ryegrass and oil radish as compared with control. Significant increases in yield of ryegrass and oil radish were accompanied by significant increase in plant P uptake. In our experiment application of RSA statistically showed similar yield to Fert-P which may be ascribed to fact that RSA has the ability to buffer the soil which may initiate the release of available nutrients in the soil, which is in agreement with the findings of Bachmann and Eichler-lobermann (2010), who reported that application poultry litter ash produced statistically similar yield of ryegrass and oil radish and plant P uptake to fertilizer P (KH$_2$PO$_4$) applied.

Jamil *et al.* (2004) investigated the effects of BA on the yield of wheat and reported that application of BA at the rate 2.0 % caused significant increase in plant height, spike length, number of productive tillers m^{-2}, number of grains spike^{-1} and grain yield over control. Priyadharshini and Seran (2009) reported that application 4.5 t RHA ha^{-1} produced higher number of nodules, pods per plants and 100 seed weight of cowpea over control. Adjei-Nsiah and Obeng (2013) reported that application of palm bunch ash (PBA) produced significantly higher fruits per plant, fruit length and fresh fruit yield of okra per plant over control. Akanbi *et al.* (2014) observed that the application of 6 t PBA ha^{-1} caused significant increase in plant height, leaf area, number of leaves, girth of cocoa seedlings over control. Majeed *et al.* (2014) reported that increase in the application rate of fertilizer P from 0 to 60 kg ha^{-1} significantly increased the wheat plant height and effective tiller count. Increase in plant height as compared to control treatment might have been due to that P stimulates root development and growth in the seedling stage and thereby it helps to establish the seedling quickly and Increase in number of fertile tillers with P might have been due to balanced fertilizer application, which might have resulted in better plant growth and more number of total tillers per unit area. The findings are in accordance with the investigations of Pareek *et al.* (2004) and Memon *et al.* (2005) who reported that P application increases plant height and number of fertile tillers in wheat.

Total uptake was significantly increased with increase in P levels. Fageria (2014) reported that P uptake in shoot as well as in grain was significantly increased with increase in P levels from 0 to 200 mg kg^{-1}. Hence the overall total P uptake was also increased. Mehla *et al.* (2006) reported that grain yield and P uptake of rice increased significantly with the combined use of RHA and fertilizer N compared with fertilizer N alone.

Sammauria and Yadav (2010) reported that with application of P at the rate of 26.2 kg P ha^{-1}, significant decrease in Zn content of seed and straw of fenugreek was observed as compared with control. They observed that the decrease in Zn content might be due to the reduced translocation of Zn in plant body under environment of increased concentration of P. Imtiaz *et al.* (2006) reported that at Zn-deficient level, Zn concentrations in the wheat shoot decreased with increase in level of P and more severe Zn deficiency was observed at the P level of 250 mg g^{-1} soil. They also reported that P-induced Zn deficiency is accompanied by decrease in chlorophyll and Cu/Zn superoxide dismutase activity.

With regard to molar ratio of P to micronutrients, Zhang *et al.* (2012) observed that the molar ratios of P/Zn and P/Cu in grain and straw of wheat was significantly increased with P application. The increased P/Zn would suggest potentially decreased Zn bioavailability due to P applications. Izsaki (2014) observed that with increase in application of P from 120 to 339 mg kg^{-1} there was significant decrease in Zn and Cu concentrations in maize leaves. They further reported that P/Zn and P/Cu was significantly increased with increase in P application.

The application of different biomass ash increased the soil pH. Similar results were reported by Okon *et al.* (2005) that application of RHA significantly increased soil pH from 4.9 to 6.0 in acid sands under okra cultivation. Njoku and Mbah (2012) observed significantly increased the soil pH when amendment with RHA over the control in maize under ultisols. Lopez *et al.* (2009) reported that poultry litter ash caused significantly increase the soil pH over control.under field conditions. Akanbi *et al.* (2014) observed that application of PBA significantly increases soil pH from 6.4 to 7.85 compared to control. The increase in the pH of the soil after the application of the PBA was due to the high pH level of the PBA and relatively high levels of Ca and Mg which had liming effect on the soil. Nwite *et al.* (2011) reported that application of RHA at the rate of 3 t ha^{-1} caused significant increase in available P (8.22 to 31.4 mg ha^{-1}), cation exchange capacity (3.24 to 5.34 cmol (+) kg^{-1}). Ayeni *et al.* (2008) reported that cocoa pod ash at the rate of 10 t ha^{-1} significantly increased soil organic matter and soil P by 71 and 45 %, respectively. Gupta *et al.* (2013) reported that application of RHA and BA

at the rate of 10 t ha^{-1} to both wheat and rice caused significant increase in Al-P, Fe-P, Ca-P and Olsen-P over control. Sihag *et al.* (2005) reported that organic ashes significantly increased the amount of P recovered in Fe-P, Al-P and Ca-P over control in rice-wheat cropping system. Bachmann and Eichler-lobermann (2010) reported that the application of poultry litter ash caused significant increase of most bioavailable resin P fraction and failed to cause significant increase in Na-HCO$_3$-P and NaOH-P in catch crop cultivation.

Conclusion

Phosphorus applied through all the biomass ashes resulted in significant increase in root, shoot biomass, grain and straw yield over control. Among biomass ashes P applied from RSA (14.3 g pot^{-1}) produced significantly higher yield which was statistically at par with P from Fert-P (13.5 g pot^{-1}). Phosphorus uptake was significantly increased with P applied through biomass ashes which were comparable to Fert-P. Application of P from all sources resulted in significant decrease in micronutrients content in grain, which increased molar ratio of P to micronutrient showed decreased bioavailability of micronutrients in grain. Phosphorus applied from all the biomass ashes recorded significant increase in soil pH while P from Fert-P did not show any effect on soil pH. Application of P through biomass ashes resulted in significant increase in Olsen-P over control which further increased with increase in P levels which showed similar affect like Fert-P. Therefore, application of biomass ashes can act as substitute for fertilizer P as well as the disposal problem can be averted without creating environmental hazard.

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