

Fly-ash from Coal-fed Thermal Power Plants: Bulk Utilization in Horticulture – A Long-term Risk Management Option

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ABSTRACT: Management of solid waste (flyash) has attained an apparent scenario for scientific & strategic concern in India due to large-scale dependence on coal-based thermal power plants. Waste utilization as the best option of pollution-prevention and disaster risk strategy has been worked out during previous decades to open doors for flyash utilization on various sectors of developmental and manufacturing sectors. Low application of flyash has reportedly been employed as a soil ameliorant and experiments have demonstrated tree plantation over flyash landfills using organically rich wastes to prepare the suitable substrates. However, the large-scale and voluminous generation of flyash averagely on regular basis calls for bulk utilization options in a productive purpose. Present study discusses the features of coal-combustion flyash and a study of two important vegetable crops, *viz.*, Brinjal and Spinach, grown on flyash substrate. The results advocated the flyash application as higher as up to 50% in case of common garden soils, supporting the options of bulk utilization of flyash in horticultural cropping. The discussions suggested screening of suitable species on the basis of dose-response studies for evolving a protocol for flyash management under ecofriendly protocols.

Key words: Solid waste, Crop Plants, Biochemical parameters, Chlorophyll, Protein

INTRODUCTION

Coal based thermal power plants are one of the most prevalent means of power generation in the world today. In India, coal based thermal power generation today occupies the largest proportion (more than 75%) of total power produced, and the trend would increase in coming years owing to its rich coal reserves. Flyash is formed of minute glossy particles ranging in size from 0.01 to 100 μm that are combustion by-product of coal (Davison *et al.*, 1979). It is collected through electrostatic precipitators, and is potentially hazardous industrial waste due to toxicity associated with the constituent trace elements concentration (Adriano *et al.*, 1980). The effect of fly ash on vegetation was also measured by (V. Kumar., 2009).

In India, about 82 utility thermal power plants are operational, in addition to several captive power plants (CPPs), using bituminous coal (with ash content >30%) to produce about 85 million ton of flyash in a year. Flyash generation estimate was around 100 million ton per year-by-year 2000, 125 million ton by 2003-2004 and

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is likely to touch 155 million tones by year 2020 (Singh & Kumar, 1997). Huge amount of flyash so generated, coupled with the limitations and risks of disposal, calls for alternative utilization of flyash in varying goods and services, however, estimates of utilization marked only around 10% of the total flyash generated in year 1998. Flyash is an also a part of solid waste, which creates problem not only for human being also for environment. Solid waste management (SWM) is defined as the control of waste generation, storage, collection, transfer and transport, processing and disposal of solid wastes (SW) consistent with the best practice of public health, economics and financial, engineering, administrative, and legal and environmental considerations (Omran *et al.*, 2009).

Coal ash is known to contain significant quantities of heavy metals such as arsenic, lead and selenium, which can cause cancer and neurological problems and is thus disastrous. A spill occurred at the Kingston Fossil Plant, a Tennessee Valley Authority generating plant about 40 miles west of Knoxville on

the banks of the Emory River, which feeds into the Clinch and then the Tennessee River just downstream. There is also a demand that coal ash may be declared as a hazardous material. Similar ponds and mounds of ash exist at hundreds of coal plants worldwide and when in hilly areas, pose multifold risk of disastrous ash-pond failures (Dewan, 2008). Application of Coal Fly-ash to replace Lime in the management of reactive mine tailings have also been recommended (Wong et al., 2009).

Chemically, all naturally existing elements can be found in flyash (Klien et al., 1975). Flyash can be considered a material not much different from common clay as both of them contains oxides of aluminum (Al), silicon (Si), iron (Fe), calcium (Ca), magnesium (Mg), etc. (Natusch et al., 1975). Trace elements like boron (B), cadmium (Cd), lead (Pb), molybdenum (Mo), nickel (Ni), selenium (Se) and zinc (Zn) are found in higher concentration in flyash than soil (USEPA, 1988). A recent analysis of physico-chemical properties of the flyash used in present study is given in Table 1 (Kumar et al., 2002).

As stated by other researches also mineralogy is the important way to understand the coalescent status of elements in the waste (Saedi, M. and Amini, H.R., 2007). Therefore, the current study also has been done for Flyash composition through X-ray power diffraction. Flyash consists of mostly amorphous glossy

phases of SiO₂ and aluminosilicate in the poorly crystalline mullet form. X-ray power diffraction analysis and IR-spectrophotometry have confirmed the presence of alpha quartz and mullet (Figs 1a and 1b; Suresh et al., 1998). Fe is reported mostly in the form of Magnetite having d (A) =2.5 (Fig. 1b). It is observed partially molten and coating the surface of the aluminosilicate cenospheres as evident from scanning electron-micrography revealing spherical shape particles with hardly any crystalline structure of phase separation (Fig. 1c). However, the SiO₂ rich phase is crystalline having tetrahedral structure (Fig. 1d). But the amorphous nature of spherical particles commonly leads to disordered crystal structure. Many cations and anions are held in spaces of aluminosilicate network (Fig. 1e) (Gupta, 2001).

Disposal of huge amount bearing a large volume is a serious concern. Several areas of flyash utilization wherein technologies have been demonstrated or are underway include mine filling, construction of roads, embankments, hydraulic structures, raising of dykes, manufacture of several of building components like bricks, blocks, tiles, and its use in agriculture.

Although it contains potentially harmful trace elements such as As, Cd, Mo, Pb, Se and Sb, but it also contains mineral constituents such as Cu⁺², Fe⁺², Zn⁺², Mn⁺² and Mo⁺² and hence, can act as a secondary source of fertilizers (Singh & Chauhan, 1997). Flyash,

Table 1. Physico-chemical properties of flyash and common garden soil in Lucknow

Parameter	Flyash	Garden soil
PH	8.8±0.42	7.7±0.32
Electrical conductivity	7.61±0.38	1.6±0.08
Total nitrogen (%)	0.02±0.001	0.09±0.002
Total phosphorous (%)	0.14±0.006	0.78±0.032
Organic carbon (%)	1.172±0.059	1.483±0.072
Metals (µg/g)		
Al	4615±230	460±20
B	29.0±1.26	1.36±0.04
Cd	42.3±2.12	<0.002
Cr	40.25±1.98	<0.002
Cu	58.6±2.83	24.4±1.16
Fe	4150±207	2850±142
Hg	1.88±0.042	<0.001
K	9005±450	NE
Mn	70±3.4	45.8±2.20
Na	5200±260	NE
Ni	204±10.2	23.8±1.10
Pb	40.1±2.00	<0.005
Si	5600±280	350±18
Zn	82±3.1	22.6±1.10

Values are mean (n=3) ±SD; NE=not estimated

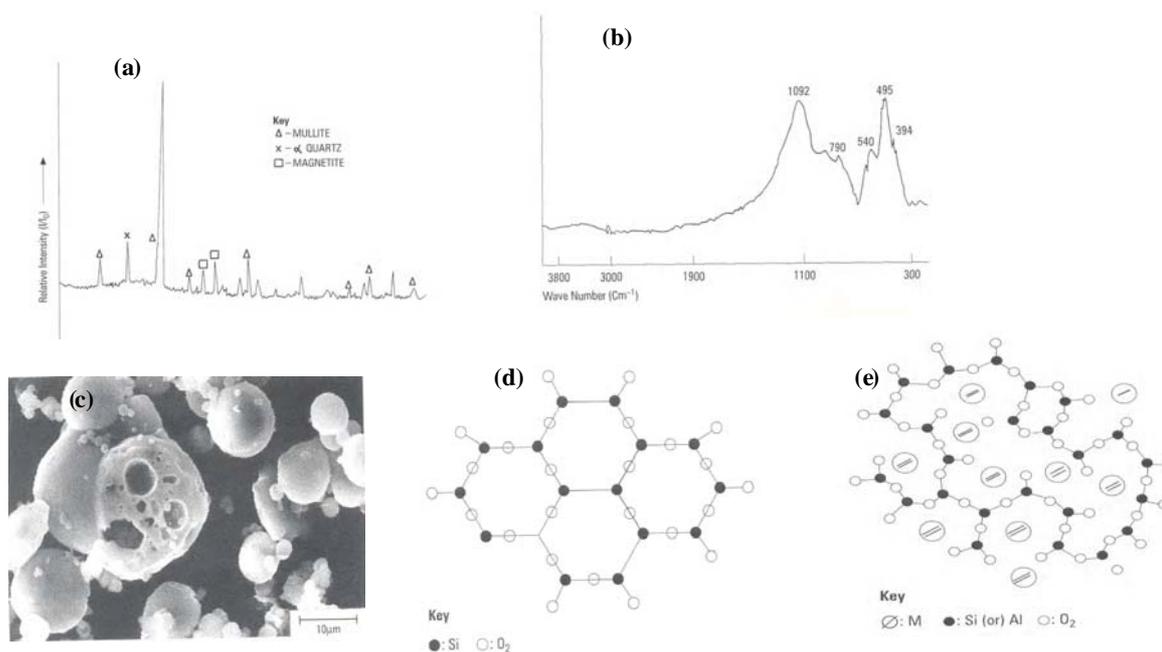


Fig. 1. a) X-ray diffraction pattern of flyash, (b) Infrared spectra of flyash, (C) SEM micrograph of flyash, (d) Crystal structure network of silica, and (e) Crystal structure of aluminosilicate glass in flyash (Suresh *et al.*, 1998)

with its abundant availability and remarkable ameliorative and nutritive properties, warrants an ecofriendly approach to waste utilization in reclamation of problem soils. Application of flyash for growing crops or form soil amendments may be tried through the scientific research studies to explore its feasibility, as it is necessary to model the concentration-uptake-dose-response functions between the amended medium and crop plant.

Certain studies on different crop plants and certain tree species have focused on acidic soils with low level (2 to 20%) of flyash application (Molinger & Street, 1982; Mishra & Shukla, 1986). An off track study has been carried out through pot experiments in the field-station of School for Environmental Sciences of Ambedkar University in Lucknow, to assess the potential of bulk utilization of flyash on garden soils (1:1) for growing two important crops, *Solanum melongena* (Brinjal) and *Spinacia oleracea* (Spinach). Both the crops are fast growing and accumulate high biomass, offering medicinal and nutritive values. In India, these vegetable crops make regular and important ingredient of diet for a large portion of population under economy class.

MATERIALS & METHODS

Garden soil substrate was collected from the University Department of Horticulture Fields and the

flyash was provided by M/s. Feroz Gandhi Thermal Power Plant, Unchahar, Raebareli district in Uttar Pradesh, an undertaking plant of National Thermal Power Corporation Limited (NTPC). Commercial cultivar seeds of *S. melongena* (Family- Solanaceae) and *S. oleracea* (Family- Chenopodiaceae) were procured from a certified seed shop in Lucknow, and sown in pots of different sets containing: (i) control of campus soil (C), (ii) 100% flyash (T₁), and (iii) 1:1 mixture of garden soil and flyash (T₂). The parameters studied were: germination (%), water content, growth (root & shoot length), phytomass & net primary productivity, biochemical contents (pigment, protein and sugar) and yield. Chlorophyll and carotenoid contents were estimated by method adapted by Arnon (1949). Formulae given by Maclachlan and Zalic (1963) for chlorophyll 'a' and 'b' has been used:

$$Chla = \frac{12.3D_{663} - 0.86D_{645}V}{1000W} \cdot 100$$

$$Chlb = \frac{19.3D_{645} - 3.6D_{663}V}{1000W} \cdot 100$$

Protein and total sugar contents were estimated using the methods as suggested by Lawry *et al.* (1951) and Dubois *et al.* (1956), respectively.

RESULTS & DISCUSSION

The physico-chemical properties of the flyash used in the experiment as shown in Table 1 indicated its significantly alkaline nature (pH 8.8±0.4). Higher ionic concentration was evident through the higher electrical conductivity, as has also been discussed by Eary *et al.* (1990). Metal contents were observed relatively higher than normally in any cultivable soil including garden soil, as suggested by Kumar *et al.* (2002). However, low levels of nitrogen (0.01%) and phosphorous (0.14%) coupled with lack of organic content mark it as a nutritive deficient substrate. General characteristics of the garden soils in Lucknow as developed from sodic land is given in Table 1.

Experiments were conducted to study the opportunity of bulk utilization of flyash in horticulture sector. Enhanced seed germination of *S. melongena* and *S. oleracea* was observed in flyash amended soil substrate (T2) as compared to control (C) or 100% flyash (T1). Results deviated from the earlier findings of Singh *et al.* (1997) that reported inhibition of delay in germination and growth but for *Vicia faba* L. at 20-30% flyash application against 6-8% enhancement at 5-10% application. However, species-specific positive responses in the present study advocated bulk utilization of flyash (1:1 mixture) with respect to germination (Table 2). Improved growth in plants of *S. oleracea* (root and

shoot length) was observed in flyash+soil substrate (T2) during almost all growing period of 90 days (Table 3). Inversely, the growth retardation was observed for plants of *S. melongena* in T2 set for the entire period for shoot but only for age of 30 to 60 days in case of root length. Plants in T1 set (100% flyash) could not survive the period after 4-5 weeks may be due to ambient heat (induced drought) stress coupled with 100% flyash substrate conditions posing risk of metal toxicity (Inouhe *et al.*, 1994; Gupta *et al.*, 2002). Differing water content (%) pattern for root and shoot parts in *S. melongena* and *S. oleracea* was evident from the results (Table 4). On average, elevated root water levels were observed in the plants grown in T2 as compared to their control (garden soil). However, the amendment resulted in slight decrease of shoot water content level.

Marginally irregular patterns but insignificant differences in levels of chlorophyll ('a' and 'b') and carotenoids were observed in the plants grown in T1 as compared to control (Table 5). However, *S. oleracea* registered improved level of chlorophyll in T2 (50% flyash) plants up to around 9 weeks age. Results were in disagreement with reports of Singh *et al.* (1994) but those were for significantly minor (2% to 8%) application of flyash to soil for growing different crop *Beta vulgaris* L.

Table 2. Seed Germination (%) of *S. melongena* and *S. oleracea*

Duration in weeks	Germination (%)					
	<i>S. melongena</i>			<i>S. oleracea</i>		
	C	T1	T2	C	T1	T2
I	0.0	0.0	0.0	73.0±0.89	51.6±0.17	74.4±1.60
II	27.0±1.57	22.6±1.52	31.0±4.02	74.4±0.17	63.6±1.60	87.4±0.62
III	34.4±1.84	30.2±0.08	46.0±2.68	99.0±0.44	88.2±2.90	95.2±0.08
IV	67.6±1.16	46.0±2.68	81.0±1.94	99.0±0.44	93.0±0.89	95.2±0.08

N=5, mean±SD, C=100% soil, T1=100% flyash, T2=1:1 mixture of flyash with soil

Table 3. Potential of flyash ash utilization in horticulture (early seedling growth studies)

Duration in weeks		Growth (cm.)					
		<i>S. melongena</i>			<i>S. oleracea</i>		
		30 days	60 days	90 days	30 days	60 days	90 days
Root	C	1.9±0.22	9.6±0.84	9.6±0.25	2.5±0.49	9.9±1.12	10.3±0.13
	T1	2.6±0.08	--	--	1.7±0.31	--	--
	T2	2.6±0.17	4.9±0.26	9.8±1.78	5.0±0.22	8.3±0.35	17.0±0.64
Shoot	C	1.8±0.76	5.8±0.93	15.9±0.17	5.6±0.08	7.3±0.08	16.6±0.49
	T1	1.7±0.05	--	--	2.0±0.04	--	--
	T2	1.3±0.76	4.4±0.04	11.8±1.78	7.0±0.89	13.0±1.34	18.0±0.67
Total	C	3.7±0.96	15.4±1.69	25.5±0.40	8.0±0.57	17.2±0.20	26.9±0.62
	T1	4.3±0.12	--	--	3.7±0.35	--	--
	T2	3.9±0.93	9.3±0.30	20.6±2.67	12.0±1.11	21.3±0.69	35.0±1.31

N=5, mean±SD, C=100% soil, T1=100% flyash, T2=1:1 mixture of flyash with soil

Table 4. Water content (%) level in different plants parts

Duration->	30 days			60 days			90 days		
	C	T1	T2	C	T1	T2	C	T1	T2
<i>S. melongena</i>									
Root	25	54	25	70	--	56	60	--	52
Stem	75	56	60	68	--	70	73	--	68
Leaf	47	58	37	60	--	52	75	--	60
<i>S. oleracea</i>									
Root	77	85	93	73	--	79	54	--	86
Shoot	93	83	77	88	--	77	83	--	70

N=5, mean±SD, C=100% soil, T1=100% flyash, T2=1:1 mixture of flyash with soil

Table 5. Biochemical health of plants grown on flyash

Parameters / Experimental set		Germination (%)					
		<i>S. melongena</i>			<i>S. oleracea</i>		
		30 days	60 days	90 days	30 days	60 days	90 days
Chlorophyll 'a' (mg/g fresh wt.)	C	0.1051±0.012	0.4239±0.015	1.3327±0.163	0.1095±0.001	0.7357±0.006	1.2346±0.061
	T1	0.0800±0.004	--	--	0.0299±0.000	--	--
	T2	0.0761±0.000	0.6556±0.014	1.7694±0.062	0.1217±0.001	0.6018±0.000	1.3583±0.032
Chlorophyll 'b' (mg/g fresh wt.)	C	0.0308±0.002	0.7883±0.047	0.4964±0.084	0.0346±0.000	0.5312±0.007	1.1387±0.252
	T1	0.0321±0.007	--	--	0.0061±0.000	--	--
	T2	0.0281±0.002	0.5598±0.004	1.4762±0.073	0.0532±0.004	0.5709±0.008	0.4872±0.002
Carotenoids (mg/g fresh wt.)	C	0.0478±0.003	0.6671±0.018	0.4891±0.004	0.0452±0.000	0.4924±0.001	1.1627±0.230
	T1	0.3980±0.000	--	--	0.2010±0.000	--	--
	T2	0.0329±0.000	0.4845±0.021	0.6441±0.027	0.0507±0.007	0.5059±0.002	0.5526±0.014
Protein (mg/g fresh wt.)	C	46.5±1.36	267.3±0.53	101.3±0.89	85.00±2.44	234.60±1.17	198.57±1.69
	T1	31.1±0.84	--	--	53.00±1.44	--	--
	T2	58.6±3.08	345.3±1.92	128.3±2.54	56.08±1.78	218.13±1.89	193.00±1.07

N=5, mean±SD, C=100% soil, T1=100% flyash, T2=1:1 mixture of flyash with soil

Potential bulk utilization of coal combustion residue (flyash) from thermal power plants in growing horticulture crops appeared an approachable option for further studies related to identification of suitable species, analysis of sensitivity and potential risks. Significant enhancement of plant health (biochemical and vigour) (Tables 5 & 6) and productivity (Figs 2a & 2b, 3 & 4) of studied crops (*S. melongena* and *S. oleracea*) grown on 1:1 flyash-soil mixture can be attributed to improved substrate conditions and nutrition (Mandal & Saxena, 1997; Tripathi *et al.*, 2004).

Flyash added to soil significantly increased the electrical conductivity of the soil mixture by increasing the levels of soluble major and minor inorganic constituents (Eary *et al.*, 1990). Flyash itself is not effective in retaining water but it significantly increases water holding capacity of the soil mixture (Chang *et al.*, 1977). Flyash+soil medium has been reported characterized for better soil porosity and thus increased water holding capacity (Gupta *et al.*, 2002) and decreased bulk density (Page *et al.*, 1980) allowing workability of the substrate leading to better root penetration. Many chemical constituents of flyash benefit plant growth and can improve the agronomic properties of the soils (Chang *et al.*, 1977). The seed germination, early growth, plant-

health aspects including phytomass studies suggested better or similar performance of studied vegetable crops on 1:1 flyash+soil substrate with reference to pure soil. Better yield of plants in quantitative as well as qualitative aspects evidenced the tolerance potential and the role of metal binding peptides (phytochelatins) in the cells that countered the growth retarding risk of toxic metals otherwise rich in the flyash substrate as compared to normal soils (Tripathi *et al.*, 2004).

Consequently, the present study on bulk utilization of flyash (up to 50%) on garden soil for growing vegetable crops has scientifically advocated the option to be further explored and implemented at field. The usage of flyash for agriculture as a potential fertilizer or soil amendment has been a global problem related to the concept of so-called zero emission or ecological recycling, whereas its utilization in many other industrial purposes has been established (EPD, 1993).

However, hazards associated with the metal contents and the alkaline nature of the flyash has been studied and reported (Singh & Kumar, 1997; Gupta *et al.*, 2002; Tripathi *et al.*, 2004). It is important to note that metal deposition in the root may restrict movement of the toxic metals to the leaves and other shoot

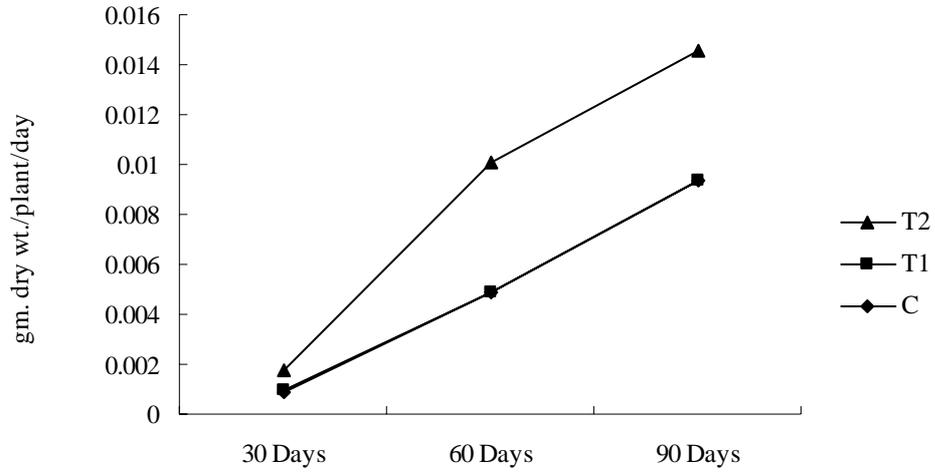


Fig. 2a. Net Primary productivity (gm dry wt./plant) *S. metongena*

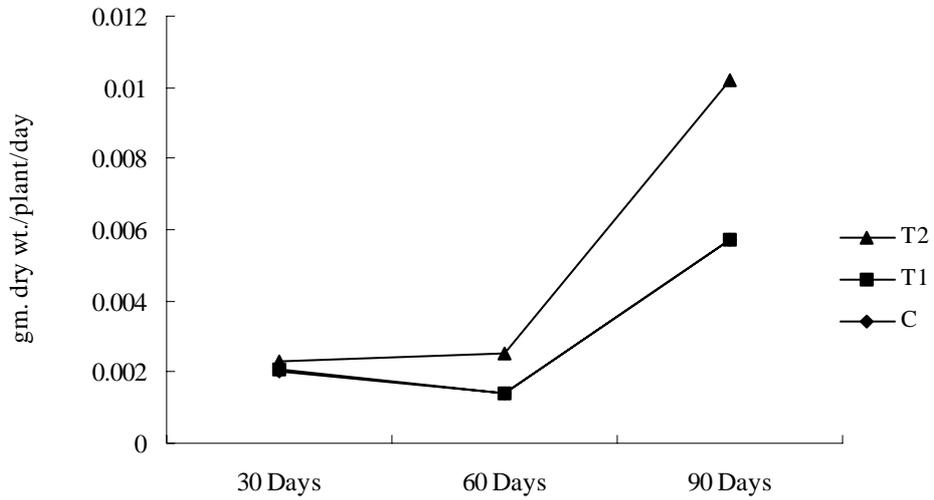


Fig. 2b. Net Primary Productivity (gm. dry wt./plant/day) *S. oleracea*

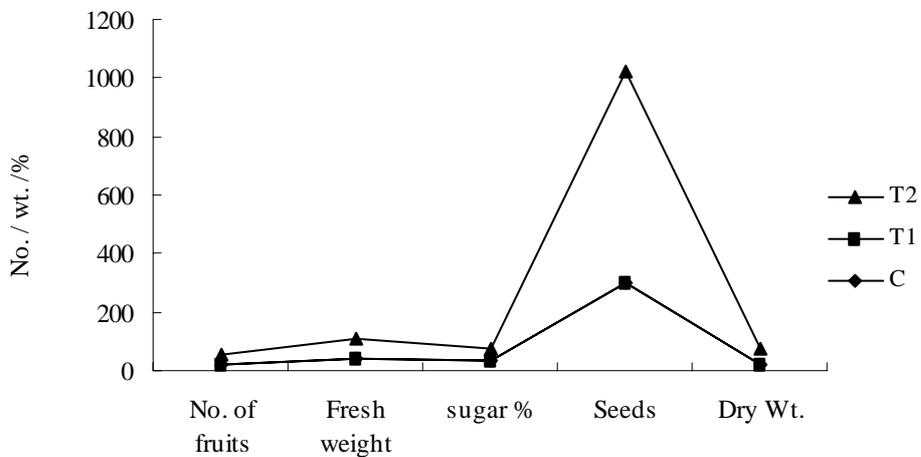


Fig. 3. Quantitative and qualitative aspects of yield of *S. melongena*

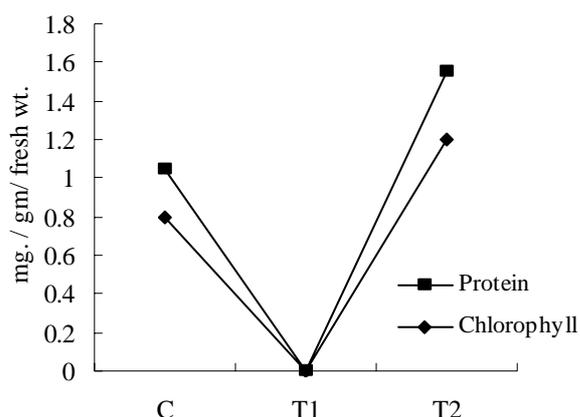


Fig. 4. Quantitative aspects of final yield of *S. oleracea*

organs (Inouhe *et al.*, 1994), and hence, the different tolerance characteristics of roots may serve as limiting factor for overall plant growth responses to flyash. The greater availability of metals has been correlated with a lowering of pH of flyash after addition of organically rich wastes that is usually acidic in nature (Tripathi *et al.*, 2000). It is, therefore, suggested that in order to develop the protocols for horticultural or agricultural utilization of flyash, systematic screening for suitable crop species and optimum level of flyash application must be undertaken. Application of biofertilizers, *viz.*, mycorrhiza alone or in combination with nitrogen fixers may help varying levels of improvement in countering phosphate and nitrogen unavailability to the plants (Singh & Yunus, 2000). Understanding the metal uptake or avoidance mechanism will help minimize the risk of food safety or food chain contamination risks. Reducing the load to exceed the carrying capacity is the prime risk management stage for disaster management relating to ash-pond failures or breach, which otherwise may pose serious disruption of communities resources or livelihood besides damaging the environment. Flyash disposal & utilization shall continue to be an important area of national concern due to India's dependence on thermal power generation for its energy supply. According to the estimates India needs to grabble with about 30,000 hectares area of flyash dumps at current times. To prevent the flyash from being airborne the dumping grounds need to be kept wet all the time. Sprinklers are employed are agencies are hired to water the flyash dump grounds. This is a very costly affair and Thermal Power Plants in India are reportedly spending about US\$14 million (equivalent) annually on these activities. However, due to the pozzolanic properties, it has been extensively used as an ingredient of cement, concrete, mixes, soil stabilizer in road making, and structural filling (Singh & Yunus, 2002). Flyash has also being used in amendment of acidic mine-spoils and mining wastes (Jastrow *et al.*, 1981), it neutralizes acidity, decreases bulk density, increases

water-holding capacity and reduces compactness. Mandal & Saxena (1997) studied flyash utilization for ameliorating black cotton soil (pH 8.02) with water logging, alkalinity, and lack of aeration, and reported increase in porosity, reduced water-logging, modification of texture from silty loam to loam, reduced crack formation and caused yield enhancement by 15%.

CONCLUSION

The study concluded that the flyash application as higher as upto 50% in case of common garden soils, supporting the options of Fig. 2a. Net Primary Productivity (gm dry wt./plant/day) *S. melongena* Fig. 2a. Net Primary Productivity (gm dry wt./plant/day) *S. melongena* bulk utilization of flyash in horticultural cropping. Most of the options of flyash utilization systematically and explored yet at field level allow restricted level of application, whereas the present study offers claim to harness potential of bulk utilization of thermal power plant waste and also to help in managing the problems of land-uses as well as food security.

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