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# Role of Fly Ash in Augumenting Physical and Chemical Properties of Soils

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**ABSTRACT**

The easy availability of fly ash (whose disposal is a problem) and its favorable properties like no modulus of rupture, dark colour, high water holding capacity and hydraulic conductivity, makes it worth using as a physical conditioner for soils having problem of crusting, low water holding capacity and hydraulic conductivity. To test this hypothesis laboratory investigations were carried out using three soils; sandy, sandy loam and loam. The fly ash was mixed at the rate of 0.0, 2.5, 5.0, 10.0 and 20.0% (w/w) to all the three soils and the changes in various physical and chemical properties and available nutrient status of the soils were monitored. The results evealed that mixing of fly ash with soils increased hydraulic conductivity from 47.3 to 96.2% for loam followed by 15.2 to 58.5% in sandy loam and 9.5 to 47.2% in sandy soils. The water holding capacity of soil underwent an increase in sandy loam and sandy soil but showed a slight decreased in loam soil. There was a decrease in the bulk density of all soils whereas, modulus of rupture declined by 3.5 to 2.5 times in loam and sandy loam respectively. The pH of these soils remained almost unaffected while electrical conductivity (EC) increased a little with application of fly ash. Organic carbon and available nitrogen content decreased in all the soils while phosphorus content decreased in loam and sandy loam and potassium in loam and sandy soils with application of fly ash. Available phosphorous showed a little improvement in sandy and potassium in sandy loam soil with addition of fly ash. Reflectance characteristics showed that mixing of Panipat and Faridabad fly ash, with the soil may result in more favorable modification of hydrothermal regimes of soil. These beneficial affects of fly ash may help improve soil physical environment of some problematic soils and thus ensure better plant growth.

## Introduction

Fly ash is a waste product of coal fired thermal power plants. In India about 60Mt Fly ash is being produced every year (Vimal Kumar, 1996). It is dumped in usable land around thermal power plants. There are very few uses for the tonnages of fly ash produced and the disposal of fly ash has become a significant problem. The common practice is to dispose of these residues is the dumping sites of the power plant, which cover huge areas of agriculturally productive land. Eventually, collected residues may also adversely affect the environment by mobilizing their beneficial or hazardous constituents; and hence affect, to varying degrees, the quality of surface and ground waters, soils and vegetation. Efforts are in progress throughout the world to find economic uses of fly ash to tide over the above-mentioned environemntal problem. Several studies (Page *et al.*, 1979; Sikka and Kansal 1994; Sims *et al.*, 1995) have demonstrated that fly ash usually possesses variable sized particles, high water holding capacity, medium to high hydraulic conductivity, low modulus of rupture and dark colour. These beneficial effects of fly ash may help in improving soil physical environment for better plant growth in some problematic soils.

To test this hypothesis, systematic laboratory investigations were carried out with Panipat fly ash (coarse textured without toxicity) to study changes in physical and chemical properties by mixing fly ash in varying quantities with different textured soils.

## Materials and Methods

The investigation was conducted on three soil-loam (calcareous mixed Hyperthermic typic comborthids), sandy loam (Typic comborthid) and

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sandy (Typic ustipsamment) collected from and around the experimental area of the Department of Soil Science, CCS Haryana Agricultural University, hisar, Haryana (India). The soils were air-dried and analyzed for various physical and chemical properties. For characterization of fly ash, bulk samples were collected from the dumping site of Thermal Power Plant at Panipat and Faridabad (Haryana) and Bathinda (Punjab). The samples of fly ash were analyzed for important physical and chemical properties (Table 1). However, for experimental purposes only the Panipat fly ash was used. A laboratory study was carried out to analyze physical and chemical properties of fly ash, experimental soils and their different combinations. The experimental soils were mixed with the fly ash (Panipat) in different combinations as i) Control (Pure soil), ii) Soil amended with 2.5% fly ash on weight basis, iii) Soil amended with 5.0% fly ash on weight basis, iv) Soil amended with 10.0% fly ash on weight basis and v) Soil amended with 20.0% fly ash on weight basis.

After thorough mixing of fly ash with the experimental soil, samples were drawn and kept in polyethylene bags for analysis of the various physical and chemical properties. For determining soil moisture characteristics, the sieved soils, fly ashes and their mixtures were filled in the Plexi glass rings (internal diameter 5.2 cm, height 1.1 cm) at the uniform bulk density attained by uniform tapping. The samples were placed in a water tray and saturated with water by capillary action. These samples were placed on a water saturated ceramic plate. Soil moisture content at saturation ($\theta_S$) was

Table 1. Physcal and chemical properties of soils and fly ashes

| Property | Soil-1 | Soil-2 | Soil-3 | Panipat* | Faridabad** | bathinda* |
|---|---|---|---|---|---|---|
| Particle size (%) | | | | | | |
| Sand (2.0-0.02 mm) | 55.9 | 68.0 | 92.0 | 93.4 | 92.0 | 38.0 |
| Silt (0.02-0.0002 mm) | 20.0 | 10.5 | 3.8 | 3.4 | 4.1 | 49.0 |
| Clay (<0.002 mm) | 24.1 | 21.5 | 4.2 | 3.2 | 3.9 | 13.0 |
| Texture | Loam | Sandy loam | Sand | | | |
| Colour | | | | Gray (10Y5/1-D) | Black (7.5Y 2/1-D) | Olive gray (5GY 5/1-D) |
| Bulk density (Mg m$^3$) | 1.31 | 1.39 | 1.50 | 1.20 | 0.85 | 0.91 |
| Particle density (Mg m$^3$) | | | | 2.53 | 2.37 | 2.21 |
| Pore space (%) | 50.6 | 47.5 | 43.4 | 52.6 | 64.1 | 58.8 |
| Water holding capacity (% v/v) | 50.9 | 44.6 | 41.0 | 50.2 | 63.0 | 55.3 |
| Modulus of rupture (Pa) | 56.1 | 67.2 | - | - | - | - |
| Hydraulic conductivity (cm h$^{-1}$) | 1.82 | 2.77 | 3.69 | 7.25 | 7.52 | 0.93 |
| pH (1:2) | 6.9 | 8.3 | 8.6 | 8.8 | 8.4 | 8.3 |
| EC (1:2) (dS m$^{-1}$) | 0.44 | 0.84 | 0.17 | 1.08 | 0.12 | 0.23 |
| Organic carbon (%) | 0.64 | 0.12 | 0.07 | 0.07 | 0.09 | 0.35 |
| Available N (ppm) | 54.6 | 28.9 | 15.9 | 6.3 | 5.1 | 15.2 |
| Available P (ppm) | 19.7 | 5.0 | 0.8 | 7.0 | 5.0 | 11.3 |
| Available K (ppm) | 422 | 90 | 155 | 15.7 | 80.3 | 38.9 |

*Dumped **Fresh

taken as the amount of water held by the soil samples at zero pressure. The moisture retention ($\theta$) at various pressures ($\Psi$) viz. 0, 10, 50, 100, 300, 500, 1000 and 1500 kPa was determined in triplicate using pressure plate apparatus. Gravimetric moisture content of the samples in the ring was determined after the samples attained equilibrium at each pressure. Moisture retention ($\theta$) and tension ($\Psi$) relationship for each soil, fly ash and their mixture was determined independently. For each soil, fly ash and their combinations, best fit line between long $\Psi$ and log $\theta$ was obtained in the following functional form

$$\text{Log } \Psi = a + \log \theta$$

Where $\Psi$ = Soil moisture suction (k Pa), corresponding to moisture content ($\theta$), per cent on volume basis, a = Intercept of the curve and b = a soil parameter.

The slope of the equation is a measure of b value.

The modulus of rupture for different soils, fly ashes and their mixture was determined by the procedure given by Richards (1953). Briquets of each screened air-dry sample were prepared in brass molds (7.0 cm x 3.5 cm x 0.95 cm). A thin layer of vaseline was applied inside the mold to prevent the sample from sticking. The molds were rested on a ceramic plate and a long neck funnel was used to fill the sample init. The sample was leveled with a spatula avoiding any compaction. The ceramic plate was placed in a tray in which water was added until the level reached to the top of the molds. The water was allowed to stand for 2 hours.After draining for an hour the ceramic plate along with briquets were placed in an oven for drying the briquetes to a constant weight at 50°C. The force required to break the briquets was determined by the procedure outlined by Agarwal and Sharma (1979). The modulus of rupture was calculated by the formula.

$$S' = (3\ FL)/(2\ bd^2)$$

Where

S' = modulus of rupture, Pascal (Pa)

F = breaking force applied at the center of the briquet beam span,

L = distance between lower supporting bars, (cm)

b = width of the briquet (cm)

d = thickness of the briquet (cm)

A hand held radiometer was used for the measurement of radiance over dry fly ash, and soils between 11.30 a.m. to 12.00 noon on a clear day. Reflectance (%) from different objects was calculated by dividing radiance from the object and the irradiance obtained from the barium sulphate standard.

## Results

### Physical and chemical characteristics of experimental soils and fly ashes

It is evident from the data (Table 1) that the soils belonged to textural groups of sandy, sandy loam and loam. Both sand and sandy loam soil were slightly alkaline in nature while loam had neutral pH. The organic carbon and water holding capacity were found to be maximum in loam followed by sandy loam and sand. However, for hydraulic conductivity the trend was reversed. The values of modulus of rupturewere 56.1 and 67.2 Pa for loam and sandy loam soils, respectively.

The fly ashes data (Table 1) shows that the fly ash from Bathinda was finer than the other two fly ashes collected from Faridabad and Panipat which were nearly identical in particle size distribution. This difference may be due to the source of coal used in these Plants. The bulk density of fly ash was found to be maximum for panipat (1.20 Mg $m^{-3}$) followed by Bathinda (0.91 Mg $m^{-3}$) and Faridabad (0.85 Mg $m^{-3}$). The fly ash from Faridabad had highest water holding capacity (63.0 %) followed by Bathinda (55.3 %) and Panipat (50.2 %) while the hydraulic conductivity was found maximum for Faridabad (7.52 cm $h^{-1}$) followed by Panipat (7.25 cm $h^{-1}$) and Bathinda (0.93 cm $h^{-1}$). The particle density was also highest in Panipat and was followed by Faridabad and Bathinda. The values of pH and EC of fly ash were 8.3 and 0.23 dS $m^{-1}$ for Bathinda, 8.4 and

0.12 dS $m^{-1}$ for Faridabad and 8.8 and 1.08 dS $m^{-1}$ for Panipat. This shows that all the fly ashes were alkaline in nature with low salinity. The organic carbon content was nearly equal in Panipat and Faridabad while for Bathinda it was relatively high. The three fly ashes had negligible available nitrogen, medium to high phosphorus and very low potassium.

**Reflectance characteristics of soils and fly ashes**

In this study the colour of Faridabad fly ash was black, than that of Panipat gray and olive gray of Bathinda. Therefore, they were likely to absorb more heat radiations than the usual soils. Incorporation of such a fly ash in either of these soils may enhance soil temperature and alter plant growth parameters. An attempt was therefore made to determine the reflectance characteristics of various fly ashes with the help of radiometer at various wave lengths ranging from 400 nm to 1100 nm. It is explicitly clear from the Fig. 2 that the over all reflectance of fly ashes was higher in Bathinda followed by Panipat and Faridabad. The mean value of reflectance across the various bands was lowest for fly ash from Faridabad (10.9%) followed by Panipat (17.5%) and Bathinda (23.0%).

The spectral reflectance of soils recorded at different wavelengths was quite variable. The reflectance (Fig. 1) was lowest in loam (12.1 to 25.3%, mean 18.0%) followed by sandy loam (12.8 to 32.1%, mean 21.5%) and sand (19.1 to 40.1%, mean 30.1%). It shows that more solar radiations were absorbed by loam followed by sandy loam and sand. In comparison, the mean reflectance of fly ashes from Faridabad and Panipat was less than the experimental soils whereas, fly ash from Bathinda had reflectance between the sandy loam and sand. This indicates that mixing of fly ash, with the soil may result in more temperatures for fly ashes from Faridabad and Panipat than the fly ash from Bathinda.

**Moisture characteristics of soils and fly ashes**

Soil moisture characteristics curves of all the soils and the fly ashes are shown in Figures 3 and 4. The various functional relations established mathematically are as follows:

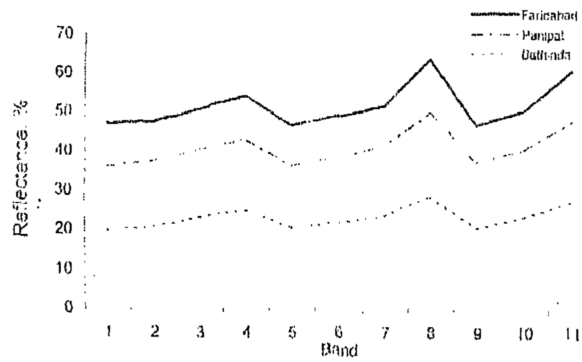


Fig. 1. Spectral reflectance of flyashes at various wave lengths (400 to 1100 nm)

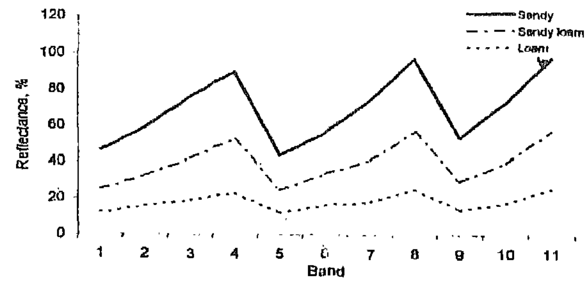


Fig. 2. Spectral reflectance of soils (2 mm fineness) at various wave lengths (400 to 1100 nm)

Soil

$\log \psi = -4.77 \log \theta + 8.47$

($r^2 = 0.92^*$) for loam

$\log \psi = -4.14 \log \theta + 7.32$

($r^2 = 0.93^*$) for sandy loam

$\log \psi = -3.26 \log \theta + 5.44$

($r^2 = 0.99^{**}$) for sand

Fly ash:

$\log \psi = -3.69 \log \theta + 6.44$

($r^2 = 0.94^{**}$) Panipat

$\log \psi = -5.68 \log \theta + 9.65$

($r^2 = 0.99^{**}$) Faridabad

$\log \psi = -10.26 \log \theta + 18.78$

($r^2 = 0.96^{**}$) Bathinda

It is evident from Fig. 3 that the loam soil maintained higher water content for the whole range of soil water potentials up to 1500 k Pa than

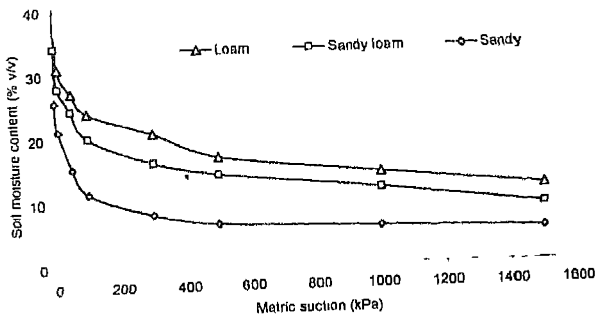


Fig. 3. Water holding characteristics of experimental soils

the sandy loam soil while, the sandy retained the lowest. The soil parameter (b value) was lowest (-4.77) under loam followed by sandy loam (-4.14) and sandy (-3.26). These values of b indicate that sandy soil releases more soil water easily than the sandyloam and the loam. In case of fly ash, highest water retention was observed with fly ash from Bathinda followed by fly ashes from Faridabad and Panipat (Fig. 4). It is clear from equations of fly ashes that Panipat ash releases soil-water easily (b=-3.69) followed by fly ash from Faridabad (-5.68) and Bathinda (-10.26). An interesting result which emanates from these equations is that addition of flyash from Faridabad or Bathinda is likely to increase water retention of all the soils while the Panipat fly ash can increase the retention of sandy soil only.

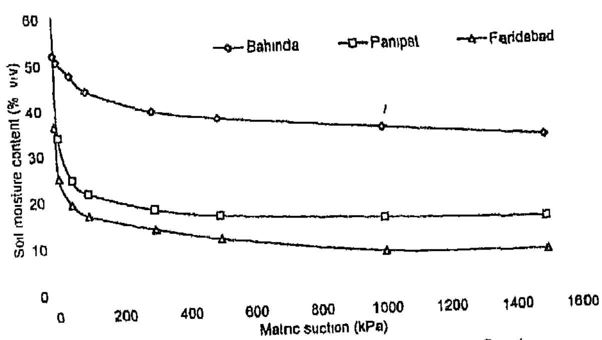


Fig. 4. Water holding characteristics of different fly ashes

## Physical and chemical characteristics of fly ash amended soils

The results reveal that addition of fly ash decreased the bulk density of all the experimental soils. The bulk density of loam varied from 1.31 Mg $m^{-3}$ in control to 1.46 M $m^{-3}$ with 20.0% ash application (Table 2). Application of fly ash had little influence on soil pH while the electrical conductivity increased with increasing quantum of fly ash application. Due to low organic carbon content of fly ash used in this study, its addition to soils reduced organic carbon content (Table 2) of the resultant soils. However, the decrease was noticed only up to 5.0% level of flyash application and thereafter no change in organic carbon content was noticed in sandy loam and sandy while in loam almost a proportional decrease in organic carbon from 0.64 to 0.46% was recorded with fly ash addition.

The available N decreased with increasing level of fly ash addition to all experimental soils. The decrease was 7.7, 11.2, 11.9 and 13.7% in loam, 3.1, 6.2, 11.1 and 18.3% in sandy loam and 7.5, 13.2, 16.4 and 20.8 in sandy over control with addition of 2.5, 5.0, 10.0 and 20.0% ash, respectively. Addition of fly ash decreased P availability in loam and sandy loam while in case of sand it increased. The decrease in P availability was from 16.2 to 39.1% in loam and from 0.0 to 20.0% in sandy loam. In sandy, P availability increased from 17.4 to 60.9% with addition of 2.5 to 20.0% fly ash. In loam and sandy, addition of fly ash decreased availability of K while in sandy loam it increased depsite low K content of flyash. The maximum reduction in available K was 5.9% in loam and 17.7% in sandy. Whereas, it increased by 25.0% in sandy loam with addition of 20.0% fly ash. Page *et al.*, 1979, and Carlson and Adriano 1993 in agreement with those report these results.

## Modulus of ruptrue (S')

The highest value of modulus of rupture was observed in untreated soils which decreased with increasing level of fly ash application to the soil from 2.5 to 20.0%. The loam soil containing 20.0% fly ash had modulus of rupture about 3.5 times less than that of untreated soil (56.1 Pa) whereas, in the sandyloam soil it decreased by about 2.5 times as compared with the untreated soil (57.2 Pa). Modulus of rupture was higher in sandyloam than in the loam soil at all levels of fly ash addition (Fig. 5). The sand and its combinations with fly ash as well as the fly ash had nil value for modulus of rupture. This is in agreement with finding of Jhorar 1991.

Table 2. Effect of different fly ash treatments on bulk density, pH, EC, organic carbon and available N, P and K of different soils

| Fly ash treatment | Soils | Bulk density ($Mg^{-3}$) | pH (1:2) | EC (1:2) ($dS\ m^{-1}$) | Organic carbon (%) | Available N (ppm) | Available P (ppm) | Available K (ppm) |
|---|---|---|---|---|---|---|---|---|
| Control | S-1 | 1.31 | 6.9 | 0.44 | 0.63 | 54.6 | 19.7 | 422 |
| | S-2 | 1.39 | 8.3 | 0.84 | 0.12 | 28.9 | 5.0 | 90 |
| | S-2 | 1.50 | 8.7 | 0.17 | 0.07 | 15.9 | 2.3 | 155 |
| Soil + 2.5% FA | S-1 | 1.31 | 6.9 | 0.46 | 0.60 | 50.4 | 16.5 | 422 |
| | S-2 | 1.38 | 8.3 | 0.85 | 0.11 | 28.0 | 5.0 | 95 |
| | S-3 | 1.49 | 8.6 | 0.20 | 0.06 | 13.8 | 3.3 | 133 |
| Soil + 10.0% FA | S-1 | 1.29 | 6.9 | 0.54 | 0.55 | 48.1 | 13.7 | 404 |
| | S-2 | 1.36 | 8.2 | 0.95 | 0.09 | 25.7 | 4.7 | 107 |
| | S-3 | 1.48 | 8.5 | 0.323 | 0.06 | 13.3 | 3.3 | 130 |
| Soil + 20.0% FA | S-1 | 1.28 | 6.8 | 0.70 | 0.46 | 47.1 | 12.0 | 398 |
| | S-2 | 1.35 | 8.2 | 0.99 | 0.09 | 23.6 | 4.0 | 113 |
| | S-3 | 1.46 | 8.4 | 0.48 | 0.06 | 12.6 | 3.7 | 128 |

S-1 - loam, S-2 - sany loam, S-3 - sandy and FA-Fly ash

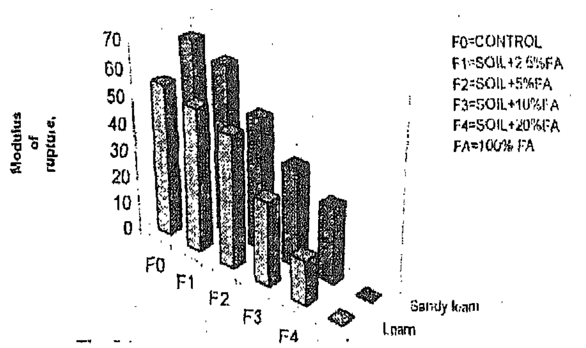


Fig. 5. Effect of different rates of fly ash on modulus of rupture of soils

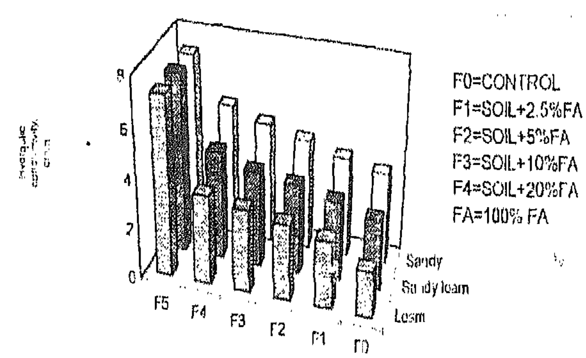


Fig. 6. Effect of different rates of fly ash on saturated hydraulic conductivity of soils

### Hydraulic conductivity

The fly ash from Panipat, due to its coarse texture, possessed highest hydraulic conductivity (7.25 cm $h^{-1}$) as compared with experimental soils (1.82, 2.77 and 3.69 cm $h^{-1}$ for loam, sandy loam and sandy, respectively). Therefore, all the soils amended with fly ash recorded more hydraulic conductivity as compared with control (Fig. 6). The increase in hydraulic conductivity due to mixing of 2.5 to 20.0% fly ash was highest (from 47.3 to 96.2%) for loam followed by (15.2 to 58.5%) sandyloam and (9.5 to 47.2%) in sandy.

### Water holding capacity

The water holding capacity of the loam, sandyloam and sandy was observed to be 50.9, 44.6 and 41.0% (v/v), respectively as against 50.2% of fly ash. On amending the soils, with the fly ash there was an increase in water holding capacity in sandy and sandy loam soil but it decreased in loam (Fig. 7). The amended soils registered higher water holding capacity at zero tension (44.9, 45.3, 46.0 and 46.7% in sandyloam and 41.4, 41.7, 42.6 and 44.1% in sandy with the adition of 2.5, 5.0, 10.0 and 20.0% fly ash, respectively) compared to

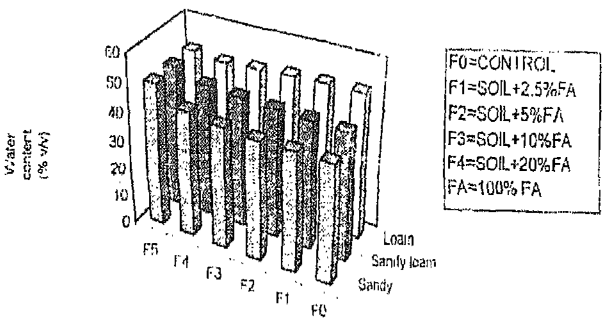


Fig. 7. Effect of different rates of fly ash on water holding capacity of soils

control. Despite coarse texture of fly ash, its addition to sand and sandyloam soil increased water holding capacity. Singh (1995) also reported significant increased in plant available water with addition of fly ash.

**Moisture characteristics curve of amended soils**

At a specify suction the water retention increased in the order loam > sandy loam > sandy for all matric suction values. As anticipated, the loam soil had inherent ability to retain more moisture followed by sandy loam and sandy. This is attributed to its relatively more orgaic matter, clay content and low bulk density of the soil. The water retention increased with increasing fly ash content in sandy while it decreased in loam and sandy loam. The water content in the suction range of 10 to 1500 k Pa varied from 31.1 to 11.6% in loam, 28.0 to 8.7 in sandy loam and 21.4 to 5.0 in sandy soils as against 30.0 to 8.7, 26.3 to 7.2 and 24.0 to 6.0%, respectively with addition of 20.0% fly ash (Fig. 7). The moisture content, with addition of 2.5, 5.0 and 10.0% fly ash, remained between zero and 20.0% fly ash application in all the soils.

Table 3. Soil water functional relationship of soils as affected by different fly ash treatments

| Fly ash treatment | Soil water functional relationships | |
|---|---|---|
| | **Loam** | |
| Control | $\log \Psi = -4.77 \log \theta + 8.47$ | ($r^2$ = 0.92*) |
| Soil + 2.5% FA | $\log \Psi = -4.73 \log \theta + 8.34$ | ($r^2$ = 0.04**) |
| Soil + 5.0% FA | $\log \Psi = -4.19 \log \theta + 7.55$ | ($r^2$ = 0.93*) |
| Soil + 10.0% FA | $\log \Psi = -3.85 \log \theta + 7.04$ | ($r^2$ = 0.03*) |
| Soil + 20.0% FA | $\log \Psi = -3.74 \log \theta + 6.79$ | ($r^2$ = 0.95**) |
| | **Sandy loam** | |
| Control | $\log \Psi = -4.14 \log \theta + 7.32$ | ($r^2$ = 0.93*) |
| Soil 2.5% FA | $\log \Psi = -4.06 \log \theta + 7.19$ | ($r^2$ = 0.93*) |
| Soil + 5.0% FA | $\log \Psi = -3.95 \log \theta + 6.97$ | ($r^2$ = 0.93*) |
| Soil + 10.0% FA | $\log \Psi = -3.84 \log \theta + 6.78$ | ($r^2$ = 0.94*) |
| Soil + 20.0% FA | $\log \Psi = -3.69 \log \theta + 6.56$ | ($r^2$ = 0.94*) |
| | **Sandy soil** | |
| Control | $\log \Psi = -3.26 \log \theta + 5.44$ | ($r^2$ = 0.99**) |
| Soil + 2.5% FA | $\log \Psi = -3.25 \log \theta + 5.48$ | ($r^2$ = 0.99**) |
| Soil + 5.0% FA | $\log \Psi = -3.26 \log \theta + 5.56$ | ($r^2$ = 0.99**) |
| Soil + 10.0% FA | $\log \Psi = -3.29 \log \theta + 5.67$ | ($r^2$ = 0.98**) |
| Soil + 20.0% FA | $\log \Psi = -3.39 \log \theta + 5.88$ | ($r^2$ = 0.98**) |

Y-Soil water suction (kPa), θ -Moisture content (1: v/v), FA-Fly ash
*Significant at 5% level, **Significant at 1% level

**Ψ-θ relationship of the fly ash treated soils**

The data on soil moisture (θ) contents at various suctions (Ψ) of fly ash treated soils were best fitted to Ψ-θ functional relationship (Table 3). The vaue of air entry suction ($h_e$) that is the intercept was found to decrease from 8.47 in control to 6.79 with 20.0% fly ash mixing for loam and from 7.32 to 6.56 for sandy loam soil while in case of sandy soil it increased from 5.44 to 5.88. For b value the trend was reverse. As a consequence the available water holding capacity of sandy enhanced while that of loam and sandy loam did not alter much with the fly ash treatment. Similar observation was recorded by Sharma *et al.*, 1990).

**Conclusion**

It is evident from these observations that application of fly ash to the soils improved water holding capacity of medium textured soils only, and improved hydraulic conductivity and reduced modules of rupture for loam, sandy loam and sandy soils. In case of sandy soils fly ash improves substantial improvement in water retention capacity was noticed with application of fly ash. Further, there was a little improvement in available P (from 2.3 to 3.7 ppm) in sand and available K (from 90.0 to 112.5 ppm) in sandy loam with application of fly ash.

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