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Soil properties as influenced byfly ashapplication to different crops with special emphasis on heavy metals and radionuclides

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Abstract
Fly ash is the major waste product generated in coal based industries and thermal power plants. Fly ash can be utilized in agricultural field crops for improving soil properties and increase nutrient supply. The properties of Fly ash (FA) and Pond ash (PA) indicated that these are having good water holding capacity and have more of sand and silt particles. The pH of ashes were alkaline. These were found to be good sources of potash, calcium, magnesium, sulphur and micronutrients. The heavy metal content of FA varied more than that of PA. The level of radio activity in both ashes were not significant but double the soils. The use of FA and PA with or without FYM to different crops enhanced moisture holding capacities of soil (MWHC, FC and PWP, 40.53% to 46.80%, 21.10% to 23.20% and 8.40% to 8.80, respectively). The soil chemical properties did not very much. The micronutrient contents of soil were also influenced by these ashes. The heavy metal contentin soil due to FA application varied more than that of PA application in black soil, however it is less significant in red soils. Application of ashes at the rate of 30 t/ha along with FYM in both red soil and black soil was found beneficial.

Keywords: Soil properties, flyash, crops, heavy metals, radionuclides

Introduction
The thermal power units are mainly based on coal which is used for the fuel purpose. After burning of the coal huge amount of ash will be generated. The finer ash (flyash) material will be separated from slightly coarser ash. Handling and disposal of the ash produced is a big task (Manish *et. al.,* 2008) [6]. The ash is known to contain some trace elements, heavy metals and radionuclides which is a potential hazardous waste (Sikka and Kansal, 1974) [14]. The high ash content (30–50%) of the coal in India makes this problem complex. Safe disposal of the ash without adversely affecting the environment and the large storage area required for dumping are the major concerns. Hence attempts are being made to utilize the ash rather than dumping it. The coal ash can be utilized in agriculture field crops for improving soil properties and nutrient supply. In this context an in-depth understanding of the influence of flyash on growth and yield of crops is required. This paper reports the work carried out by research scholars in this context at the Department of Soil Science, UAS Raichur.
The types of ashes available at Racihur Thermal Power station (RTPS) are the Fly ash which is finer and the other is the Pond ash which is stored in a big pond at the site adjacent to Yarmarus village in Raichurtaluk which is dumped here after mixing the fresh coarse ash with water and carried through pipes and channels. The huge amount of ash coming out from the industry is needed to utilize in various field fields.
The research work carried out at the Department of Soil Science, UAS Raichur has come out with package to utilize it in the field of agriculture. The scholar research carried out on use of Fly ash (FA) and Pond ash (PA) in sunflower crop are delineated here.

Methodology
Ash samples were drawn from the industry plant (FA) and pond (PA) from RTPS and applied to field @ 30 and 40 tons per hectare with and without FYM as per the treatments during kharif season. Incorporation of the ashes were done using tractor after manual spreading. The initial soil samples, FYM, Fly ash and Pond ash were characterized in the laboratory (table 1). The analysis for physico-chemical properties and heavy metal content was carried out at Department of Soil Science, College of Agriculture, Raichur.

And the measurement of activity level of radionuclides was carried out at Institute of Physics, Bhubaneswar. The soil analysis after harvest of crop, during each season (kharif / *rabi*) was carried out for two yearsand the influence of ashes on soil propertieswas recorded with an emphasis on heavy metals and radionuclides (Papastefanou, 2008) [10].

Results

Characteristics of soils, fly ash, pond ash and FYM

The characteristics of samples are presented in table 1. The texture of red soil (Alfisol) is sandy clay loam and its maximum water holding capacity is 41 per cent. Water Holding Capacity (WHC) of flyash is generally 49-66% on weight basis, while the moisture retention ranges from 6.1% at 15 bar to 13.4% at 1/3 bar (Natusch and Wallace, 1974). The soil is alkaline, non saline with medium organic carbon content. Available N status is low and available P and K status is medium. The texture of black soil (Vertisol) is clayey and the maximum water holding capacity is 64 per cent. The soil is alkaline and medium in available N and the available K status of soil is high.

The properties of Fly ash (FA) and Pond ash (PA) indicated that the particles present in FA were finer than PA. The texture of FA was silt clay loam and that of PA was silt loam. These two properties make the soil friable and favour plant growth when applied. Coal ashes were predominantly silt sized with some sand-size fraction. Fly-ash particles are empty spheres (Cenospheres) filled with smaller amorphous particles and crystals (Plerospheres) (Manish pande *et. al*., 2008) [6]. The moisture holding capacity is also higher with PA (68%) than FA (50%). And these are having good water holding capacity and have more of sand and silt particles. The pH of ashes were strongly alkaline (9.3 to 10.5), among the two, FA was having more. The EC of the ashes is <1.0 dS/m among the two, FA is having more. These were found to be good sources of potash, calcium, magnesium, sulphur and micronutrients. The DTPA extractable micronutrients in fly ash and pond ash is quite good which can contribute more amounts when applied in tons. The total NPK contents (0.007 to 0.015, 0.2 to 0.4 and 1.1 to 1.8% respectively) and the plant available NPK contents in these ashes are very low (20 to 40, 10 to 16 and 94 to 145 ppm, respectively). The total content of calcium in these ashes is 2.5 to 3.6 percent, however the ammonium acetate extractable calcium is very low (9 to 16 Cmol/kg). The total content of magnesium in these ashes is 1.2 to 1.7%, however the ammonium acetate extractable magnesium is also very low (2 to 13 Cmol/kg). The total sulphur in ashes is varied between 1.4 and 2.5 percent and plant available sulphur is varied between 45 and 78 ppm. The plant available micronutrients Cu, Fe, Mn and Zn are in the range of 0.3 to 0.6, 8.6 to 12.5, 8 to 13 and 1.0 to 1.5, respectively. These results indicate the potential source of ashes which can be exploited to utilize in agricultural fields (Patil, 1999). Theis and Wirth (1977) [15] found that the major components were Al, Fe and Si, with smaller concentrations of Ca, K, Na, Ti, and S. Fly-ash contains varying amounts of numerous trace elements, some of which are required by plant and animals in varying amounts (Martens, 1971) [7], whereas some may have toxic effect. Fly-ash contains essential macronutrients including P, K, Ca, Mg and S and micronutrients like Fe, Mn and Zn. Agricultural utilization of fly ash has been proposed because of its considerable content of K, Ca and S (Kalra *et al*., 1997; Singh *et al*., 1997).

The heavy metal content of FA varied more than that of PA. Davison *et al.* (1974) [1] indicated that the trace elements concentration in fly ash: depends on particle size. The level of radio activity in both ashes were not significant but double the soils. The FYM also showed appreciable moisture holding capacity than soils and ashes. The pH was near neutral and did contain good amounts of plant available nutrients. The heavy metal contents and activity of radionuclides was lower.

Influence of application of FA and PA on soil properties with an emphasis on heavy metals and radionuclides

The use of FA and PA with or without FYM to different crops enhanced moisture holding capacities of soil (MWHC, FC and PWP, 40.53% to 46.80%, 21.10% to 23.20% and 8.40% to 8.80, respectively). Similar reports have been made by Khan and Khan (1996) [5]. The soil chemical properties did not vary much. Sarangi *et al*. (2001) [12] observed that gradual increases in soil pH, conductivity and organic carbon increased application rate of fly ash The micronutrient contents of soils were also influenced by these ashes (available Fe, Zn and Mn, 3.45 to 4.27 mg/kg, 0.70 to 1.08 mg/kg and 8.70 to 12.67 mg/kg in red soil while 3.30 to 5.01 mg / kg, 1.10 to 1.06 mg/kg and 10.43 to 10.61 mg/kg in black soil, respectively). The heavy metal content in soil due to FA application varied more than that of PA application in black soil, however it is less significant in red soils (Natush and Wallace, 1974). The activity of radionuclides content in soil due to application of flyash and pondash with and without FYM indicated that, the alpha acivity was found to vary from 151. 4 to 201. 2 Bq/kg of red soils and 152.3 to 184.7 Bq/kg of black soils. The Beta activity was also twice the alpha activity in both the soils. However higher 40K gamma activity (288 to 276.8 Bq/kg in red soilsand about 263 Bq/kg red soil) was recorded due to application of ashes. Even with the application of FYM there was release of more gamma activity. The atoms ^{226} Ra and ^{228}Ac radio activity, i.e. decay of one nuclei per second (Bq/kg soil) was lower. There was decline in the ^{228}Ac activity over years (Papastefanou, 1971). Application of ashes at the rate of 30 t/ha along with FYM in both soils was found beneficial in reducing ^{228}Ac radioactivity.

Conclusions

Fly ash and Pond ash both can be used as a potential nutrient supplement for agricultural soils thereby solving the solid waste disposal problem to some extent. An ultimate goal would be to utilize FA in oils of less WHC/marginal soils to such an extent as to achieve enhanced fertility without affecting the soil quality and minimizing the accumulation of toxic metals in plants below critical levels for human health. Fly ash gives beneficial Effects: improves water holding capacity; provides micro-nutrients like Fe, Zn, Cu, Mo, B etc.; provides macro-nutrients like K, Ca, S etc. The plant availability of trace elements / heavy metals are below detection limit. The danger of radionuclides is also not at alarming level. Application along with FYM would reduce the effect.

Table 1: Characteristics of soils, ashes and FYM

Sl. No.	Parameter	Red soil	Black soil	Fly ash	Pond ash	FYM
1.	**Texture**	**Sandy Clay**	**Clay**	**Silt clay loam**	**Silt loam**	**-**
Moisture holding capacity						
2.	MWHC %	41.9	64.2	50.2	68.1	155
3.	FC %	23.2	36.7	24.2	38.0	82.0
4.	PWP %	9.1	16.4	5.6	11.0	17.8
Chemical properties						
5.	pH	8.50	8.60	9.82	8.99	7.7
6.	EC, dS/m	0.10	0.10	0.87	0.34	0.6
7.	Organic C (%)	0.60	0.90	-	-	-
Nutrient Content						
8.	Total N %	0.07	0.09	0.007	0.015	1.24
9.	Available N	206 kg/ha	306 kg/ha	30.2 ppm	39.6 ppm	355 ppm
10.	Total P %	0.06	0.08	0.43	0.42	0.80
11.	Available P2O5	33.9 kg/ha	19.2 kg/ha	16.7 ppm	11.6 ppm	890 ppm
12.	Total K %	1.20	1.65	1.8	1.6	1.10
13.	Available K2O	292 kg/ha	770 kg/ha	145.2 ppm	101.2 ppm	1126 ppm
14.	Total Ca %	0.52	1.30	3.36	2.66	1.00
15.	Exch.Ca (Cmol/kg)	14.5	39.7	19.2	10.1	-
16.	Total Mg %	0.30	0.78	1.19	1.53	0.14
17.	Exch.Mg (Cmol/kg)	1.4	12.1	13.4	5.0	-
18.	Total S %	0.03	0.06	2.50	1.75	0.36
19.	Available SO4-S	13.9	38.7	78.2	51.2	15.3
20.	Total Cu, ppm	32.5	40.0	100	80	40
21.	DTPA Extr-Cu, ppm	2.60	1.59	0.62	0.44	2.1
22.	Total Fe, %	1.46	2.16	2.00	2.59	1.13
23.	DTPA Extr-Fe, ppm	4.41	2.17	12.50	12.46	26.2
24.	Total Mn, ppm	315	390	270	380	300
25.	DTPA Extr-Mn, ppm	9.1	8.1	12.17	3.00	11.2
26.	Total Zn, ppm	43	50	170	70	31.0
Heavy metals (mg/kg)						
27.	Total Se	1.20	0.90	1.60	1.90	0.50
28.	Available Se	BDL	BDL	BDL	BDL	BDL
29.	Total As	1.40	1.20	2.3	20.2	0.80
30.	Available As	BDL	BDL	BDL	BDL	BDL
31.	Total Pb	14.8	19.9	18.4	20.2	7.9
32.	Available Pb	0.03	0.18	0.03	0.03	0.06
Activity of Radionuclides (Bq/kg)						
33.	Alpha	161.7	126.5	236.6	210.8	115.2
34.	Beta	32.4	318.0	623.1	609.5	141.0
35.	^{40}K Gamma	291.3	282.3	359.3	353.7	136.6
36.	^{226}Ra Gamma	38.5	37.5	99.7	91.8	16.6
37.	^{228}Ac Gamma	60.1	65.9	108.2	106.2	24.4

Table 2: Influence of application of FA and PA with and without FYM to crops on soil moisture constants

Treatment	In Red soil				In Black soil			
	FY*FC**	**FY SC*****	**SY**** FC**	**SY SC**	**FY FC**	**FY SC**	**SY FC**	**SY SC**
Maximum water holding capacity (%)								
T1-Control (Only NPK)	40.53	40.37	42.23	41.80	62.73	62.43	62.60	62.30
T2-FA@30 t/ha	40.50	42.90	45.07	44.27	63.47	63.90	64.60	65.20
T3-FA@40 t/ha+FYM	46.03	45.30	46.57	45.97	65.17	64.33	67.23	67.33
T4- FA@40 t/ha	45.43	44.67	45.80	45.07	64.20	63.93	65.87	66.17
T5-FA@30 t/ha only once in 3 years	44.70	43.37	42.97	42.70	63.43	63.83	64.30	59.20
T6- PA@30 t/ha	44.93	44.27	45.73	44.93	63.97	64.60	65.27	65.10
T7- PA@40 t/ha+FYM	46.70	46.23	47.93	46.80	67.17	66.30	67.83	67.17
T8- PA@40 t/ha	45.37	44.30	46.17	46.17	68.20	65.60	67.77	68.03
T9- PA@30 t/ha only once in 3 years	45.73	44.40	43.50	42.87	64.52	63.33	63.50	58.90
SEm+/-	0.121				0.095			
D at 5%	0.341				0.269			
Field Capacity (%)								
T1-Control (Only NPK)	21.10	20.83	21.70	21.17	35.57	32.90	34.70	32.00
T2-FA@30 t/ha	22.27	22.70	22.83	22.33	36.80	36.10	37.43	37.00
T3-FA@40 t/ha+FYM	23.37	23.43	24.27	23.20	38.73	3813	39.03	39.57
T4- FA@40 t/ha	22.22	22.90	23.17	22.27	38.10	37.40	38.03	38.03
T5-FA@30 t/ha only once in 3 years	21.67	22.03	21.63	20.87	37.57	36.40	35.33	33.23
T6- PA@30 t/ha	22.38	22.93	23.23	22.93	37.60	38.13	38.13	38.80
T7- PA@40 t/ha+FYM	22.03	23.37	23.70	22.67	39.20	39.33	39.57	39.80

T8- PA@40 t/ha	22.63	23.13	23.20	22.47	39.47	39.03	39.53	39.73
T9- PA@30 t/ha only once in 3 years	22.40	22.77	23.20	22.40	36.70	36.10	35.27	34.27
SEm+/-	0.063				0.073			
D at 5%	0.179				0.207			
Permanent wilting point (%)								
T1-Control (Only NPK)	8.40	8.47	8.50	8.37	15.93	15.57	15.67	15.57
T2-FA@30 t/ha	8.40	8.43	8.23	8.33	16.07	15.87	16.13	15.60
T3-FA@40 t/ha+FYM	8.70	8.67	8.73	8.70	16.43	15.97	16.30	15.80
T4- FA@40 t/ha	8.57	8.47	8.27	8.47	16.53	16.27	16.47	15.97
T5-FA@30 t/ha only once in 3 years	8.40	8.47	8.47	8.40	16.00	15.57	15.47	15.17
T6- PA@30 t/ha	8.30	8.27	8.47	8.43	16.53	16.13	16.57	16.27
T7- PA@40 t/ha+FYM	8.90	8.60	9.03	8.80	16.80	16.37	17.10	16.63
T8- PA@40 t/ha	8.93	8.70	9.07	8.93	16.67	16.20	16.67	16.40
T9- PA@30 t/ha only once in 3 years	8.40	8.30	8.50	8.60	16.47	16.27	16.80	16.13
SEm+/-	0.235				0.083			
D at 5%	NS				0.233			

Note: FY*= First Year, FC**= First Crop (Sunflower in both years),
SC***= Second Crop (Maize in black soil / Groundnut in red soil), SY****= Second Year

Table 3: Soil properties as influenced by application of FA and PA with and without FYM to crops

Treatment	In Red soil after harvest				In Black soil after harvest			
	FY* FC**	FY SC***	SY**** FC	SY SC	FY FC	FY SC	SY FC	SY SC
Soil pH (1: 2.5 soil-water ratio)								
T1-Control (Only NPK)	8.30	8.12	8.43	8.50	8.18	8.14	8.35	8.40
T2-FA@30 t/ha	8.30	8.63	8.35	8.41	8.21	8.36	8.37	8.49
T3-FA@40 t/ha+FYM	8.32	8.51	8.35	8.30	8.10	8.30	8.11	8.35
T4- FA@40 t/ha	8.19	8.66	8.40	8.42	8.38	8.31	8.48	8.45
T5-FA@30 t/ha only once in 3 years	8.36	8.51	8.37	8.43	8.37	8.37	8.38	8.43
T6- PA@30 t/ha	8.33	8.50	8.42	8.43	8.28	8.34	8.35	8.43
T7- PA@40 t/ha+FYM	8.33	8.44	8.30	8.42	8.22	8.34	8.20	8.43
T8- PA@40 t/ha	8.32	8.51	8.35	8.35	8.31	8.26	8.40	8.35
T9- PA@30 t/ha only once in 3 years	8.32	8.51	8.25	8.39	8.25	8.24	8.35	8.46
SEm+/-	0.017				0.028			
D at 5%	0.050				0.083			
Soil EC (dS/m)								
T1-Control (Only NPK)	0.120	0.160	0.250	0.287	0.203	0.200	0.213	0.240
T2-FA@30 t/ha	0.117	0.163	0.240	0.300	0.207	0.187	0.223	0.240
T3-FA@40 t/ha+FYM	0.133	0.177	0.240	0.310	0.197	0.183	0.230	0.250
T4- FA@40 t/ha	0.123	0.140	0.260	0.260	0.197	0.237	0.230	0.240
T5-FA@30 t/ha only once in 3 years	0.123	0.160	0.240	0.150	0.257	0.207	0.220	0.240
T6- PA@30 t/ha	0.117	0.143	0.217	0.230	0.207	0.230	0.200	0.230
T7- PA@40 t/ha+FYM	0.120	0.150	0.230	0.260	0.200	0.250	0.200	0.243
T8- PA@40 t/ha	0.107	0.167	0.220	0.260	0.237	0.210	0.200	0.227
T9- PA@30 t/ha only once in 3 years	0.137	0.150	0.213	0.250	0.190	0.200	0.200	0.240
SEm+/-	0.005				0.009			
D at 5%	0.016				NS			
Soil Organic Carbon (%)								
T1-Control (Only NPK)	0.62	0.79	0.72	0.85	0.81	0.74	0.66	0.73
T2-FA@30 t/ha	0.69	0.82	0.79	0.89	0.81	0.84	0.73	0.63
T3-FA@40 t/ha+FYM	0.78	0.85	0.94	0.96	0.99	0.83	0.94	0.85
T4- FA@40 t/ha	0.68	0.81	0.76	0.85	0.83	0.75	0.73	0.62
T5-FA@30 t/ha only once in 3 years	0.68	0.81	0.75	0.87	0.86	0.86	0.69	0.64
T6- PA@30 t/ha	0.68	0.81	0.73	0.85	0.84	0.70	0.73	0.81
T7- PA@40 t/ha+FYM	0.78	0.85	0.97	0.94	0.88	0.84	0.87	0.84
T8- PA@40 t/ha	0.71	0.81	0.82	0.85	0.78	0.77	0.82	0.81
T9- PA@30 t/ha only once in 3 years	0.66	0.81	0.77	0.85	0.78	0.77	0.74	0.82
SEm+/-	0.011				0.011			
D at 5%	0.032				0.032			

Note: FY*= First Year, FC**= First Crop (Sunflower in both years),
SC***= Second Crop (Maize in black soil / Groundnut in red soil), SY****= Second Year

Table 4: Micronutrient status in soil as influenced by application of FA and PA with & without FYM to crop

Treatment	In Red soil after harvest				In Black soil after harvest			
	FY* FC**	FY SC***	SY**** FC	SY SC	FY FC	FY SC	SY FC	SY SC
Available Iron (Fe, mg/kg soil)								
T1-Control (Only NPK)	3.45	2.95	3.12	2.51	3.30	3.09	3.09	3.09
T2-FA@30 t/ha	3.40	3.51	3.30	3.47	3.74	3.69	4.04	3.73
T3-FA@40 t/ha+FYM	4.57	4.58	4.74	4.17	4.47	3.38	4.47	4.05
T4- FA@40 t/ha	3.41	2.83	3.42	2.82	3.02	2.85	3.01	2.85
T5-FA@30 t/ha only once in 3 years	3.77	3.52	3.37	3.12	3.62	2.81	3.42	2.92
T6- PA@30 t/ha	3.39	3.03	3.72	3.23	3.23	2.73	3.46	2.93
T7- PA@40 t/ha+FYM	4..05	3.05	4.06	4.27	4.99	5.01	4.99	5.01
T8- PA@40 t/ha	4.21	3.76	4.41	3.24	3.77	2.83	3.73	2.93
T9- PA@30 t/ha only once in 3 years	3.66	3.34	3.12	3.04	3.15	2.95	3.15	3.08
SEm+/-	0.10				0.11			
D at 5%	0.27				0.32			
Available Zinc (Zn, mg/kg soil)								
T1-Control (Only NPK)	0.70	0.51	0.70	0.65	1.10	1.10	0.98	1.04
T2-FA@30 t/ha	1.00	0.73	1.02	0.86	0.91	0.90	0.89	0.98
T3-FA@40 t/ha+FYM	1.30	0.83	1.22	0.96	1.10	1.19	1.14	1.27
T4- FA@40 t/ha	1.04	0.92	1.24	1.14	0.98	0.97	1.03	0.92
T5-FA@30 t/ha only once in 3 years	0.96	0.90	0.88	0.74	1.09	1.01	0.97	1.01
T6- PA@30 t/ha	0.86	0.86	0.98	0.83	1.12	1.01	1.14	1.06
T7- PA@40 t/ha+FYM	1.04	0.84	1.11	1.08	1.10	099	1.09	0.91
T8- PA@40 t/ha	0.94	0.66	1.09	0.97	0.89	0.82	0.98	1.04
T9- PA@30 t/ha only once in 3 years	0.94	0.88	0.76	0.74	1.08	1.00	0.94	1.00
SEm+/-	0.04				0.02			
D at 5%	0.10				0.05			
Available Manganese (Mn, mg/kg soil)								
T1-Control (Only NPK)	8.70	8.50	8.68	8.87	10.43	9.90	10.30	10.01
T2-FA@30 t/ha	9.00	12.40	10.52	12.39	10.91	10.42	10.59	10.53
T3-FA@40 t/ha+FYM	9.61	13.30	11.48	13.59	11.45	11.19	11.07	11.37
T4- FA@40 t/ha	9.98	9.80	11.54	10.54	10.52	9.42	10.93	10.84
T5-FA@30 t/ha only once in 3 years	9.24	9.89	11.00	10.58	10.97	10.68	10.68	10.87
T6- PA@30 t/ha	9.43	9.03	10.57	9.97	10.92	10.56	10.57	10.01
T7- PA@40 t/ha+FYM	8.38	10.80	11.66	12.67	10.82	11.97	10.97	10.61
T8- PA@40 t/ha	9.74	12.10	11.16	13.86	12.19	11.17	11.40	12.78
T9- PA@30 t/ha only once in 3 years	9.53	10.85	11.86	9.58	10.39	11.07	10.14	12.78
SEm+/-	0.37				0.23			
D at 5%	1.05				0.63			

Note: FY*= First Year, FC**= First Crop (Sunflower in both years),
SC***= Second Crop (Maize in black soil / Groundnut in red soil), SY****= Second Year

Table 5: Heavy metals status in soilas influenced by application of FA and PA with and without FYM to crops

Treatment	In Red soil after harvest				In Black soil after harvest			
	FY* FC**	FY SC***	SY**** FC	SY SC	FY FC	FY SC	SY FC	SY SC
Selenium (Se, mg/kg soil)								
T1-Control (Only NPK)	1.00	1.00	1.00	1.00	1.00	0.80	1.00	0.80
T3-FA@40 t/ha+FYM	0.90	1.00	1.60	1.50	0.90	0.90	1.00	0.80
T4- FA@40 t/ha	1.40	1.20	2.00	1.70	1.20	1.00	1.30	1.00
T7- PA@40 t/ha+FYM	1.10	1.1	1.40	1.50	1.10	0.70	1.00	1.00
T8- PA@40 t/ha	1.30	1.10	1.80	1.40	1.30	0.90	1.10	0.90
Arsenic (As, mg/kg soil)								
T1-Control (Only NPK)	1.30	1.50	1.30	1.50	1.40	1.20	1.40	1.20
T3-FA@40 t/ha+FYM	1.60	1.60	1.10	1.10	1.50	1.00	1.70	1.20
T4- FA@40 t/ha	2.10	1.60	1.50	1.20	1.60	1.30	1.90	1.40
T7- PA@40 t/ha+FYM	1.30	1.40	1.00	1.10	1.20	1.20	1.30	1.00
	1.70	1.70	1.40	1.10	1.60	1.20	1.60	1.10
Lead (Pb, mg/kg soil)								
T1-Control (Only NPK)	14.0	14.3	14.0	14.2	15.0	15.3	15.0	15.1
T3-FA@40 t/ha+FYM	14.6	15.1	14.4	15.3	15.8	16.1	15.7	15.8
T4- FA@40 t/ha	15.4	15.9	15.8	15.2	16.6	16.6	16.7	16.9
T7- PA@40 t/ha+FYM	14.5	14.9	14.9	15.0	15.3	15.5	15.1	15.9

T8- PA@40 t/ha	15.2	15.7	15.5	16.0	16.1	16.4	16.3	16.8

Note: FY*= First Year, FC**= First Crop (Sunflower in both years),
SC***= Second Crop (Maize in black soil / Groundnut in red soil), SY****= Second Year

Table 6: Activity status of Radionuclides in soil as influenced by application of FA and PA to crops

Treatment	In Red soil after harvest				In Black soil after harvest			
	FY* FC**	FY SC***	SY**** FC	SY SC	FY FC	FY SC	SY FC	SY SC
Alpha activity (Bq/gk)								
T1-Control (Only NPK)	151.4	150.9	-	-	152.3	129.4	144.3	-
T3-FA@40 t/ha+FYM	185.0	165.8	153.6	181.3	174.6	140.8	167.3	151.8
T4- FA@40 t/ha	201.6	182.3	192.4	201.2	198.6	199.0	178.4	184.7
T7- PA@40 t/ha+FYM	157.5	172.8	140.6	1525	146.2	141.5	163.8	152.7
T8- PA@40 t/ha	201.2	184.5	185.3	168.6	188.5	175.0	178.3	178.8
Beta activity (Bq/gk)								
T1-Control (Only NPK)	326.9	306.5	-	-	287.3	315.0	278.2	-
T3-FA@40 t/ha+FYM	359.1	324.1	320.0	253.7	300.7	355.7	294.9	284.2
T4- FA@40 t/ha	373.3	361.2	353.1	312.2	360.1	375.0	329.7	316.5
T7- PA@40 t/ha+FYM	351.1	333.9	300.9	298.2	288.6	343.8	271.9	280.0
T8- PA@40 t/ha	374.5	363.2	334.8	319.2	361.6	366.3	306.9	311.9
^{40}K (Bq/gk) gamma activity								
T1-Control (Only NPK)	288.0	285.9	-	-	263.4	277.1	254.2	-
T3-FA@40 t/ha+FYM	316.6	292.7	289.8	261.6	271.2	312.1	359.5	258.4
T4- FA@40 t/ha	357.0	318.3	309.1	276.8	310.5	318.7	277.7	263.5
T7- PA@40 t/ha+FYM	319.4	307.2	250.7	261.7	284.6	308.9	245.9	245.9
T8- PA@40 t/ha	329.0	308.2	291.9	273.1	306.5	307.6	265.8	272.7
^{226}Ra (Bq/gk) gamma activity								
T1-Control (Only NPK)	34.5	36.2	-	-	34.9	34.8	34.9	-
T3-FA@40 t/ha+FYM	37.1	42.2	33.3	37.7	39.9	42.7	37.4	35.1
T4- FA@40 t/ha	44.2	44.2	36.7	38.9	40.3	50.50	40.5	41.8
T7- PA@40 t/ha+FYM	36.1	40.7	31.6	34.7	37.6	45.4	36.6	36.7
T8- PA@40 t/ha	37.4	42.9	31.8	49.9	41.1	42.1	37.4	41.0
^{226}Ac (Bq/gk) gamma activity								
T1-Control (Only NPK)	60.0	52.6	-	-	54.2	62.1	62.1	-
T3-FA@40 t/ha+FYM	71.4	60.5	60.2	54.2	57.3	66.5	60.7	55.3
T4- FA@40 t/ha	77.1	61.9	66.2	54.6	61.2	75.8	67.5	61.6
T7- PA@40 t/ha+FYM	67.3	66.2	60.8	53.8	57.8	77.0	60.0	57.7
T8- PA@40 t/ha	71.6	59.2	62.5	56.9	57.3	70.7	64.5	62.1

Note: FY*= First Year, FC**= First Crop (Sunflower in both years),
SC***= Second Crop (Maize in black soil /Groundnut in red soil), SY****= Second Year

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