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Original Research Article

Impact of Fly Ash on Physical Properties of Waterlogged Soil, Plant Growth and Root Yield of *Withania somnifera* (L.) Dunal (Ashwagandha)

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Abstract

In present study, to explore the possibility of using fly ash as soil modifier and micro nutrients supplier to upgrade soil for its use in cultivation of a medicinal plant *Withania somnifera* (Ashwagandha) and to improve the productivity of dry root yield. Results revealed that the application of fly ash in soil improved the physico-chemical properties of soil *viz.*, bulk density, porosity and water holding capacity. The initial pH of soil and fly ash was 8.2 and 7.8 respectively. Electrical conductivity of soil (0.416 dS/m) was higher as compared to fly ash (0.185 dS/m) and the bulk density of fly ash (1.02 g/cc) was lower as compared to soil (1.32 g/cc). The water holding capacity of soil and fly ash was 60.0% and 66.8% respectively. The plant growth parameters in terms of plant height and leaf area were found to be higher in maximum fly ash treated plot as compared to control plot during different growth stages of *Withania somnifera*. The root yield (35.545 g/plant and 39.002 g/plant) of *Withania somnifera* were found higher in maximum fly ash (20%) treatment compared to control plot in first and second year of cultivation. The outcome of this study reveals the bulk use of fly ash in the cultivation of medicinal plant (Ashwagandha), specifically enhances the plant growth and root yield, and also improves physico-chemical properties of the waterlogged soil.

Keywords

Fly ash

Leaf area index

Physical properties

Root yield

Withania somnifera

Introduction

Presently in India, coal based Thermal Power Plants are generating ~171 million tonnes of fly ash by the year 2014 and it is expected to increase 225 million tonnes in the year 2017 (Bhattacharjee and Kandpal, 2002; Kumar and Mathur, 2004; Asokan et al., 2005a; Sachdev, 2007; TIFAC, 2007; Bhisham et al., 2013). This will lead to major environmental problems. In India ~40% of fly ash is being used in various applications such as cement, road/embankment, building construction materials, land reclamation, wasteland development for agriculture and as an adsorbent in waste water treatment (Tiwari and Saxena, 1999; Sikdar et al., 2000; Iyer and Scott, 2000; Saxena and Asokan, 2002; Asokan et al., 2005a; TIFAC, 2007; Bhisham et al., 2013).

According to several researchers the application of fly ash in agriculture revealed that fly ash has some beneficial as well as undesirable effects on the soil fertility and crop yield (Matsi and Keramidas, 1999). Addition of fly ash neutralized the soil acidity to suitable for agricultural crops (Moliner and Street, 1982). It has been reported that physical and chemical properties of fly ash can contribute to enhance agronomic properties of soil (Asokan et al., 1999). Application fly ash increased the plants growth and yield of vegetables, oils and cereals crops like tomato, potato, cabbage, pea, wheat, mustard, oats and sunflower (Mittra et al., 2005; Saxena et al., 2005). The impact of fly ash on soil fertility and crop yield depends on various factors such as pH, conductivity, reactivity of fly ash, ion exchange capacity, moisture content, particle size and finally percentage addition of fly ash. It is evident from the analysis of Indian fly ash that the presence of heavy/toxic elements and radionuclides are at levels that may not lead to serious concern (Vijayan, 2000; Asokan et al., 2005b).

Withania somnifera (L.) Dunal (Ashwagandha) is an Ayurvedic medicinal plant which is popular as a home remedy for several diseases and human requirements. It is mentioned in Vedas as an herbal tonic and health food. It is in use for a very long time for all age groups and sexes and even during pregnancy without any side effects. Different investigators reported antiserotogenic, adaptogenic, anticancer and anabolic activity, and beneficial effects in the treatment of arthritis and geriatic problems (Asthana and Raina, 1989). *Withania somnifera* roots are the source of drug "Ashwagandha" an important ingredient of various Ayurvedic formulations. *Withania somnifera* roots of commerce are obtained mostly from common cultivated source of Manasa, Neemuch and Javed Tehsil of Mandsaur District, Madhya Pradesh and adjoining area of Rajasthan, India in about 4000ha (Kumar et al., 2001; Nigam, 1984). According to an estimate, the annual requirement of the roots is ~7000 tonnes in India. The cultivation is confined to annual production ~1350 tonnes, which is too low to meet the ever increasing demand (RRL, 2004). The survey of the plants, which provide valuable ingredients for a range of medicinal formulations, reveals that many such plants grow wild on wastelands in different areas of the country.

Still no data has been reported that the fly ash was used in bulk quantity to admit the waterlogged soil for increasing the growth and productivity of medicinal plants. Keeping in view, the lab scale experiments were conducted following a statistically valid experimental design to assess the cultivation of the medicinal plant, *Withania somnifera* which can profitably be taken up on large scale in the waterlogged clay soil using fly ash as soil modifier and microfertiliser. The present paper also deals with the effect of fly ash on physico-chemical properties of waterlogged soil and root yield production of *Withania somnifera*.

Materials and methods

Lab scale experiments

Lab scale experiments were conducted at Advanced Materials and Processes Research Institute (CSIR), Bhopal, Madhya Pradesh, India. The experiments were carried out in Randomized Block Design (RBD). Plot size was 8×6.5 m and sub-plot size was 1×1 m. The experiments were designed with five treatments i.e.T1 (Control, no fly ash), T2 (5% fly ash), T3 (10% fly ash), T4 (15% fly ash) and T5 (20% fly ash) with four replications (R1, R2, R3 and R4).

Fly ash was mixed with soil manually on the basis of soil bulk density in dry state at about 3 to 5% moisture which was transported from the ash dyke of Satpura Thermal Power Station, Sarni, Dist. Betul, Madhya Pradesh, India. One of the important medicinal plants, *Withania somnifera* belonging to the family Solanaceae was considered for this study, since it is an excellent value added medicinal plant in Indian traditional medicinal system.

Sampling of soil and fly ash

Equal volume of soil sample from each plot of same depth from the root zone area was collected. Samples were prepared by adopting conventional quartering and coning method. The fly ash samples were collected from ash dyke of Satpura Thermal Power Station, Sarni, Dist. Betul, Madhya Pradesh at the time of fly ash transportation by the same method. The collected soil and fly ash samples were air dried and sieved through 2 mm size sieve and were used for physical properties characterization.

Physical properties of soil and fly ash

Bulk Density (BD) was measured following Veihmeyer and Henderielson (1946) method. Porosity was calculated empirically using particle density and bulk density following Bodman (1942) method. Water holding capacity (WHC) was measured using saturated soil past and was verified with Keen Box Method (Piper, 1966). The electrical conductivity (EC) was measured using Colones Conductivity Meter in 1:2 soil water suspensions (Jackson, 1973) and pH was determined calorimetrically using pH meter (Jackson, 1973).

Morphological measurements

Observations on plant growth were recorded at successive intervals starting from vegetative stage (60 DAS) up to seed maturity (at harvest). Present study includes morpho-physiological studies and inter-relationship between the morpho-physiological characters of *Withania somnifera* at various growth stages during 220 days life span of the plants to evaluate the best stage of growth for optimum benefit. The 220 days of life span of *Withania somnifera* was grouped into 4 growth stages (i) 60 days after sowing (DAS) (ii) 120 DAS (iii) 180 DAS and (iv) at harvest (220 DAS). Ten numbers of plants at random were harvested each time for recording data.

The plant height of *Withania somnifera* was determined by measuring scale and leaf area was determined by Leaf Area Meter (Modal 100), ADC, UK. The root yield production of plants were harvested 15-20 cm above the ground level and fresh root was weighed and oven dried at 80°C till it reached constant weight and used for determining root yield production at different developmental stages. The remaining plants were uprooted, washed with fresh water, weighed, oven dried at 80°C to constant weight and used for determining biomass. These were done for two successive cropping, i.e., first year (2006-07) and second year (2007-08) of cultivation.

Results and discussion

Physical properties of initial soil and fly ash

The physical properties of initial soil and fly ash are shown in Table 1. Results from the textural analysis showed that initial soil and fly ash was clayey and loamy sand respectively. The sand content in fly ash was higher (85.50%) than in initial soil (21.25%). The silt and clay content was found higher in soil than in fly ash. The obtained results showed that the pH of the fly ash and initial soil varies from 7.85 to 8.23. The Electrical Conductivity (EC) of fly ash was 0.416 dS/m and that of soil was 0.185 dS/m which is invariably low. The bulk density of soil was 1.32 g/cc and fly ash showed relatively less bulk density (1.02g/cc). The porosity of fly ash was 48.22% and soil was 42.18%. The water holding capacity (WHC) of soil and fly ash was observed as 58.36% and 66.79% respectively. Fly ash was applied only one time at the start of the experiment in the first year.

Table 1. Physico-chemical chemical property of initial soil and fly ash.

Parameters	Initial Soil	Fly ash *
Sand (%)	21.25	85.50
Silt (%)	30.65	13.60
Clay (%)	48.10	0.90
Texture	Clay	Loamy sand
pH	8.23	7.85
Electrical conductivity (dS/m)	0.416	0.185
Bulk density (g/cc)	1.32	1.02
Porosity (%)	42.18	48.22
Water holding capacity (%)	58.36	66.79
*Fly ash was applied only at the start of the experiments 2006 – 2007		

The texture of fly ash is loamy sand, and such type of texture materials are easy to handle in tillage operations, which facilitate good drainage and aeration (Buckman and Brady, 1960). The clay particles play a very important role in soil fertility. The study carried out by Wigley and Williamson (1998), indicates that medium size of fly ash particle diameter is 20 µm and the maximum fly ash particles are usually in the range of 150-200 µm. The particles size distribution and texture of the fly ash varies distinctly based upon the source, topography of disposal site and location from where the fly ash was collected and was confirmed by several authors (Rajasekhar, 1995; Sivapullaiah et al., 1998).

The low electrical conductivity of soil indicates that the presence of both anions and cations are higher in fly ash as compared to the soil. The increase in density attenuated due to presence of more clay fractions, which is fine textured (Buckman and Brady, 1960). The low bulk density of fly ash is attenuated due to its lightweight, as it is a burnt residue of coal. The porosity of fly ash was found higher as compared to initial soil. Porosity of the soil was low; this allows relatively slow air and water movement despite of the large amount of total space available (Shaw et al., 1952).

Porosity of fly ash was found higher which is beneficial for low porosity of clay soil. For ideal condition of aeration, permeability and water retention, a soil should have an equal amount of macro and micro-pores (Buckman and Brady, 1960). The silty nature of fly ash has comparatively, increased the water holding capacity (WHC) by 66.79% than the initial soil (Table 1). This has also resulted in higher water holding capacity and increases the water level in the pore space with the soil get clogged resulting in water-logging problem (Millar et al., 1958).

Effect of fly ash on physico-chemical properties of admixed soil at the time of harvesting of *Withania somnifera* during two cultivation periods

The effect of fly ash on the physical properties of soil after harvesting of first and second year of cropping is shown in Table 2. The clay content in T1 treatment was recorded maximum 46.12% in after harvesting of first year. The sand, silt and clay content in the T5 treatment in first year was 32.26%, 39.28% and 28.46% respectively and in second year sand, silt and clay content were 32.66%, 40.24% and 27.10% respectively. The second cropping results revealed that maximum EC was found in maximum fly ash treated plot as compared to control plot. Also increasing trend was noticed in T2, T3 and T4 treatments after completion of second cropping season (Table 2).

Table 2. Effect of fly ash on physical properties of admixed soil after harvesting of *Withania somnifera* during first and second year of cropping.

Parameters Vs Treatments	Treatments									
	T1		T2		T3		T4		T5	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Sand (%)	21.52	22.68	24.86	28.14	25.26	30.94	31.46	31.72	32.26	32.66
Silt (%)	32.36	32.44	35.78	36.48	36.34	35.52	36.34	37.46	39.28	40.24
Clay (%)	46.12	44.88	39.36	35.38	38.40	34.54	32.20	30.82	28.46	27.10
pH	8.15	8.12	8.12	8.10	8.12	8.10	8.10	8.00	8.10	8.00
Conductivity (dS/cm)	0.228	0.248	0.236	0.254	0.243	0.258	0.254	0.264	0.262	0.274
Bulk Density (g/cc)	1.31	1.30	1.29	1.23	1.28	1.24	1.27	1.23	1.25	1.21
Porosity (%)	44.65	45.62	45.75	46.85	46.56	46.88	47.65	48.58	48.11	48.56
WHC (%)	57.36	57.66	57.42	57.76	57.45	57.88	57.82	48.12	58.21	58.54

Results showed that pH of after harvest soil samples, not much variation was found in all treatments of the both cropping. The plant absorbs most of the nutrient within the pH range from 8.00 to 8.15 in soil (Table 2). Though, there is not much variation was found between the pH of after harvesting soil sample, pH plays an important role in improving the soil fertility (Brady, 1985). The soil, pH may influence nutrient absorption and plant growth through a direct effect on the hydrogen ions, indirectly through its influence on nutrient availability and presence of trace and heavy elements (Weissenhorn et. al., 1995). Fly ash significantly increases the soil pH, the plant biomass and root biomass. The soil was amended with fly ash, root growth occurred throughout the material

(Keefer, 1993). Alkaline pH also enhances mineralization of organic matter and promotes nutrient supply to the plants (Mittra et al., 2005).

During the cultivation of *Withania somnifera* in the fly ash treated soil showed increase in the availability of free ions along with an increase in EC from control plot (T1) to maximum fly ash treated plot (T5) in the first cropping (Table 2). In the second cropping the result revealed that higher EC was found in maximum fly ash treatment as compared to control in both morphotype plots.

A greater reduction is observed that bulk density in both cropping. Fly ash addition to soil lowered bulk density and improved the moisture retention. Organic matter also plays an important role in increasing soil fertility, nurturing crops, regulating soil quality, improving the soil physico chemical properties (Xu, 2004; Jasinska et al., 2006). Fly ash addition had changed the compactness and could be attributed to the presence of sand content in fly ash which was affected the bulk density. This result has been supported by the findings of Saxena et al. (2005).

Increasing trend has been observed in porosity and WHC in all treatments after harvesting of first and second cropping seasons (Table 2). Fly ash has been shown to increase the WHC of soils and hence the amount of available water to the plant (Menzies and Aitken, 1996). The addition of lower doses of fly ash also improved physical, chemical and biological properties of soil and has been demonstrated to result in enhanced growth of a number of plants (Gupta et al., 2002; Jala and Goyal, 2006).

Effect of fly ash on chemical properties of dry root of *Withania somnifera* harvested after first and second year of cropping

Table 3 shows the chemical properties of roots of *Withania somnifera*, cultivated in different fly ash treated plots, harvested during first and second cropping. Results showed that maximum nitrogen content was observed in T5 treatment compared to T1 plot in the both cropping season. The phosphorous was found higher in T5 treatment as compared to control plot. Not much variation of phosphorous concentration was found between first year and second year harvested roots of *Withania somnifera* in all treatments. The maximum potassium content was found in T5 treatment as compared to other treatments after completion of first and second cropping. However, the sulphur content was showed decreasing trend from T1 to T5 treatments in the both cropping years. The Cu, Zn, Fe and Mn contents were noticed to increase in all the treatments amended with different concentration of fly ash during first and second year.

Table 3. Effect of fly ash on chemical properties of root of *Withania somnifera* after harvesting during first and second year of cropping.

Parameters Vs Treatments	Treatments									
	T1		T2		T3		T4		T5	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Nitrogen (%)	1.45	1.46	1.51	1.52	1.57	1.56	1.63	1.65	1.74	1.75
Phosphorus (%)	0.296	0.296	0.289	0.291	0.298	0.296	0.312	0.313	0.322	0.320
Potassium (%)	0.012	0.013	0.014	0.014	0.016	0.015	0.016	0.016	0.018	0.019
Sulphur (%)	0.517	0.526	0.365	0.413	0.236	0.368	0.230	0.312	0.226	0.305
Copper (ppm)	12.36	14.26	15.84	16.38	16.25	17.75	16.28	17.85	18.56	17.96
Zinc (ppm)	32.26	36.25	34.26	38.64	36.38	41.23	42.56	45.68	54.26	48.65
Manganese(ppm)	14.26	18.56	15.24	21.49	15.26	22.37	15.36	22.55	16.38	23.68
Iron (ppm)	256.34	265.56	388.34	372.61	396.28	386.41	416.34	412.8	485.26	421.35
Cobalt (ppm)	1.56	1.45	1.42	1.38	1.32	1.35	1.28	1.31	1.16	1.26
Lead (ppm)	5.63	4.26	5.64	4.12	5.26	4.25	5.42	4.11	4.98	4.10

Higher nitrogen content was found in T5 treatment when compared to T1 plot in the both years. Not much variation was found of phosphorous concentration between first year and second year in the all the treatments. The maximum content of potassium and sulphur was found in T5 in the root in comparison to other treatments, after completion of first and second cropping. But the maximum content of these micronutrients was recorded in roots in all the treatments. The total accumulation of toxic metals particularly, Ni and Pb, were recorded many times higher in the plants grown in fly ash amended soil (Tripathi et al., 2004). It is possible that high accumulation of Mn and Zn, particularly in the root tissues could be due to the complexation of metals with the sulphydryl groups, which resulted in less translocation of metals in upper parts of the plant. The total heavy metals such as Co and Pb were observed within the limit and Ni, As, Cr and Cd were found below detectable limit in all the treatments of both morphotype roots harvested in first cropping season. Higher mobility of Ni was through xylem tissues of shoot and its transport from root to shoot is greater (Kramer, 2005). Ni has been considered as an essential element for the microbes (Hausinger, 1987), plants (Welch, 1995) and animals (Barceloux, 1999). However, the accumulation of Cr was below detection limit (BDL) in all the fly ash treated plots as well as control plot.

Tripathi et al. (2004) and Sinha and Gupta (2005) reported significantly high accumulation of essential metals like Fe, Mn, Zn and Cu in different parts of the plant namely *Cassia siamea* (Lamk.) and *Sesbania cannabina* (L.). The content of heavy metals in grains of wheat and soybean were within the normal range and no toxic effects were found in the soil and the food products (Bhisham et al., 2007a). Several reports indicated that the metal accumulation in the plants depended on the concentration of available metals in the soils, solubility sequences and the plant species growing on these fly ash treated soils (Singh and Siddiqui, 2003; Sinha and Gupta, 2005). During this study, accumulation of metals such as Zn, Fe and Mn were recorded more in roots of maximum fly ash treated plots compared to control plot. This result has been supported by the finding of Sinha and Gupta (2005) who reported that the translocation of metals was more from roots to shoots in the plants grown on fly ash treated plots.

Effect of fly ash on growth parameter of *Withania somnifera*

Present study includes morpho-physiological studies and inter-relationship between the morpho-physiological characters of *Withania somnifera* at various growth stages during 220 days life span of the plants to evaluate the best stage of growth for optimum benefit. Biological growth, on the other hand, requires the orderly assimilation of the substance from the environment and their conversion into the very "stuff" of life, producing the highly importable arrangement which constitutes the organization of the plant body. "Growth" is often held to increase of size while "growth" denotes the changing pattern of organization as growth progresses (Stewart, 1968). According to Patil (1985) and Dhopte et al. (1989) the growth is explained at molecular level and they stated that growth is an important phenomenon such as photosynthesis and dark respiration at molecular level. Growth is an irreversible increase in size, which may or may not be accompanied by an increase in dry weight or in the amount of protoplasm. It is the sum total of all the metabolic activities normally resulting from the excess of anabolism over catabolism. It refers to quantitative changes in the life cycle of plants. Photosynthesis, being basically reduction process fixes carbon and the respiration being oxidation process losses carbon. Growth is the resultant of oxidation reduction potential of an organism. How much weight (mass) is gained or lost (±) by a plant per unit time is termed as growth. Growth commences soon after a haploid (n) cell is fertilized (2N). Resultant is an increase in total biomass and dry matter. An ultimate effect is an increase in size through cell division. Traditionally plant physiologist turned their attention to the growth which may be both seen and measured as increase of size and to problems of relative growth i.e. the unequal distribution of growth among different organs or in different parts of the same organ. Hence, an analysis of dry weight accumulation based on differentiation between assimilatory leaves and rest of the plant may be expected to be more informative than one which discriminates between meristematic and non-meristematic region where the total dry weight of the plant dw/dt becomes its absolute growth (Watson, 1952). The growth parameters such as plant height, leaf area, leaf area index, crop growth rate and root yield of *Withania somnifera* are discussed separately below.

Effect of fly ash on plant height of *Withania somnifera* at different development stages during two cropping periods

Table 4 showed the plant height of *Withania somnifera* grown in two cropping period. The plant height was measured at 60 DAS and 120 DAS. Results revealed that maximum plant height was noticed in the T5 treatment (where 20% fly ash applied) at harvest stage of both years as compared to control plot (T1). The value of critical difference at 5% in first year at 60 DAS, 120 DAS and 180 DAS were 2.089, 2.462 and 3.842 and 0.694, 0.824, 1.709 and 0.851 respectively in second year.

The results revealed that the fly ash applied plots were found to gain maximum plant height as compared to the control plot at the different phenological stages *Withania somnifera*. The maximum plant height was found in T5 treatment at the harvest stage in second year as compared to first year at different development stages. The critical difference at 5% was showed in both year of plant height at the 60 DAS, 120 DAS, 180 DAS and at harvest time (Table 4). The maximum plant height was found in fly ash treated plots as compared to the control plot during the different growth phases in both year. Rai et al. (2004) observed better growth of *Prosopis juliflora* when grown on fly ash and better growth of rice plants grown on soil amended with fly ash (Mittra et al., 2005).

Effect of fly ash on leaf area (LA) of *Withania somnifera* at different development stages during two cropping periods

Table 5 shows the leaf area of *Withania somnifera* measured at different developmental stages. The maximum leaf area was observed in fly ash treated plots as compared to the control plot during the different development stages. The leaf area of *Withania somnifera* grown under maximum fly ash (20%) applied plot at 60 DAS, 120 DAS, 180 DAS and at harvest during first cropping was 9.84, 18.85, 26.40 and 28.77 cm^2 respectively. Similarly, during second year the leaf area at 60 DAS, 120 DAS 180 DAS and at harvest was 10.49, 20.17, 27.15 and 30.21 cm^2 respectively.

The value of critical difference leaf area at 99.9% confidence level were 0.606 at 60 DAS, 0.949 at 120 DAS, 1.382 at 180 DAS and 0.919 at harvest in second year.

Table 4. Effect of fly ash on plant height (cm) of *Withania somnifera* at different development stages in the two cropping periods.

Treatments	60 DAS		120 DAS		180 DAS		At Harvest	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
T1	31.75	33.50	49.25	51.50	72.25	74.25	103.00	105.50
T2	32.75	35.50	51.00	53.50	74.50	76.50	104.50	106.50
T3	34.00	36.00	51.25	55.00	74.75	78.00	105.50	108.50
T4	35.25	37.25	52.50	56.75	76.50	79.50	105.75	109.25
T5	35.75	38.00	52.00	57.75	77.00	81.00	107.50	110.75
SEM	0.7071	0.2349	0.8329	0.2786	1.299	0.5783	1.125	0.2878
CD at 5%	2.089	0.6943	2.462	0.8235	3.842	1.709	NS	0.851

DAS- Day after sowing; SEM- Standard error mean; CD - Critical difference.

Table 5. Effect of fly ash on leaf area (LA) of *Withania somnifera* at different development stages in the two cropping periods (cm^2).

Treatments	60 DAS		120 DAS		180 DAS		At harvest	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
T1	6.45	6.91	13.23	14.69	21.26	22.24	25.18	27.13
T2	7.12	7.74	15.13	15.79	22.88	23.97	26.84	28.58
T3	8.67	8.81	16.62	17.36	23.93	24.92	27.07	28.21
T4	9.29	9.88	17.29	18.32	24.86	25.61	28.36	29.56
T5	9.84	10.49	18.85	20.17	26.40	27.15	28.77	30.21
SEM	0.7583	0.2051	1.2120	0.3211	1.7420	0.4674	1.1650	0.3109
CD at 5%	2.241	0.606	NS	0.9492	NS	1.382	NS	0.919

Leaf area is an important measure of quantifying the potential of a plant for photosynthesis. The concept of leaf area is measure of plant productive potential to field crops by defining a leaf area index as a measure of green leaf per unit area of land (Watson, 1952). It was found more than that of the control plot (there is no fly ash) in both the years. The result showed the maximum leaf area was found in second year as compared to first year in all the treatments at respective growth stages. The statistical analysis indicates that the leaf area of *Withania somnifera* showed significant variation between the treatments at 60 day after sowing seeds. In the subsequent phenological stage, there is no significant variation was observed in first year. But the second year showed significant variation at all development stages between all the treatments (Table 5). The fly ash application at the rates of 2.5-5.0%, maize and soybean crops showed an increase in the height of plants, leaf area and dry weight (Mishra and Shukla, 1986). Applications of fly ash also increase (5-12%) of plant height and leaf area of *Withania somnifera* (Bhisham et al., 2007b).

Effect of fly ash on Leaf area index (LAI) of *Withania somnifera* at different development stages during two cropping periods

Table 6 shows the leaf area index (LAI) of *Withania somnifera* during two cropping periods. Results revealed that maximum value (9.996 cm^2) at harvesting stage in maximum fly ash applied plot (T5) in the first year followed by 5.358 at 180 DAS, 1.086 at 120 DAS and 0.227 at 60 DAS as compared to control plot (T1) in first year at different growth stages. Similar trend was observed in second year also. The result revealed that maximum LAI was found in second year compared to first year in all the treatments at all development stages. The critical difference of LAI at 5% significance was observed at all stages of development of *Withania somnifera* in first year. However, in the second year no significant variation was recorded at 120 DAS.

Leaf area index (LAI) is an important physical indicator of a crop capacity to absorb photosynthetically active radiations (PAR). Net gain in dry matter depends upon the rate of photosynthesis to the rate of respiration by plant. If respiration is slower, then the rate of dry matter production is faster. Since crop yields are based on land area, the crop growth analysis should also be expressed on land area slightly more than on the individual plant basis. Watson (1947) introduced more crop-oriented concept of leaf ness in relation to land area. This, relation called as leaf area index (LAI) and defined as leaf area per unit of land area. The LAI gradually increased with the growth stages of *Withania somnifera*. The result revealed that the maximum LAI was found in second year as compared to first year in all treatment at all growth stage of both morphotype (Table 6). The statistical analysis indicates that the LAI showed significant variation between the treatments at the respected growth stages.

Table 6. Effect of fly ash on leaf area index (cm^2) of *Withania somnifera* at different development stages during two cropping periods.

Treatments	60 DAS		120 DAS		180 DAS		At Harvest	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
T1	0.138	0.142	0.648	0.872	3.384	3.514	8.245	8.595
T2	0.161	0.171	0.784	1.360	3.616	3.875	8.803	9.346
T3	0.170	0.212	0.966	1.134	3.906	4.115	9.606	9.395
T4	0.204	0.245	1.063	1.278	4.647	4.362	9.860	10.064
T5	0.227	0.273	1.086	1.460	5.358	4.802	9.996	10.503
SEM	0.0111	0.0058	0.0468	0.0876	0.1480	0.0935	0.3553	0.0365
CD at 5%	0.0337	0.0172	0.138	NS	0.438	0.2765	1.050	0.1078

Table 7. Effect of fly ash on crop growth rate ($g/m^2/day$) of *Withania somnifera* at different development stages during two cropping periods.

Treatments	60 - 120 DAS		120 - 180 DAS		180 - At Harvest	
	1st year	2nd year	1st year	2nd year	1st year	2nd year
T1	0.0611	0.0635	0.1685	0.1712	0.2493	0.3056
T2	0.0625	0.0633	0.1757	0.1795	0.2562	0.3070
T3	0.0788	0.0642	0.1905	0.1916	0.2624	0.3075
T4	0.0880	0.0677	0.1928	0.1983	0.2670	0.3084
T5	0.0920	0.0675	0.1950	0.2028	0.2697	0.3107
SEM	0.2622	0.0774	0.3251	0.1164	1.4142	0.1098
CD at 5%	NS	0.2289	0.9612	0.3442	4.180	0.3246

The results show that the maximum LAI was observed in other fly ash treated plots as compared to the control plot during the different growth stages of *Withania somnifera* (Table 6). The environmental conditions also affected the growth of the plants as it was reflected in LAI. In the present study, the LAI of *Withania somnifera* at vegetative stage was below due to growth stage and higher LAI value was noticed in maximum fly ash treated plot compared to control plot at harvest stage in both the year.

Effect of fly ash on crop growth rate (CGR) of *Withania somnifera* at different development stages during two cropping periods

Table 7 shows the CGR of *Withania somnifera* during the course of development. The maximum CGR at 60 days interval between each growth stages were found in T5 treatment i.e., 0.2697 g/m^2/day between 180 DAS - at harvest (240 DAS), 0.1950 g/m^2/day between 120 DAS - 180 DAS and 0.0920 g/m^2/day at 60 DAS - 120 DAS in the first year and 0.3107 g/m^2/day between 180 DAS - at harvest, 0.2028 g/m^2/day between 120 DAS - 180 DAS and 0.0675 g/m^2/day between at 60 DAS - 120 DAS in second year. The statistical analysis indicates that the CGR showed significant variation between the all the treatments at all development stages in first and second year. The results revealed that the increasing trend of CGR was observed in all treatment of *Withania somnifera* grown in fly ash treated plot. The statistical analysis indicates that the CGR showed significant variation between the treatments at the all developmental stage except at 60 DAS of first year (Table 7). The increases in the photosynthetic rates were to be associated with the decreased leaf size as has been observed in several crop species (Planchon and Fesquet, 1982; Bhagsari and Brown, 1986). Similar to NAR and CGR also followed the same pattern but the frequencies were found to be specific to each morphotype of *Withania somnifera* and it resumed the pattern of increasing with the advancement of age.

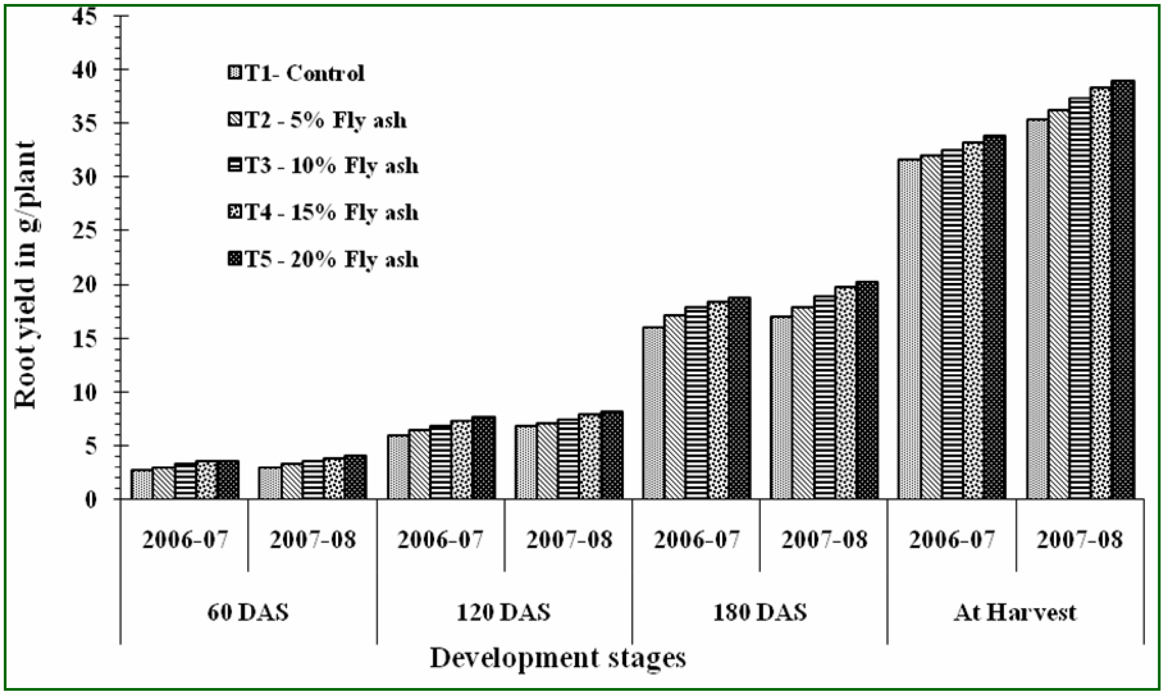
Effect of fly ash on dry root yield of *Withania somnifera* at different development stages during two cropping periods

Fig. 1 shows the dry root yield per plant in the first and second year at various development stages. The result revealed that the dry root yield of *Withania somnifera* was increased due to application of fly ash (5-20%). The maximum dry root yield was obtained in T5 i.e. 35.545 g/plant in first year and 39.002 g/plant in second year where 20% of fly ash was applied as compared to the control i.e. 31.480 g/plant in first year and 35.413 g/plant in second year at harvesting stage. Increase in dry root yield of *Withania somnifera* in the first year at the each growth stages was in the following order: T5> T4>T3>T2>T1.

The increasing trend in dry root yield of *Withania somnifera* during the second year showed almost similar results to that of first year. However, maximum dry root yield was recorded in the second year. During both the cropping periods, dry root yield of *Withania somnifera* showed significant variation between treatments with few exceptional. The statistical analysis (ANOVA) indicates that the dry root yield of *Withania somnifera* showed significant (p<0.001) difference from all the treatments in both the years (Table 8 and Table 9). It was visible from the results that the addition of fly ash was more effective to get optimum benefit. The slow release of nutrients from the fly ash could be noticed in the second year, which might have resulted in the improvement of the productivity.

Right from the pot study, it was reported that application of fly ash to agriculture soil significantly increased seed germination, which was beneficial for the plant growth at lower dose (up to 10%) of fly ash application (Matsi and Keramidas, 1999). Statistical analysis indicates that the dry root yield of *Withania somnifera* showed significant variation between the treatments in the both cropping. It is observed from the results that addition of fly ash is most effective to get optimum benefit. The application of fly ash might have increased of the roots productivity of *Withania somnifera* (Bhisham et al., 2007b). Data recorded on root yield and its attributes showed that the tap root length and number of secondary roots contributed significantly towards root yield. Tap root diameter was also positively associated with root yield and increased with age, but from the economical point of view young and soft root (5-6 months old) with 1.0-2.0 cm diameter are given preference over thick and woody root. Root diameter was significantly and positively associated with root yield and other components, except root branches (Kandalkar et al., 1993) and it had smaller positive direct effect and more positive indirect effect through plant height and stem branches. It had highest negative effect on root yield via root length in *Withania somnifera*. Root yield increase in addition of alkaline fly ash to soils has been reported for various plant species (Khan and Khan, 1996).

Fig. 1: Effect of fly ash on dry root yield of *Withania somnifera* at different development stages in the two cropping (g/plant).



Fly ash application also increased the growth and yield at the lower doses as has been reported earlier in rice and wheat (Singh and Siddiqui, 2003; Mittra et al., 2005). The effect of pond ash on crops like paddy, wheat, maize, sunflower, pea, tomato, cabbage, potato, onion, etc. have shown increase of crop yields by 12-46 % over control (Saxena et al., 2005). Although, root yield of *Withania somnifera* was found higher at seed ripening stage but alkaloid and withanolide content were low, probably due to increase in fibrous content of roots leading to decrease chemical constituents in roots (Kumar et al., 2001). From the above mentioned results it has been concluded that crop should be harvested at full maturity stage to get optimum root yield production and better root chemical composition. The root yield of *Withania somnifera* increased (~7%) by fly ash application (Bhisham et al., 2007b).

Table 8. Analysis of Variance (ANOVA) of dry root yield of *Withania somnifera* in first cropping.

Source of Variation	DF	SS	MS	F	P
Between Groups	4	44.092	11.023	14.594	<0.001
Residual	15	11.330	0.755		
Total	19	55.422			

Table 9. Analysis of Variance (ANOVA) of dry root yield of *Withania somnifera* in second cropping.

Source of Variation	DF	SS	MS	F	P
Between Groups	4	33.972	8.493	27.274	<0.001
Residual	15	4.671	0.311		
Total	19	38.643			

The dry root yield per plant progressively increased with the increase in age during the course of growth and was found to be associated with increase in biomass production. The maximum root yield was noticed in the maximum fly ash applied plot (T5) during the different developmental stages as compared to control plot during both years of cropping. The fly ash application resulted in the improved productivity of roots. The slow release of nutrients from the fly ash could be noticed in the second year, which might have resulted in the improvement of the productivity. The biomass residues generated from the first year cropping might have also contributed toward improvement in the fertility of soil. The statistical analysis indicates that the dry root yield per plant showed significant variation between the treatments in the each developmental stage. The result revealed that the maximum root yield was found in T5 treatment as compared to control at 60 DAS, 120 DAS, 180 DAS and at harvesting (240 DAS) respectively during both cropping periods.

Results on the dry root yield in the present study revealed increase till harvesting stage in fly ash treated plots when compared to control plot. The application of fly ash increased the roots productivity of *Withania somnifera* (Bhisham et al., 2007b). Data recorded on root yield and its attributes showed that the maximum root length and number of secondary roots which contributed significantly towards dry root yield. Addition of alkaline fly ash increased root yield of various plant species (Khan and Khan, 1996).

Conclusion

The addition of flu ash in clayey soil improved the physical properties such as pH, porosity and water holding capacity. The physical properties of fly ash significantly contributed to the increase in aeration and percolating water for better root development of plants and also contributed to the reduction in the surface water logging. The plant growth was found maximum in fly ash treated plots compared to control plots. Application of fly ash increased the dry root yield of *Withania somnifera* in both cropping periods against the control, where no fly ash was applied. The quality of *Withania somnifera* roots grown under different concentration of fly ash is comparable to the control and meets the quality standards. The outcome of the study revealed that fly ash can be effectively utilized as a soil modifier and micro fertilizer resulting in the increase of fertility of waterlogged soil and in the increase of plant growth and dry root yield of *Withania somnifera*. The utilization of fly ash solves the dumping problem of fly ash.

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