STUDY OF FLY ASH INCORPORATION ON YIELD AND PARTITIONING OF HEAVY METALS IN RICE

Ph.D. Thesis

by

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STUDY OF FLY ASH INCORPORATION ON YIELD AND PARTITIONING OF HEAVY METALS IN RICE

Thesis

Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

THANESHWAR KUMAR

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Doctor of Philosophy

in

AGRICULTURE

(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)

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MARCH, 2018

CERTIFICATE – I

This is to certify that the thesis entitled **"Study of fly ash incorporation on yield and partitioning of heavy metals in rice"** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agriculture** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Thaneshwar Kumar** under our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

Date: 19.03.2018

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THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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CERTIFICATE - II

This is to certify that the thesis entitled **"Study of fly ash incorporation on yield and partitioning of heavy metals in rice"** submitted by **Thaneshwar Kumar** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy in Agriculture** in the Department of Soil Science & Agricultural Chemistry has been approved by the external examiner and Student's Advisory Committee after oral examination.

Signature External Examiner

Date: 20/07/18

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Faculty Dean ____________

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%	Percent
@	At the rate of
^{o}C	Degree Celsius
CD	Critical difference
cm	Centimetre
$dS\ m^{-1}$	Deci siemens per meter
et al.	And others/ co-workers
Fig.	Figure
$ug\ g^{-1}$	Micro per gram
$mg\ kg^{-1}$	Milligram per kilogram
$ml\ l^{-1}$	Millilitre litter
g	Gram
ha^{-1}	Per hectare
i.e.	Id est (that is)
kg	Kilogram
cm	Centimetre
m	Metre
Mt	Million tonne
mg	Milligram
mm	Millimetre
NS	Non significant
$SEm^{\pm}$	Standard error of mean
q	Quintal
viz.	Videlicet
p	Page
$t\ ha^{-1}$	Tonne per hectare

LIST OF ABBREVIATIONS

BC	Broadcast
CEC	Cation Exchange Capacity
EC	Electrical conductivity
FA	Fly ash
FYM	Farm Yard Manure
GRD	General recommended dose
LS	Line sown
NS	Non significant
ppm	Parts per million
HM	Heavy metals
MPL	Maximum permissible limit
SF	Safe limit

THESIS ABSTRACT

a)	Title of the Thesis :	Study of fly ash incorporation on yield and partitioning of heavy metals in rice
b)	Full Name of the Student :	Thaneshwar Kumar
c)	Major Subject :	Soil Science and Agricultural Chemistry
d)	Name and Address of the Major Advisor :	Dr. K. Tedia Professor, Soil Science and Agricultural Chemistry, College of Agriculture, IGKV, Raipur (C.G.)
e)	Degree to be Awarded :	Doctor of Philosophy

Signature of the Student

Signature of Major Advisor

Date: _____________ Signature of Head of the Department

ABSTRACT

A field experiment was carried out during *kharif* season of 2016 and 2017 at Krishi Vigyan Kendra, Research Farm, Janjgir – Champa (Chhattisgarh) to assess the effect of different doses of fly ash on yield of rice and partitioning of heavy metals in different plant parts. The experiment was laid out in Randomized Block Design having three replications and eight treatments viz., no fly ash (control) , GRD (100:60:40), 75% GRD + 20 t ha^{-1} fly ash, 75% GRD + 40 t ha^{-1} fly ash, 75% GRD + 60 t ha^{-1} fly ash, 75 % GRD + 20 t ha^{-1} fly ash+ 5 t ha^{-1}+ FYM, 75 % GRD + 40 t ha^{-1} fly ash+ 5 t ha^{-1} FYM and 75 % GRD + 60 t ha^{-1} fly ash+ 5 t ha^{-1} FYM. The experimental soil was clay loam in texture having neutral soil reaction (pH) and low soluble salt content (EC), low in organic carbon, available nitrogen, phosphorus and high in available potassium status, adequate in cationic micronutrients except in Zn which was above than critical limit.

Two years study indicated that fly ash can act as a supplemental source of plant nutrients and could be used in agricultural soil for production of the rice crop. Fly ash integrated with recommended dose of fertilizers and FYM imprinted significant positive effect on yield and yield attributes of crop and major and micronutrients availability in soil. Soil available micronutrients and heavy metals at harvest were influenced by different treatments and increased with increasing doses of fly ash combined either with or without FYM. The available major, micronutrients and heavy metals in different treatments were higher in surface than the subsurface soil. Total major (N, P and K) and micronutrients (Fe, Mn, Zn and Cu) content in different plant parts in rice were increased by the different fly ash doses and found beneficial when fly ash integrated with FYM. Total heavy metals (Cr, Co, Ni, Pb and Cd) content were increased when fly ash was applied with increasing doses with and without FYM in different plant parts of rice and higher status was recorded when fly ash applied without integration of FYM. Most of the macro, micro and heavy metals studied were found to accumulate more in roots of rice plant, while low content was observed in grain, leaf and stem except in Mn and Cd which were more in the leaves. Application of 40 t ha^{-1} fly ash either with FYM or without FYM along with 75% GRD found to be best with respect to nutrients availability as well as yield of rice. The micronutrients and toxic metals concentration in soil at harvest and different plant parts of rice observed within the maximum permissible limits reported by WHO even after fly ash applied at the highest dose (60 t ha^{-1}). The occurrence of heavy metals in soils was in the order of Fe>Mn >Cr > Cu > Pb > Co >Ni>Zn> Cd and in rice plant parts Fe>Mn >Zn> Cu > Ni > Cr > Co >Pb> Cd.

The two years study suggest that continuous application of fly ash @ 20 and 40 t ha^{-1} with and without FYM can be recommended without any harmful effect of different heavy metals concentration in different plant parts of rice but intermittent long term monitoring is required to avoid any load of heavy metals in the soils and crop.

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CHAPTER-I

INTRODUCTION

The ill effect of Industrialization all over the world is production of huge quantities of industrial waste that has arise challenges in front of administrators, environmentalists and scientists for its safe disposal and proper management. In India to achieve the national goal of energy independence, the amount of coal consumption is expected to increase rapidly and millions of acres of agricultural land is occupied by fly ash lagoons which is a byproduct of coal based thermal power plant. Increased urbanization and industrialization worldwide has resulted in increased release of solid waste and enhanced environmental pollution around the globe.

In India, about 57% of the power is produced from coal-based thermal power plants. Coal is used in the thermal power plants as a fuel, contains high amount of ash upto 40%, sulphur in the range of 0.2 – 6% and heavy metals like Hg, Mn, Cu, Pb, Ni, Fe, Cr and Cd in different concentrations. When coal is burnt to generate heat, the residue contains fly ash and bottom ash about 80% and 20%, respectively (Agarwala and Kumar, 1993).

Presently about 118 Mt/year of coal FA is produced in India from more than 80 thermal power plants, which will be about 440 Mt/year by the end of 2030 (Ram *et al*., 2008). The production of vast quantity of FA will create dumping and management problems. The management of this huge amount of solid waste at both regional and global level is a prime concern for the present and coming future (Ahmaruzzaman 2010; Kishore *et al*., 2009), therefore agricultural utilization and waste area management techniques have emerged as prime utilization methods for solving fly ash problems. Various uses of fly ash are depicted in fig. 1.1.Field and green house experiments have proved that it can be used in growing agricultural crops (Gupta *et al*., 2002).

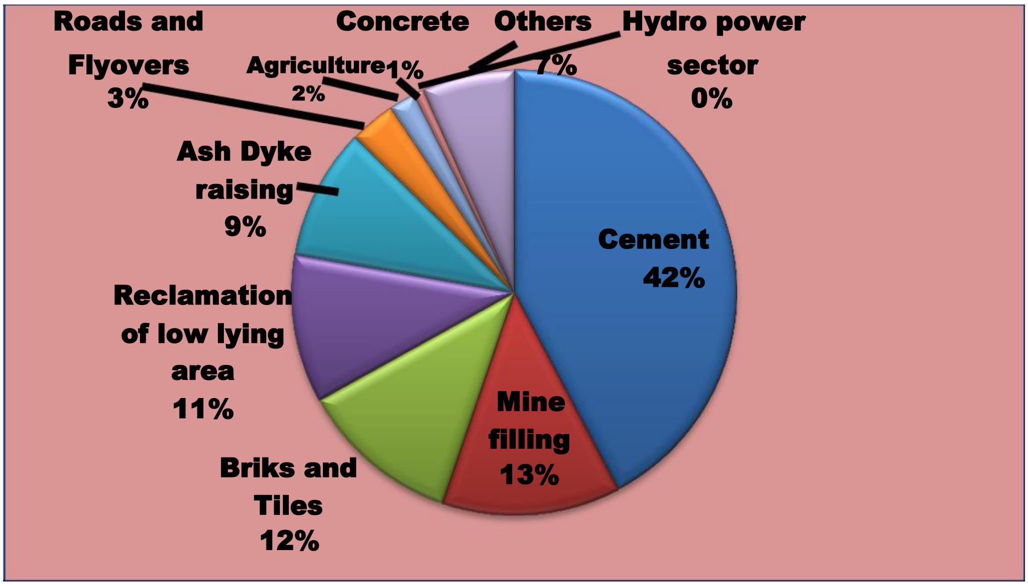

Fig.1.1 Modes of fly ash utilization (CEA, 2014-15)

Fly ash is an amorphous mixture of ferroaluminosilicate minerals. Its physical and chemical characteristics depend on composition of parent coal, combustion conditions, the efficiency and type of emission control devices and the disposal methods used.

It contains small quantity of various essential plant major and secondary nutrients (N, P, K, Ca, Mg and S) and adequate quantity of micronutrients such as Fe, Mn, Zn, Cu, and B make not only be used as a supplemental source of plant nutrients but also an amendment for improving acid, alkaline and degraded soils and thereby enhanced the physical and chemical properties of soils. It is found to improve permeability status, soil texture, reduces bulk density, optimizes pH value, improves soil aeration, water holding capacity, soil reaction, soil microbial activities, nutrient availability and plant productivity when applied alone or in combination with organic manure (Sikka and Kansal, 2000).

As it is known to contain quantities of heavy metals such as As, Cd, Cr, Ni, Mo, Pb, Se and Co, a major concern regarding FA augmented soil is linked with elevated level of heavy metal in soil and their accumulation through uptake by crops and associated risk in humans and animal health through its consumption.

Therefore, presence of toxic metals in FA may be a serious concern for agriculture and there is a need to quantify the status of these metals in soil and plant, when applied on long-term basis.

At higher doses, FA can adversely affect soil biological properties (Nayak *et al*., 2014). Fly ash, with its abundant availability and remarkable ameliorative and nutritive properties, warrants an eco-friendly approach to be used as a soil amendment. Fly ash may be used in plant growth and soil reclamation but scientific research is certainly necessary to model the concentration-uptake-dose-response functions between the amended medium and plants (Jala and Goyal, 2006; Ritchey *et al*., 2012).

The favorable and adverse effects of fly ash on soil physico-chemical properties and crop yield were also reported by various workers. Fly ash may either have a positive and negative effect on plant growth and yield if not used in optimum doses. This has resulted in low and inconsistent production of crop yield systems. This calls for development of an integrated nutrient management system by supplying organic and inorganic sources of fertilizers and for improving physical and chemical properties of soil. One of the possible ways of enhancing productivity of soil is use of fly ash and other industrial wastes in combinations with organic matter and chemical fertilizers which would act as a soil amendment and source of secondary nutrients (Yeledhalli *et al*., 2007).

A number of investigations have been made on the aspect of utilization of fly ash for agricultural purposes. Utilization of FA to agricultural land would not always be beneficial for crops (Singh *et al*., 1997). However, earlier reports suggest that small application of FA in agricultural fields are suitable for better crop management. Lower amendment levels of FA caused enhancements of both growth and yield observed for different crops including rice, maize, soybean, barley, cabbage, apple, alfalfa, and beet while, adverse effects at higher levels were observed for several crops (Miller *et al*., 2000).

Consistent accumulation of heavy metals due to continuous application of fly ash in paddy soils stresses the need for continuous monitoring and investigating several inter-related issues.

Keeping above in viewed, the present experiment was designed to study the impact of varied levels of fly ash on soil health, plant growth, toxic metal accumulation and productivity of rice (*Oryza sativa L.*). Therefore, the present investigation entitled "**Study of fly ash incorporation on yield and partitioning of heavy metals in rice**" was undertaken with the following objectives:

Objectives of Investigation

1. To study the effect of different doses of fly ash on rice yield and its yield attributing characters.
2. To monitor the soil nutrients and heavy metals status as influenced by fly ash application.
3. To assess the effect of fly ash on heavy metals accumulation and it's partitioning in rice crop.

CHAPTER-II
REVIEW OF LITERATURE

In intensive cropping system, continuous application of chemical fertilizer degrades the soil health resulting in stagnant crop yield. In order to the maintain soil health over the years for sustained crop production, the application of soil amendment resulted waste and organic residues is essential. Industrial waste such as fly ash (FA) often being neutral to alkaline in nature, containing most of the essential elements and having high water holding capacity can be successfully utilized as soil amendment and supplemental fertilizer for raising productivity and fertility of the soil. Growing of crops with chemical fertilizer alone cannot mitigate the loss of C, N and P while combined application of organic manure and chemical fertilizer was effective in this respect (Agbenin and Goladi, 1997). Organic wastes which contain varying amounts of undegraded organic materials can play an important role in the stimulation of biological activity and release of nutrients in soil. Besides these direct chemical and biological effects, it also improves physical conditions and soil health by increasing water holding capacity and promoting the formation of stable structure. Therefore, it is imperative to study the effect is application of FA on nutrient status and crops yield and heavy metals content in soil.

The chapter deals with a review of the literature on the various researches conducted on the use of fly ash in agriculture in the country and abroad with the more emphasis placed on the work done in recent years. The literature on the aspects is reviewed under following heads.

2.1 Characterization of fly ash
2.2 Effect of fly ash on plant growth and yield of different crops
2.3 Effect of fly ash on physical and chemical properties of soil
2.4 Effect of fly ash on heavy metals in soil and crops

2.1 Characterization of fly ash

The properties of fly ash are dependent on the composition of parent coal, condition during combustion, efficiency of emission control devices, storage and handling of other by-products and prevailing weather conditions. Fly ash particles are mostly spherical and glassy with their colour ranging from white to yellow, orange to deep red, grey to black or brown to opaque. The particle size distribution of fly ash is similar to silt or silt loam soil. It contains 35% sand, 55% silt, 10% clay with 9% total Fe_2O_3 , 2.3% total Al_2O_3, 1.6% total CaO, 73%SiO_2, 1.5% total K_2O, 0.09% total N and 0.3% total P (Maiti *et al*.,1990).

The fly ash from Mettur Thermal Power Station. The fly ash was neutral in soil reaction and non saline. Particle size analysis evinced its texture as silt loam. The physical properties viz., bulk density, particle density, porosity and water holding capacity were 1.24 (Mg m^{-3}), 1.99 (Mg m^{-3}), 42 and 33 per cent respectively. With reference to the CEC, fly ash recorded 2.1 c mol (p+) kg^{-1} and organic carbon was found to be very low (0.01 %). The total N content of the fly ash was found to be very low (0.04 per cent),total P content was recorded low (0.22 %) and the total K was comparatively high (0.51 %) among three macro nutrients (Theresaa and Vijayakumar, 2016).

Wankar and Wadhai (2016) studied the physical and chemical and some mineralogical properties of coal fly ash generated from Thermal power plant. Fly ash contains some micro and macro nutrients viz. K (0.18 %), P (0.06 %), Fe (2.51 ppm), Ca (5125 ppm), Mg (1500 ppm), Cu (5.2 ppm), Zn (150 ppm) and Mn (186 ppm) which may change the physico- chemical and some mineralogical properties of degraded soil. Toxic metal contents such as Ni, Cd, Cr, Co and Pb are 42.5, 1.6, 86.3, 16.6 and 1 ppm, respectively.

Nalawade *et al*. (2015) collected fly ash from Nashik Thermal Power Plant (NTPP), Nashik, India and characterized the properties. The SiO_2 ranged between 54.9 to 64.03% with an average of 59.46 ± 3.0%, Fe_2SO_3 ranged between 6.50 to 9.30% with an average 7.9 ± 0.9%. The Al_2O_3, CaO, MgO were value between 19.6 to 26.4%, 1.2 to 2.9% and 0.2 to 0.6% with an average value between 23 ±

2.2%, 2.05 ± 0.1% and 0.4 ± 0.5%, respectively. The water holding capability of Indian fly ash is 35.6 to 48.6 percent and the organic carbon content is between 1.2 to 1.9 percent.

Fly ash is the burnt inorganic part of coal amorphous structure and spherical in shape. It contains SiO_2, Al_2O_3, and Fe_2O_3 in higher amount. Major crystalline phases present in fly ash are quartz (SiO_2). They concluded it to be an excellent potential raw material for the manufacture of construction material like cement, light weight building block, and concrete. Due to the presence of various plant nutrients elements and similarities of pH and EC to that of soil, it is also suitable for agriculture use (Rani and Jain, 2015).

Saraswat and Chaudhary (2014) studied on the utilization of Fly Ash (FA) for improving soil quality and increasing crop productivity. The properties such as silt-sized particles, low bulk density (BD), higher water holding capacity (WHC), favorable pH and presence of plant nutrients in FA, make it a prospective amendment for soils. Use of FA is to improve cultivable, waste land, mine soil, landfills, and also for reclamation of abandoned ash ponds for agriculture and forestry.

Shaheen *et al*. (2014) studied coal fly ash (CFA), a by-product of coal combustion which has been regarded as a problematic solid waste, mainly due to its potentially toxic trace elements, PTEs (e.g. Cd, Cr, Ni, Pb) and organic compounds (e.g. PCBs, PAHs). However, CFA is a useful source of essential plant nutrients (e.g. Ca, Mg, K, P, S, B, Fe, Cu and Zn). It is comprised of very fine particles, with an average diameter <10 mm, aggregated into spherical particles of 0.01-100 mm sizes which are hollow spheres (ecospheres) filled with smaller amorphous particles or crystals (pelospheres). The specific gravity of CFA varies from 2.1 to 2.6 g cm^{-3} and it has a low to medium bulk density, ranging from 1 to 1.8 g cm^{-3}. Its moisture retention capacity ranges from 6.1% at 15 bars to 13.4% at 0.33 bar.

Suresh and Murugaiyan (2013) reported the potential of fly ash as a resource material in agriculture and related areas. Fly-ash generally contains 65–90% of silt loam texture with the particles of diameter less than 0.010 mm. The silt loam texture leads to increases the dust formation, which posses' difficulty during the transportation and storing of fly ash. The pH of fly ash range from 6 to 11 and Electrical Conductivity (EC) from 42 to 450 µS/cm. Most of the fly ash has the Bulk Density (BD) values less than 1 g/cm^3, Water Holding Capacity (WHC) 43 to 66%. Fly-ash consists about 95 to 99% of Si, Al, Fe and Ca and about 0.5 to 3.5% consists of Na, P, K and S and the remaining of the ash is composed of trace elements like lanthanum, terbium, and mercury which are found in Below Detection Limit (BDL). As compared to soil, fly-ash contains all the elements except organic carbon and nitrogen. It also contains natural radio nuclides such as

U^{238}, Th^{232}, K^{40}.

Parab *et al*. (2012) reported that ash produced by burning of anthracite, bituminous and lignite coal has different composition. Physically fly ash occurs as very fine particles having an average diameter of <10 um and has low to medium bulk density, high surface area and light texture. Water holding capacity of fly ash is 49 to 66% on weight basis. The pH of fly ash varies from 4.5 to 12.0 depending largely on the sulphur content of parent material. Chemically consists of oxides of Si, Al, Fe and Ca besides trace element as Be, B, Cd, Cr, Co, Pb, Mn, Hg, and Mo. Fly ash addition alters physical and chemical properties of soil and works as soil conditioner or modifier.

Yadava *et al.* (2012) reported fly ash to increase water holding capacity, hydraulic conductivity and porosity and decrees bulk density, modulus of rupture and surface encrustation owing its physical and chemical properties. Use of fly ash alone or in combination with farm yard manure, sewage sludge, water hyacinth, lime, gypsum and microbial culture has been found to improve growth, yield and nutrient uptake of various crops including vegetables. Fly ash has also been found to control several insects, pests and disease in several vegetable crops. Thus it has tremendous potential for its use as soil ameliorant and also as a source of secondary and micronutrient and can be used as a carrier for bio-inoculants and pesticides.

Rai *et al*. (2011) using fly ash from a TISCO power plant at Jamadoba, Dhanbad, Jharkhand, India characterized their physical and chemical properties.

The physical properties such as bulk density, moisture content, specific gravity, porosity water holding capacity and grain size distribution (sand, silt and clay) were of the order of 0.94gm/cm^3, 0.73%, 1.84%, 60.25% 76.55% and 63.3% sand, 32.6% silt, 2.6% clay, respectively.

Tena *et al*. (2011) using fly ash from Thermal Power Plant, Republic of Macedonia observed cation exchange capacity (CEC) and ammonium exchange capacity (AEC) to be in the range of 0.19 to 0.28 meq/ g and 0.17 to 0.33 meq/g, respectively. The particular fly ash showed EC of 0.13 to 0.15 mmhos/cm, organic carbon content of 3.17 to 3.85 % and specific gravity 2.04 to 2.37g/cm^3.

Shrivastava *et al*. (2009) reported fly ash to be a noncombustible inorganic part of coal which is generated as a byproduct during coal combustion process in thermal power plants. Physical, chemical and mineralogical characterization of fly ash depends on various factors like parent coal, combustion conditions, the efficiency and type of emission control devices and the disposal methods used Physically, fly ash occurs as very fine particles having an average diameter of <10 μm and has high surface area and light in texture. It consists of all the essential elements present in soil except organic carbon, nitrogen and available phosphorus due to volatilization during combustion. Fly ash is generally referred to as a ferroalluminosilicate mineral with Al, Si, Fe, Ca, K and Na as the predominant minerals and contains high levels of potentially toxic elements like V, Se, As, B, Al, Cd, Pb, Hg and Cr.

Prem Kishor *et al*. (2009) reported fly ash to be a coal combustion residue of Thermal Power Plants which is a problematic solid waste all over the world. The mineralogical, chemical and physical properties of fly ash depend on nature of parent coal, condition of combustion, types of emission control device and storage and handling method. Bulk density varied from 1 to 1.8 g cm^{-3}, water holding capacity from 49-66% on weight basis. The specific gravity of fly ash range from 2.1 to 2.6 g cm^{-3}. Chemically 90-99% fly ash comprised of Si (9.6 to 15.8 %), Al (5.4 to 28.2 %), Fe (4.3 to 7.5 %),Ca (2.9-4.9 %), Mg (0.7-1.3 %), Na (1.0 %) and K (0.8 to 1.3 %) with Si and Al forming major matrix. The pH of fly ash of varies from 4.5 to 12 depending largely on the sulphur content of parent coal.

Ismail *et al*. (2007) characterized fly ash collected from Stesen Janakuasa Elektrik Sultan Abdul Aziz Shah, Kapar, and Selangor. It is the finely divided mineral residue resulting from the combustion of coal in electric generating plants. Fly ash consists of inorganic, incombustible matter present in the coal that has been fused during combustion of coal and has amorphous structure. Fly ash particles are generally spherical in shape and varies in size from 2 μm to 10 μm. They consist mostly of 59.00 SiO_2, 21.00 Al_2O_3, 3.70 Fe_2O_3, 6.90 CaO, 1.40 MgO, 1.00 SO_3 and 0.90% K_2O, respectively.

Padmakaran and Raju (2007) reported that fly ash is a source of essential nutrients and has ability to modify the physical properties of soil which makes it a suitable substitute for fertilizer. In their investigation ash samples of VTPS (Vijaywada Thermal Power Stations) were collected from boiler bottom and electrostatic precipitator. The bulk density of ash ranged from 0.87 to 1.01 g m^3. The variation is bulk density values was probably due to the presence of considerable unburnt carbon. The chemical constituents of fly ash were of major oxides like SiO_2 (59.80 %) and Al_2O_3 (28.76 %) and minor oxides like Na_2O (0.53 %), K_2O(1.76 %), CaO (1.01 %) and MgO (1.89 %). In addition it has other macro nutrients like N, P and S and micro-nutrients Cu (0.050 %), Zn (0.042 %), Mn (0.061 %) and Fe (3.86 %).

Pujari and Dash (2006) summarized the problems associated with fly ash by virtue of its physical characteristics as:

(1) Due to heavy disposal, fly ash particles both as dry ash and pond ash occupy many hectares of land in the vicinity of power station.
(2) Because of its fineness, it is very difficult to handle fly ash in dry state. Flying fine particles of ash decay structural surfaces and affect horticulture.
(3) It disturbs the ecology through soil, air and water pollution.
(4) Long inhalation of fly ash causes various serious diseases like silicosis, fibrosis of lungs, bronchitis, and pneumonitis due to its heavy metal contents.

Sharma and Kalra (2006) reported that fly ash can be used for soil reclamation and enhance crop productivity depending upon the nature of soil and fly ash. It may improve physical, chemical and biological properties of problem soils and enhance the availability of macro and micronutrient for plants. The high concentration of major nutrients (P-0.04 to 0.8, K-0.15 to 3.5, S-0.1 to 1.5, Ca-0.11 to 22.2 and Mg-0.04 to 7.6 %) and trace (Fe-1 to 29, Mn-58 to 3000, Cu-14 to 2800, B-10 to 618, Co- 7 to 520, Cr-10 to 1000, Mo-7 to 160, Ni-6.3 to 4300, Pb-3.1 to 5000, Cd-0.7 to 130 and As- 2.3 to 6300 ug/g) elements in fly ash increases yield of agricultural crops. However, application of fly ash, particularly unweathered ones, show a tendency of accumulation of elements like B, Mo, Se and Al. Accumulation of these elements of toxic levels at responsible for the reduction of crop yield and consequently influences animal and human health.

Dubey *et al*. (1999) collected fly ash from Koradi Thermal Power Station, Nagpur, Maharashtra characterized it for its physical, chemical and nutrient capacity. The particle size distribution showed wide variation in the <0.25 mm' size fraction. Bulk density was between 0.85 to 1.16 g/cm^3. The available water holding capacity ranged between 40.1 to 55.6%. The organic carbon content varied between 1.9 to 4.5 g kg^{-1}. The fly ash was slightly alkaline in reaction. Cation exchange capacity was 2.8 to 4.1 cmol (p+) kg^{-1}. The presence of various elements was in the order of Si > AI >Fe > Ca > Ti > Mg > K. The DTPA extractable micronutrients were in the order of Fe>Mn>Zn>Cu where as available N, P, K showed the trend as N>K>P.

Selvakumari *et al.* (2000) reported that the fly ash collected from Neyveli Lignite Corporation (NLC), Tamilnadu showed physical and chemical properties such as pH, EC, CEC, organic carbon, total N, total P, total K, $KMn0_4$-N, Olsen's P, neutral N NH_4OAC-K, total Ca, total Mg, total S, $CaCl_2$-S, total Cr, total Pb and total Cd is 11.6, 5.20 dS m^{-1}, 1.60 c mol (p$^+$) kg^{-1}, 3.5 g/kg, 0.6 g/kg, 0.7 g/kg, 5.1 g/kg, 480 mg kg^{-1}, 21 mg kg^{-1}, 400 mg kg^{-1}, 140 g kg^{-1}, 64.0 g kg^{-1}, 15.0 g kg^{-1}, 0.15% 4300 mg kg^{-1}, 45 g/kg, 10.6 g/kg and 4.5 g/kg, respectively.

Bhoyer (1998) studied the properties of fly ash and found that ash had slightly higher bulk density (1.40 g cm^{-3}) and higher water holding capacity (37.71%). Total major nutrients N and P were low i.e. 0.056 and 0.078%, respectively, but it contained sufficiently higher amount of total K (0.172%), CaO

(1.60%) , MgO (0.96%) and total trace elements including Mn (3.98 ppm), Cu (3.60 ppm), Zn (1.30 ppm) and Fe (3.81 ppm), respectively. Based on the characteristics of fly ash, it can be used as soil amendment to increase surface area and porosity of soil and effectively act as a cheap source of plant nutrients especially of micronutrients.

2.2 Effect of fly ash on plant growth and yield of different crops

Fly ash improved physical, chemical and biological properties of problem soils and a source of readily available plant macro and micronutrients in soil. Fly ash application with organic manure and microbial inoculants can enhance plant biomass production from degraded soils (Jala and Goyal, 2006). Basu *et al*. (2007) reported that fly ash, having both the soil amending and nutrient enriching properties is helpful in improving crop growth and yield in low fertility acid lateritic soils.

Many earlier researchers (Thetwar *et al*., 2007; Sridhar *et al*., 2006; Garg *et al*., 2005; Grewal *et al*., 2001; Weinstein *et al*., 1989; Elseewi *et al*., 1980; Hill and Lamp, 1980; Page *et al*., 1979 and Martens, 1971) reported that fly ash increased the crop yield of wheat (*Tritiucm aestivum*), alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), bermuda grass (*Cynodon dactylon*), Sabai grass (*Eulaiopsis binata*), cowpea (*Vigna unguiculata*) and white clover (*Trifolium repens*) along with improvement in soil properties. Amendment of fly ash up to 40% improved the growth and yield of rice crop, whereas use of 60%, 80% and 100% fly ash caused significant reductions in plant growth and yield over plants grown in soil without fly ash (Singh and Siddique, 2003).

Reddy *et al*. (2017) studied the effect of fly ash and FYM on yield of rice and cracking pattern of soil. The experiment comprised of four levels of fly ash (0, 5, 10 and 15 t ha^{-1}) and two levels of FYM (0 and 10 t ha^{-1}). The grain and straw yield of rice significantly increased with application of fly ash, FYM and by their interactions. The highest grain (5.84 t ha^{-1}) and straw yields (7.87 t ha^{-1}) were recorded by application of fly ash in combination with FYM.

Padhy *et al*. (2016) amended soil with fly ash and cyanobacteria to study the growth, metabolism, yield of rice and metal loads in plant parts. Fly ash levels were 0, 0.5, 1.0, 2.0, 4.0, 8.0 and 10.0 kg/m^2 (0 to 10 t ha^{-1}). The increase in growth and yield of rice was up to 8.0 kg/m^2 amendment levels and increase was also with several parameters (Shoot height, leaf area, tiller number per plant, plant dry weight, length of panicle and no. of seeds per panicle). Pigment contents and enzyme activities of leaves were enhanced by fly ash @ 10.0 kg/m^2. Protein content of rice seeds was the highest at FA level 4.0 kg/m^2. Fly ash amended plots with 1.0 kg/m^2 of N_2-fixing cyanobacteria mass caused further significant increments in most soil properties, rice growth and yield parameters.

Theresaa and Vijayakumar (2016) investigated the effect of fly ash in combination with three organic manures viz., Farm yard manure (FYM), green leaf manure (GLM) and Humic acid (HA) and inorganic fertilizers on the yield and uptake of rice. It was observed that fly ash (20 t ha^{-1}) + GLM (6.25 t ha^{-1}) with RDF (150:50:50) supported maximum growth, yield and uptake. The treatment which received fly ash + GLM with RDF (150:50:50) recorded the highest grain (5.49 t ha^{-1}) and straw yield (6.59 t ha $^{-1}$). The highest nutrient uptake by the grain and straw were observed with fly ash+ GLM with RDF treatment.

Panda and Tikada (2014) studied optimum level of ash addition to relate germination effects with early seedling vigor characteristics of rice crop. The experiments were carried out in polythene bags filled with different concentration of fly ash and soil mixture (Control, 25%, 50%, 75% and 100% fly ash). The seedling growth in terms of shoot length, root length and dry matter was found to be significantly higher in low concentration (25%) fly ash as compared to the control and higher concentrations of Fly ash. The root growth was less in 100 % fly ash and more in 25% of fly ash when compared to the other treatments. The shoot growth started decreasing at 75% fly ash. There was no significant difference of leaf Chlorophyll-a and Chlorophyll-b in control and different treatments, but the total chlorophyll found to be higher at 25% fly ash level followed by 100% fly ash and least was observed in control.

Sahay *et al*. (2014) reported application of fly ash and waste water on growth, yield and nickel uptake of mustard. The experiment was conducted with two levels of FA @ 10 and 20 t ha^{-1} and three doses of NPK @ 40:15:15, 60:30:30 and 80:45:45 kg ha^{-1}. The dry matter yield, seed yield and oil content of the seed was increased in both FA 10 waste water (WW) and FA20 WW as compared to crop grown under ground water (GW) treatments and control having no FA, WW and NPK. The nickel uptake and translocation factor (Tf) showed the successive potential of Ni tolerance of mustard in soil amended with FA and irrigated with WW. The Tf was higher in FA+WW treatments than FA+GW and control. The overall results indicated FA20 N60 P30 K30 was found to be most suitable combination in terms of yield and high oil content as well as Ni accumulation in plant parts.

Sireesha and Rani (2014) conducted field experiment to study the effect of fly ash and fertilizer levels on yield and nutrient uptake of groundnut. The experiment with four levels of fly ash (0, 5, 10 and 15 t ha^{-1}), four levels of fertilizers (70, 80, 90 and 100% recommended dose of fertilizers) and a control without any fertilizers and fly ash. Application of fly ash @ 10 t ha^{-1} increased the yield and nutrient uptake significantly over 0 and 5 t ha^{-1}. However, further increase in the levels of fly ash application the increase in yield and nutrient uptake was non-significant. The highest pod and haulm crop yield was obtained when 15 t ha^{-1} fly ash was applied along with 100 per cent recommended dose of fertilizers.

Yadav *et al*. (2014) explored 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. The experiments were designed with five treatments and fly ash at control, 5%, 10%, 15% and 20% level. The plant growth parameters (plant height and leaf area) were found to be higher in maximum fly ash (20% FA) treated plot as compared to control plot during different growth stages of medicinal plant. The root yield (35.545 g/plant and 39.002 g/plant) of plant was also found higher with maximum fly ash (20%) treatment compared to control in first and second year of cultivation.

Bagchi (2013) evaluated the response of *Jatropha curcas* growth in fly ash amended soil at 0%, 10%, 20% and 30% fly ash level. Total fresh biomass produced in only soil and 30% fly ash amended soil were 24.8 t/ha and 36.9 t/ha, respectively. Similarly, total dry biomass in only soil and 30% fly ash amended soil were 8t/ha and 14 t/ha, respectively. Bulk density of soil without fly ash was1.23 g /cm^3 which decreased to 1.19, 1.13 and 1.10 g/cm^3 and porosity of the soil (39.2%) decreased to 37.5, 33.6 and 32.5% for soils amended with 10, 20 and 30% fly ash, respectively. Sand percentage of the soil without fly ash (73.45 %) increased to 74.30, 79.30 and 82.20% for soils amended with 10, 20 and 30% fly ash. Organic carbon content of the soil increased with fly ash amendment and the OC values at 10%, 20% and 30% fly ash were 0.57±0.06, 0.68±0.13 and 1.02±0.34 % as compared to 0.48±0.1% in soil without fly ash.

Das *et al.* (2013) conducted experiment to study the effect of application of fly ash alone and in combination with recommended dose of fertilizers and farm yard manure on yield and uptake of rice and soil properties. Fly ash when applied @ 5 and 15 t ha^{-1} recorded increase in rice yield by 23.3% and 32.4%, respectively over absolute control. The highest rice yield (34.1 t ha^{-1}) was recorded in treatment of 50% RDF + FYM 5 t ha^{-1} + FA 15 t ha^{-1}. On the other hand, fly ash applied @ 5 t ha^{-1} in combination with 50% RDF + 5 t ha^{-1} FYM produced 40.1% higher yield over absolute control. Significant increase in the uptake indicated that fly ash could serve as a source of plant nutrients.

Deepa *et al.* (2012) found that fly ash application increased the number of leaves, plant height, biomass and yield of three crops (palak, mung bean and chilli) and recorded maximum in 25% fly ash amended soil treatment, whereas application of fly ash higher levels resulted in declined growth and yields of plants.

Bhople *et al.* (2011) evaluated seven level of fly ash (0, 20, 40, 60, 80, 100, and 120 t ha^{-1}) along with recommended dose of NPK (60:60:00) on physical and chemical properties of black cotton soil and yield of sunflower. Application of 40, 60 and 80 t ha^{-1} of fly ash in combination with recommended dose of fertilizer were at par with each other and significantly superior over RDF and rest of the treatments were found to be useful in increasing seed and straw yield of sunflower. However, application of 60 t ha^{-1} of fly ash and recommended dose of NPK recorded significantly highest yield of 6.54 q ha^{-1} and 12.5 q ha^{-1} seed and straw yield as compared to 6.55 q ha^{-1} and 11.80 q ha^{-1} at RDF, respectively.

Singh *et al*. (2011) collected fly ash from Chandrapura Thermal Power Station Jharkhand, India and used to amend fallow land @ 60, 120, 180 and 240 t ha^{-1}. The plant growth parameters of vegetables (shoot and root length) increased at all amendment levels. The bio-chemical parameters (chlorophyll a, chlorophyll b, total chlorophyll and carotenoid) were significantly increased in the treatments with 120 to 180 t ha^{-1} fly ash as compared to control.

Faizan and Kausar (2010) conducted a green house experiment to study the effect of various coal ash concentrations (0%, 5%, 10%, 25%, 50%, 70% and 100%, v/v) on growth, yield, biomass and nodulation of lentil. Application of 5%, 10% and 25% coal ash to soil caused a significant increase in the studied parameters (plant growth, yield and biomass and nodulation of lentil). Deleterious effect was observed at higher concentration with the maximum being at 100% coal ash.

Karmakar *et al*. (2010) applied two organic sources viz. farm yard manure (FYM) and paper factory sludge (PFS) at 30 kg N ha^{-1} and three amendment viz., fly ash (FA) at 5 and 10 t ha^{-1}, rice husk ash (RHA) at 5 t ha^{-1} and lime (L) at 2 t ha^{-1} under integrated nutrient management system in acid lateritic soil to grow rice crop. A uniform nutrient level of 90 kg N, 26.4 kg P and 33.2 kg K ha^{-1} through these material and chemical fertilizer (CF) was maintained for all the treatments except in control plots. The results showed that grain and straw yield under all the treatment except FA alone increased significantly over control during both the years. A marginal increase in yield was noted under FA over control. Further, there was an improvement in yield under the combined application of CF,FYM, PFS and soil amendment (lime ,FA or RHA) as compared to control .Integrated with paper factory sludge proved superior to that with FYM first year, whereas, the trend was reverse during second year.

Pandey *et al*. (2010) evaluated the effect of FA (25, 50, and 100% FA) on antioxidants, metal concentration (Fe, Zn, Cu, Cr, and Cd), photosynthetic pigments (chlorophyll a, chlorophyll b, total chlorophyll and carotenoids), growth and yield performance. All antioxidants in roots, shoots and leaves of chickpea increased with increasing FA doses. The activities of antioxidants were more in the root tissues to cope with stress induced in the plants as compared to shoot and leaf. Concentration of metals was found maximum in roots than the shoots and seeds. The highest concentration of Fe and lowest level of Cd were recorded in all treatments of FA for different parts of the plant. The treated crop showed reduced level of chlorophyll but enhanced level of carotenoids and protein. However, root length, number of nodules and biomass in 25 and 50% FA treatments did not differ significantly in comparison to control plants.

Samy *et al*. (2010) conducted an experiment to study the effect of fly-ash on growth, yield and metabolism of rice with fly-ash (FA) @ 0, 5, 10, 20, 40, 80 and 100 t ha^{-1} level for three successive seasons. Enhancement in growth parameters of rice (shoot length, leaf number, leaf area and plant dry weight) was observed at lower FA levels but subsequent inhibition in higher grades. The 40 t ha^{-1} FA level was ideal for growth. Similarly, yield and its attributes in rice (parameters such as length of the panicle, number of panicles per plant, grain yield per plant, and a few more) had initial enhancement and subsequent decline in plants from second and third seasons. Optimum yield was at 20 and 40 t ha^{-1} FA level with repeated FA amendments. Pigment contents (chlorophyll a, b and carotene) and enzyme activities (catalase and peroxidase) of fresh leaves were found to be unaffected by FA amendments and their repetitions. But, significant decline in both protein and carbohydrate contents of seeds was recorded due to FA repetitions.

Sharma *et al.* (2010) utilized fly ash which was alkaline in nature and poor in N, P and humus as compared to garden soil. The experiment was conducted in pea crop in glass house with fly ash mixed @ 0, 5, 10, 15, 20 and 25% and used to fill earthen pots (2 kg/pot). Seven days old seedlings were transplanted (3 individual/ pot) in pots. The glass house temperature (25±20C) and moisture (50% of water holding capacity) was maintained throughout the experiment. Significant increase was observed up to 10% fly ash amended in terms of chlorophyll, carotenoids, proteins, biomass and overall growth of plant. The phenols and ascorbic acid concentrations were maximum at 25% fly ash amendment.

Aggarwal *et al.* (2009) studied the effects of varying levels of fly ash (0, 5, 10, 20 t ha^{-1}) and nitrogen (0, 10, 20, 40 kg ha^{-1}) on germination, growth parameters, yield of wheat and sorghum crops and soil properties. Germination and early growth was affected adversely in wheat, but increasing levels of fly ash did not cause any harmful effect in sorghum. Grain yield of both the crops was slightly increased at higher levels of nitrogen and ash i.e. 20 t ha^{-1} coal burnt ash + 120 kg N ha^{-1} (wheat) or 40 kg N ha^{-1} (sorghum).

Gupta and Singh (2009) studied on the effect of fly ash on the physical and chemical characteristics of soil and growth of chickpea at different doses of fly ash (10%, 20%, 30%, 40% and 50%) in combination with chemical fertilizer. A positive correlation between fly ash supplement and root length was noticed. Chlorophyll a and b content of freshly harvested leaf also showed considerable increase. Average grain yield per plant increased from 32.5 to 38.65 gm and average seed weight also increased from 179 to 265 gm per thousand grains at higher fly ash level.

Singh *et al*. (2008) studied the effects of various concentrations of FA (0%, 5%, 10%, 15% and 20%) on heavy metal accumulation, growth, and yield responses of palak (*Beta vulgaris L*. var All Green H1). The results showed that application of FA caused significant reductions in growth, biomass and yield responses of Palak at different stages during growth. The concentration of all the heavy metals increased significantly with increasing concentrations of FA. Metal pollution index (MPI) of both roots and shoots showed significant and negative relationships with yield of the crop.

Yeledhalli *et al*. (2008a) evaluated long term effect of fly ash on rice yield and soil properties. Fly ash applied to soil at 20 to 40 t ha^{-1} with and without organics (20 t ha^{-1}). The results indicated that the total yield of maize 35.7 q ha^{-1} was recorded in the treatment receiving pond ash @ 40 t ha^{-1} along with FYM @

20 t ha^{-1} followed by fly ash 30 t ha^{-1} with increase by 53.3 and 45.0 percent over control. The water holding capacity of soil increased from 64 to 67.5 per cent due to pond ash applied @ 40 t ha^{-1}. There was no residual effect of fly ash/pond ash and better residual effect on succeeding crop sunflower.

Yeledhalli *et al.* (2008) reported the beneficial effect of fly ash / pond ash along with FYM on the biomass yield of sunflower and maize. The maximum biomass yield of sunflower (23.1 t ha^{-1}) was recorded with application of fly ash @ 40t/ha along with FYM @20 t ha^{-1} and per cent increase over control was 36.70, whereas highest maize biomass yields (41.2 q ha^{-1}) of maize was observed due to application of fly ash @ 40t ha^{-1} every year and the increase over control was 61.6%.

Mittra *et al*. (2005) stutied an integrated plant nutrient supply system and utilizing the fly ash along with other organic wastes. Fly ash applied @ 10 t ha^{-1} , organic material such as paper factory sludge (PFS), farm yard manure (FYM), crop residue (CR) applied in quantity supply 30 kg N ha^{-1}, Lime was applied @ 2 t $ha^{-1}$and chemical fertilizers for rice–peanut cropping system. Fertilizers were applied in different treatment combinations except two treatments where fly ash (FA) was applied at 10 t ha^{-1} and absolute control. Application of fly ash 10 t ha^{-1} in combination with organic sources (PFS/ FYM/CR) and chemical fertilizers increased the grain yield of rice and pod yield of peanut by 31 and 24% as compared to chemical fertilizers alone.

Patil *et al.* (2005) investigated the combined effect of fly ash and farmyard manure (FYM) on nutrient uptake and yield of onion. The treatments included four levels each of fly ash (0, 5, 15 and 30 t ha^{-1}) and FYM (0, 5, 15 and 30 t ha^{-1}) with the increasing level of fly ash and FYM, there was a corresponding increase in the uptake of nitrogen, phosphorus and potassium. Onion yield also increased by increasing levels of fly ash and FYM. Dry matter production of onion was maximum (6.46 g $plant^{-1}$) when crop received 30 t ha^{-1} of FYM.

Mittra *et al*. (2003) justified suitability of fly ash in agricultural crops through a field investigation for six years during 1996 to 2001. An attempt was made to develop an integrated plant nutrition system (IPNS) utilizing fly ash (FA), and paper factory sludge (PFS), along with farm yard manure (FYM), crop residue (CR) and chemical fertilizers (CF) for rice- peanut cropping system. Application of FA @ 10t ha^{-1} in combination with organic sources (PFS/ FYM/ CR) and chemical fertilizer (CF) increased the grains yield of rice, pod yield of peanut and equivalent yield of both the crops by 31, 24 and 26 percent, respectively as compared to CF alone. The beneficial effect of repeated application of FA as compared to one time application at the same level and yield advantage derived by peanut through IPNS was greater than rice. Moreover, there was saving of CF in the order of 64.4 % N, 44% P_2O_5, and 43.3% K_2O. The alkaline fly ash (pH 8.4) could be used as substitute of lime a costlier material, for amending acidic soils and to increase the availability of P, K, Ca, Mg, Zn, Cu and Co besides improving soil physical and chemical properties.

Thanunathan *et al.* (2001) studied that fly ash effect on the growth, yield and nutrient uptake of Sesame. Fly ash @ 10, 20 and 30 t ha^{-1} was applied along with well decomposed farm yard manure @ 12.5 t ha^{-1} and recommended fertilizer dose of 35:23:23 kg ha^{-1} (N, P_2O5 and K_2O). The growth characters i.e. plant height and number of branches, as well as the yield parameters, number of capsules/plant, number of seeds/capsule, 1000 seed weight, grain yield, and N P K uptake were maximum when fly ash was applied at 30 t ha^{-1}.

Jeyabal *et al*. (2000) conducted a field experiment on rice during *kharif* season with integrated application of lignite fly ash @ 1 or 2 t ha^{-1} and press mud @ 10 or 20 t ha^{-1} incorporated into the soil before transplanting. The results showed that the highest plant height (89.2 cm) was recorded with combined application of fly ash @ 2 t ha^{-1} and press mud at 20 t ha^{-1} compared to control (72.4 cm). Addition of fly ash @ 2 t ha^{-1} press mud either 10 or 20 t ha^{-1} improved the tiller number $hill^{-1}$ (8.0) compared to control (6.3) and also recorded the highest number of filled grains $panicle^{-1}$ (92.4) with combined application compared to control (61.1). They also reported highest dry matter production (grain + straw) when lignite fly ash was applied @ 2 t ha^{-1} along with pressmud @ 20 t ha^{-1} (14.02 t ha^{-1}).

Mulla *et al.* (2000) evaluated various combination levels of fly ash (0, 10, 20, 30 and 40 t ha^{-1}) and farmyard manure (FYM 0 and 10 t ha^{-1}) on the productivity of rice. Highest grain and straw yields resulted by application of 40 t fly ash +10 t FYM ha^{-1}. Application of increasing rates of fly ash improved soil properties and nutrient availability as well as the nutrient uptake in rice.

Matte and Kene (1995) conducted field experiments with four levels of fly ash (0, 5, 10 and 15 t ha^{-1}) and 3 levels of NPK (0, 100 and 75% of recommended dose) during *kharif* season using cotton, sorghum, groundnut, soybean, green gram and paddy and during *rabi* seasons on wheat, gram and mustard as test crops. The application of 10 t ha^{-1} fly ash was found to be more effective in influencing yield performance of the crops. This dose increased yield of cotton by 22.20%, groundnut pod by 22.17 to 24.15%, greengram by 20.14%, gram by 21.32%, rice by 33.29%, soybean by 9.39% and wheat by 20.14%.

2.3 Effect of fly ash on physical and chemical properties of soil

Fly ash contains essential plant nutrients such as P, K, Ca, Mg, S and micronutrients. In our earlier references it has been proved by many scientists that the application of fly ash increased the nutrient availability and plant uptake. However, application of un-weathered fly ash may have a tendency of accumulating elements such as B, Mo, Se and Al, which at toxic levels are responsible for reductions in the crop yields and consequently influence animal and human health (Sharma and Kalra, 2006).

Mishra *et al.* (2017) studied impact of coal fly ash as soil amendment on physical and chemical properties of soil. Various levels of coal fly ash were taken 0%(Control), 5%, 10%, 15%, 20%, 25%, 30%, 50%, 75%, 100% and changes in physical, chemical and structural properties were observed. Increasing level of fly ash increased properties of soil like pH (6.15 to 6.97), electrical conductivity (0.19 to 0.62 $mScm^{-1}$), water holding capacity (42.73 to 60.36%), porosity (52.46 to 57.30) and decreased the bulk density (1.49 to 1.06 gm cm^{-3}) of soil.

Dhindsa *et al*. (2016) reported that fly ash has ability to improve physical properties of both clayey as well as sandy soils. Fly ash was mixed @ 0, 10, 20, 30, 40, 50 and 100% in clayey as well as sandy soils. The addition of 20% fly ash in clayey soil and up to 30% in sandy soils improved the germination, tillering, plant height, biological and grain yield of wheat. The addition of fly-ash has also shown improvement in the soil properties viz. texture, structure and bulk density. Permeability of clay loam soil increased from 0.54 cm/hr to 2.14 cm/hr by the addition of 50% fly ash whereas it decreased from 23.80 cm/hr to 9.67 cm/hr in sandy soil by 50% fly-ash addition. Water holding capacity of sandy soil also increased from 0.38 cm/cm to 0.53 cm/cm at 50% FA level.

Malakar *et al.* (2016) conducted an incubation study to characterize soil quality as affected by organic amendments (FYM, biochar and poultry manure @ 25 t ha^{-1}) with or without fly ash (22.4 t ha^{-1}) in Vertisol. Physical and chemical parameters of soil quality like pH, EC, bulk density, porosity, moisture content, organic carbon and available N, P, K measured at the end of incubation period i.e. 10^{th} week showed that combined application of soil amendments (FYM + fly ash, biochar + fly ash and poultry manure + fly ash) had significantly better results than individual application of the respective soil amendments. Soil microbial biomass carbon (SMBC) and dehydrogenase enzyme activity (DHA) increased steadily up to 6^{th} weeks of incubation with a marginal decrease during last phase. At the end of incubation period (10^{th} week), SMBC and DHA was highest in the soil amended with FYM + fly ash.

Padhy *et al*. (2016) conducted experiment with fly ash (0, 0.5, 1.0, 2.0, 4.0, 8.0 and 10.0 kg/m^2 (0 to 10 t ha^{-1})) and cyanobacteria on growth, metabolism and yield of rice and metal loads in plant parts. Basic soil reaction, percentage of silt and clay, water-holding capacity, electrical conductivity, cation exchange capacity, and organic carbon content increased due to the FA amendment with increasing concentration. Fly ash amended plots with 1.0 kg/m^2 N_2-fixing cyanobacteria mass caused further significant increments of the most soil properties, and rice growth and yield parameters. Accumulations of K, P, Fe and several plant micronutrients (Mn, Ni, Co, Zn and Cu) and toxic elements (Pb, Cr and Cd) increased in soils and plant parts but Na content remained almost unchanged in soils and seeds.

Supplementation of cyanobacteria had ameliorating effect on toxic metal contents of soils and plant parts.

Chandraka *et al.* (2015) conducted a field experiment to compare the effect of fly ash with lime and gypsum on soil physical and chemical properties and yield of maize crop in acidic Alfisol. Application of fly ash @ 40 t/ha alone or with FYM altered the soil texture with increasing clay, silt content and water holding capacity by 8-12% both in the surface and sub surface soil. Integrated use of fly ash+lime+FYM resulted in higher pH (5.45) and higher Ca accumulation (3.7 %) in surface soil. Downward movement of Ca and SO_4 up to 30 cm soil depth was observed with gypsum application. Application of lime to each crop significantly increased the maize yield by 27 % over control.

Ciecko *et al*. (2015) from a longterm field with application of hard coal fly ash. Hard coal fly ash (HCFA) was added to soil at doses of 0 to 800 Mg ha^{-1} which increased soil pH and contents of available forms of P, K, and Mg, plus mineral forms of nitrogen and high soil organic matter. Increased ash doses applied to soils increased the C:N ratio and shares of $N\text{-}NO_3$ and N-NH4 in total nitrogen content. Fly ash originating from combustion of hard coal and applied in the form of ameliorating doses between 200-800 Mg HCFA ha^{-1} permanently raised the soil pH and available soil nutrients. It was observed that doses of 100 and 400 Mg HCFA ha^{-1} acted beneficially on the content of P, raising the level of available P forms by 13.67 and 27.05 mg kg^{-1} of soil, respectively, compared to the control. The content of nitrate nitrogen ($N\text{-}NO_3$) in the analyzed soil samples was significantly elevated, on average by 20.3, 25.9, and 31.9% over the control following the application of 400, 600, and 800 Mg HCFA·ha^{-1}, respectively. Fly ash above 200 Mg HCFA·ha^{-1} significantly increased the soil organic matter (SOM) content of soil while contributing to a significant widening of the C:N ratio which may impact a significant, residual, and stimulating effect of HCFA on sequestration of carbon in soil.

Buddhe *et al.* (2014) investigated in a field trial experiment on paddy crop using the fly ash was collected from the hopper of thermal power plant and was magnetized to produce novel soil conditioner Biosil. Recommended doses of fertilizers (RDF) were fortified by Biosil with different doses (kg ha^{-1}) namely 150, 300, 450, 600, 750 and 900, keeping RDF and vermicompost (VC) as controls. All doses of Biosil, especially 450 to 900 kg ha^{-1} improved the soil fertility and paddy productivity over RDF, control and VC control. Biosil + RDF treatments improved initial pH of soil from 7.1 to 7.3, electrical conductivity (EC) from 0.31 to 0.35 dS m^{-1}, organic carbon (OC) from 0.64 to 0.68% and effectively reduced the bulk density (BD) from 1.46 to 1.40 g cm^{3}.

Nayak *et al*. (2014) evaluated application of fly ash on microbial response, soil enzymatic activities and heavy metal accumulation in soil and grain of rice. Fly ash was applied @ 0 , 5, 10 , 20 , 40 and 100 % on soil volume basis with chemical fertilizer (40:20:20 mg N:P: K kg^{-1} soil) with six replications. There was no significant change in the concentration of zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), cadmium (Cd) and chromium (Cr) with application of fly ash up to @ 10 %. However, at FA applied 100% significantly increased all metals concentration in soil than other treatments. Population of both fungi and actinomycetes decreased with the application of fly ash, while aerobic heterotrophic bacterial population did not change significantly up to FA applied @ 40 % on soil volume basis. On the other hand, total microbial activity measured in terms of Fluorescein diacetate (FDA) assay and denitrifiers showed an increased trend up to FA applied @ 40 % on soil volume basis.

Gond *et al.* (2013) used fly ash from Chandrapura Thermal Power Station, Bokaro, Jharkhand (India) at four levels (0, 60,120 and 240 tons ha^{-1}) in brinjal (*Solanum melongena*). Fly ash amendments caused significant improvement in soil quality, organic carbon (0.75-0.86%), organic matter (1.30-1.47%), water holding capacity (52.64-65.76 %), pH (6.45-7.05), composition of photosynthetic pigment (chlorophyll a, chlorophyll b, total chlorophyll and carotenoid) and few growth parameters (fresh weight, root length, shoot length) of brinjal with increase in fly ash amendments. Fruit (edible part) of plants grown in fly ash amended soils had metal residues (mg kg^{-1}) like Cr (0.80-1.16), Co (0.34-1.46), Ni (0.85-1.00), Zn (24.41-32.33), Cu (10.61- 15.49), and Mo (0.49-1.46).

Gourab and Joy (2011) studied effect of coal fly ash doses on chemical and microbial properties of laterite cropland soil. Sandy loam soil was mixed with Farm Yard Manure (10% w/w) and amendment with 5, 10, 20 and 40% w/w (50-400 t ha^{-1}). The results shows that pH, EC, PO_4, Ca^{2+} and Na^+ of soil increased with fly ash dose and time but OC, NO_3-N and K^+ decreased with increasing doses of fly ash.

Karmakar *et al*. (2010) evaluated use of industrial waste viz., fly ash (FA) at 5 and 10 Mg ha^{-1}, rice husk ash (RHA) at 5 Mg ha^{-1} and lime (L) at 2 Mg ha^{-1} and organic sources viz. farm yard manure (FYM) and paper factory sludge (PFS) at 30 kg N ha^{-1} under integrated nutrient management system in acid lateritic soil on rice. The bulk density noticeably decreased under the treatment with combined application of organic source, soil amendmend and CF (chemical fertilizer) as compared to control and only CF. The marginal increase in nutrient content under FA was noted as compare to control. The N, P and K content of soil increased from 150.6 to 261.0, 14.31 to 27.80 and 123.6 to 168.0 kg ha^{-1}, respectively due to addition of combined fertilization.

Reddy *et al.* (2010) studied the effect of varying level of fly ash (0, 5, 10, and 15 t ha^{-1}) and FYM (0 and 10 t ha^{-1}) on physical and chemical properties and yield of rice grown on inceptisol. Application of fly ash applied at 15 t ha^{-1} + FYM 10 t ha^{-1} recorded the highest available N, P, K, S , Fe and Zn content of soil. The available Mn content was highest in fly ash applied 15 t ha^{-1} + FYM 10 t ha^{-1} (6.69 mg kg^{-1}) and available Cu content was not influenced by fly ash levels however, it was significantly higher in FYM treated plots. Application of fly ash @ 15 t ha^{-1} + FYM @ 10 t ha^{-1} (FA_{15} FYM_{10}) recorded the highest available N (224.6 kg ha^{-1}), P (24.6 kg ha^{-1}), K (366.7 kg ha^{-1}), S (8.80 mg kg^{-1}), Fe (10.62 mg kg^{-1}) and Zn (0.95 mg kg^{-1}) contents after harvest of rice crop. The available Mn content was highest in FA_{10} FYM_{10} (6.69 mg kg^{-1}). Application FA_{10} FYM_{10} resulted in the build up of available nutrients (N-5.8 %), (P-64.5 %), (K – 103.3 %), (S – 2.8 %), (Fe – 22.2 %), (Mn – 23.3%), (Cu – 156.9 %) in post harvest soils except Zn (10.5%) when compared to their initial status.

Yeledhalli *et al*. (2007) studied the effect of levels of fly ash (0, 25, 50, 75 and 100 t ha^{-1}) on physical and chemical and biological properties of soil .Application of graded level of coal fly ash amendment in Alfisol revealed an increase in the content of N (225.08 to 240.91 kg ha^{-1}) , P (32.77 to 24.38 kg ha^{-1}) , K (223.80 to 234.87 kg ha^{-1}), Ca (16.30 to 19.90 C mol (p+) kg $^{-1}$) , Mg (1.96 to 3.91 C mol (p+) kg $^{-1}$), S (11.51 to 11.21 kg ha^{-1}) , Fe (18.79 to 21.40 mg kg^{-1}), Mn (15.94 to 23.58 mg kg^{-1}), Zn (1.50 to 3.90 mg kg^{-1}) and Cu (2.56 to 4.26 mg kg^{-1}). Increasing level of coal fly ash application resulted in significant increase in pH, total contents of exchange cations, cation exchange capacity and percent base saturation.

Chirenje and Lena (2006) monitored the changes in soil properties and the availability and leaching of nutrients by the application of large quantities of boiler ash in a sandy soil (with a spodic horizon). Two application rates (900 and 1800 Mg ha^{-1}) and two application methods (surface and subsurface) were used. The soil pH increase from 5.6 to above 9.o and the electrical conductivity increased by up to 2 dS m^{-1}in all plots compared to the control. The high alkalinity from the ash in the 1800 Mg ha^{-1} rate depleted the spodic layer, and this was more pronounced in the subsurface treatments. Plant-available water was doubled to 12% in the 1800Mg ha^{-1} treatment and soil bulk density before boiler ash application was around 1500 kg m^{-3} which decreased to 1360 and 1230 kg m^{-3} after incorporating boiler ash (particle density 500 kg m^{-3}) at rates of 900 and 1800 Mg ha $^{-1}$, respectively. Total and plant available macro-nutrients (Ca, Mg, K, and P) and micronutrients (iron (Fe), Mn, copper (Cu) and Zn) increased substantially after ash application.

Sharma and Kalra (2006) reported that fly ash application improved the physical, chemical and biological properties of problem soils and enhanced the available macro and micronutrients for plants. The high concentration of elements (K, Na, Zn, Ca, Mg, and Fe) in fly ash increased yield of agriculture crops. However, application of fly ash particularly unwheatherd ones shows a tendency of accumulating elements like B, Mo, Se, and Al. The accumulation of this toxic level is responsible for reduction in the crop yields and consequently influences animal and human health.

Shenggao and Lei (2004) studied the effect of fly ash on physical properties of Ultisols. Fly ash was mixed in two acid clay loams (typic plithudult and typic hapludults) at the rates of 0, 5, 10, 20, 30 and 50% by weight. Application of fly ash @ 50% showed significant increase in percentage of silt (0.02-0.002 mm) and decrease in clay (<0.002 mm) proportion. Effect of fly ash (30 and 50%) to another soil caused a significant change in microaggregate size disruption of soil, while non significant differences were observed in the rates of 5, 10 and 20% fly ash. Fly ash application not only increased total water content (30.9 to 51.6%) but also increased plant available water (10.5 to 60.5 %).

Rautaray *et al*. (2003) evaluated direct effect of fly ash, organic wastes and chemical fertilizers (CF) on rice and their residual effect on mustard grown in sequence. The three organic wastes viz., FYM, paddy straw (PS) and green manure (GM) in combination with supplemental CF but with or without fly ash @ 10 t ha^{-1} formed six treatment combinations. Application of fly ash alone was effective in rising soil available P. Thus, integrated use of fly ash, organic wastes and chemical fertilizers was beneficial in improving crop yield, soil pH, organic carbon and available N, P and K in sandy loam acid lateritic soil. The Cd content in grain was lower than in straw and the opposite for Ni. There was a decrease in content of Cd and Ni both in grain and straw with application of fly ash @ FA10 t ha^{-1}. Integrated use of organic wastes and CF was effective in lowering Cd and Ni in rice grain and straw as compared to chemical fertilizer. Cadmium content was less in seed than in stover of mustard but the reverse was for Ni. There was a marginal increase in the content of Cd in seed and stover under the residual effect of FA.

Sahoo and Kar (1998) concluded that maximum water holding capacity of soil increased significantly when fly ash was applied at the rate of 10 Mg ha^{-1}. Fly ash application also had a significant influence on soil bulk density with increase in rate of fly ash application from 0 to 50 Mg ha^{-1}, bulk density decreased from 1.55 to 1.42 Mg M^{-3}. Apart from the decrease in bulk density, saturated hydraulic conductivity (Ks) was found to increase significantly due to fly ash application.

Fly ash @ 20 and 50 Mg ha^{-1} resulted two and three fold increase in hydraulic conductivity compared to control. As evident from the water retention curve at 0.1 bar the transmission pore volume increased from 15.4% to 17.7% and 18.25% with increase in the rate of fly ash application from 0 to 5 and 10 Mg ha^{-1}, respectively

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Sikka and Kansal (1995) evaluated the effect of fly-ash application on dry-matter yield and nutrient composition of rice and wheat plants and on pH and available nutrient status of soils in a greenhouse experiment. Fly ash was mixed with seven soils (varying in texture and $CaCO_3$ content) each at 0, 2, 4 and 8% (w/w) levels. Addition of fly ash resulted in a significant increase in the contents of N, S, Ca, Na and Fe and a significant decrease in P and Zn contents of rice. The residual effect of fly ash on dry-matter yield and nutrient composition of a subsequent wheat crop was non-significant, except for the Fe content of the wheat plants which increased significantly from 138 ppm in the control to 161 ppm at 8% level of fly-ash addition. The pH and available nutrient status of soils after harvest of the rice and wheat crops were not affected by the application of fly-ash. However, the mean DTPA-extractable Fe content in soils increased significantly from 12 ppm in the control to 18.1 ppm in soils amended with 8%fly-ash.

2.4 Effect of fly ash on heavy metals in soil and crops

Rahimi *et al.* (2017) carried out a field study to investigate uptake and translocation of Cd, Pb, Ni and Zn by a local variety of rice crop exposed to contaminated water. Average concentrations of Cd, Pb, Ni and Zn were 1.07, 17.22, 1.73 and 13.75 mg kg^{-1} in the plant's stem, 1.57, 27.90, 10.75, 25.71 mg kg^{-1} in plant root and 1.27, 12.32, 1.099 and 19.39 mg kg^{-1} in its grain, respectively.

Rana *et al.* (2017) conducted a study around the Feroze Gandhi Thermal Power Station, Unchahar for the speciation of heavy metals contamination of soil. The presence of fly ash, particularly unweathered ones, shows a tendency of accumulating elements like Zn (2.42- 3.45 mg kg^{-1}), Cu (1.41- 1.72 mg kg^{-1}), Fe (39.48 - 54.76 mg kg^{-1}) and Pb (1.35- 1.87 mg kg^{-1}). All heavy metals were increased in 500 m distance in all direction. The presence of heavy metals in the soil was mainly found at 500 m distance from the Thermal Power Station (TPS).

Singh *et al*. (2016) studied the effects of FA on soil health, plant growth, toxic metal accumulation and antioxidant responses in rice (*Oryza sativa L.*). Soil was amended with 50% FA in natural condition. FA application resulted reduction in soil enzymatic activities viz., dehydrogenase, acid phosphatase, B-glucosidase and urease than garden soil (GS). FA amendments significantly decreased the root, shoot and panicle length and augmented sterility in rice. Total accumulation of toxic metals i.e. Cd, Cr, Pb and As were 14–15 fold higher in roots and shoots and 4–20 fold higher in grains for the plants grown on FA amended soil than GS. The levels of nutrient elements viz., Mn, Co, Cu and Se were lower in grains of FA treated soil than GS.

Kumar *et al.* (2015) studied to determine toxic metal concentration in fly ash and metal accumulation potential of the Munja and Bermuda Grass, the two main grass species growing naturally on fly ash lagoon, for Fe, Ni, Zn, Cu, Mn, Pb and Cd. Accumulation of metals in both the grass species were found in the order of Fe > Zn > Mn > Cu > Ni > Pb and Cd. Maximum accumulation of Fe was found in the roots of Bermuda Grass (1396 ± 401mg kg^{-1}) where as minimum accumulation for Cd was found for Munja (0.47 ± 0.13). High concentration of Fe, Pb and Ni were found in root than shoot whereas in shoot they were found in the order of Cd > Zn > Mn in both the grass species. In spite of significant accumulation of Fe in the root and shoot, the bioconcentration factor (BCF) and bioaccumulation coefficient (BAC) were found very low (<1) in both the grasses. The metal excluding properties in shoots of both the grasses with low translocation factor (<1 for Fe, Ni and Pb), high BCF (>1 for Zn and Pb) and low BAC (<1 for Fe, Mn, Ni, Cu and Cd) suggests its suitability for phytoremediation of fly ash lagoons.

Pani *et al.* (2015) used fly ash from NALCO Captive Power Plant, Angul,Odisha for amending at 0, 25, 50, 75 and 100% fly ash in sunflower crop. Application of 25% FA not only improved the physical properties of soil but also contributed to better yield of seed, high carbohydrate and protein content in seeds of sunflower. The accumulation of heavy metals viz. Pb (0.18), Cd (0.26), Cr (3.41), Zn (30.26), Cu (9.34), Ni (1.25) and Co (0.82) mg kg^{-1} in seeds were in 25 % application of fly ash. The seeds of 100% fly ash showed accumulation of heavy metals at Pb (2.15), Cd (0.65), Cr (4.49), Zn (3.44), Cu (15.39), Ni (1.22) and Co (2.40) mg kg^{-1}, repectively. Among all the seven (Pb, Cd, Cr, Zn, Cu, Ni and Co) assessed heavy metals Zn, Cr, Cu and Ni showed more accumulation in seeds of sunflower as compared to other heavy metals.

Turkmens *et al*. (2015) investigated effects of fly ash on heavy metal contents of soil and corn plant. Six different fly ash doses (0, 2, 4, 8, 16 and 24% w/w) were mixed with soil in pots and corn seeds were sown. Significant changes were not observed in aluminum (Al) and lead (Pb) contents with fly ash treatments, significant increases were observed in boron (B), sodium (Na), sulphur (S) and molybdenum (Mo) at the level of $p< 0.01$ for soil samples. Soil Calcium (Ca) and Iron (Fe) were changed at the significance level of $p< 0.05$. While P, Cr, Mn, Ni, Zn, Mg, K, Cd and Pb contents of corn roots and stems did not change significantly, there were significant increases in B, Na, Mg, S, Cu, Cd, Mo, B, S , Mo ($p < 0.01$) and Mn ($P < 0.05$) with increasing concentration of fly ash.

Alrawiq *et al*. (2014) evaluated the accumulation and translocation of heavy metals in soil and in paddy crop that have been irrigated with recycled and non-recycled water and investigated the absorption of heavy metals in the crop. Average concentration (mg kg^{-1} dry wt.) of each heavy metal in the roots was Fe (8533.920) >Zn (16.703) > Mn (12.323) >Cr (5.605) >Pb (2.803) >Cu (1.464) >Cd (0.072). In the plants cultivated in the area that was irrigated with non-recycled water, the average concentrations of Cd (0.023 and 0.023 mg kg^{-1}), Cr (1.45 and 0.83 mg kg^{-1}) and Pb (0.15 and 0.090 mg kg^{-1}) in rice grain irrigated by recycled and non-recycled water, respectively. The concentrations of heavy metals in the soils that were irrigated with recycled water and non-recycled water were in the order of Fe >Mn >Cr >Zn >Pb >Cu >Cd and Fe >Zn >Cr >Mn >Pb >Cu >Cd, respectively.

Bansal and Singh (2014) investigated the effect of continuous application of sewage-effluent irrigation on the DTPA-extractable Cd, Ni, Cr and Pb in soils and crops for five years. Agricultural lands were irrigated by different sewage effluent for cultivation of vegetables crop. Concentration of metals in vegetables grown on sewage effluent irrigated soils ranged is Cd from 0.63-5.68: Ni from 5.54-29.32:

Cr from 5.38 – 21.22 and Pb from 9.32.-20.24 mg kg^{-1}, while in ground water irrigated soil it ranged from 0.25-0.98, 1.88-7.86, 1.94-4.64, 2.84-5.04 mg kg^{-1} for Cd, Ni, Cr and Pb respectively. Maximum accumulation of these metals was in potato followed by maize, except for Pb. Concentration of metals in sewage effluent irrigated soils became four to six folds in comparison to ground water irrigated soil. Significant accumulation of heavy metals occurs in 0-15 and 15-30 cm depth. Soil properties viz organic carbon, pH, EC and CEC exhibited positive relationship with DTPA- extractable metal content, while clay content showed a negative relationship.

James *et al*. (2014) studied the effect of fly ash on the physical and chemical properties of soil in a mustard crop with application of different doses of fly ash (5, 10, 150 t ha^{-1}) alone and in combination with chemical fertilizers and sulphur. The best treatment combination for growth and yield attributes was observed in fly ash @ 10 t ha^{-1}+ N80 P60 K40 + S10 kg ha^{-1}. Maximum concentration of heavy metals was observed in fly ash @ 15 t ha^{-1} (Ar 3.9, Cd 37, Cr 300, Pb 400, Mn 1800, Ni 1600). fly ash @ 10 t ha^{-1}+ N80 P60 K40 + S10 kg ha^{-1} showed the best treatment combination in terms of cost benefit ratio.

Juen *et al*. (2014) compared the concentration of metals accumulated in various parts (grains, stems and roots) of paddy (*Oryza sativa*). The mean concentration of metals in grain samples were 0.06±0.12 ppm for ^{75}As, 0.0038±0.0037 ppm for ^{9}Be, 0.01±0.01 ppm for ^{114}Cd, 0.14±0.19 ppm for ^{59}Co and 0.21±0.15 ppm for ^{208}Pb, while ^{52}Cr concentration in all samples were below the ICP-MS detection limit. From the calculated translocation ratio, absorption of heavy metals in paddy show trend of root > stem > grain.

Nafees and Amin (2014) evaluated heavy metal contents, their uptake and accumulation in different parts of wheat plant. Pots were filled with sediment mixed with soil in the ratio of 25:75 (sediment: soil) and 50:50 (sediment: soil) in triplicate. Different parts of wheat plant were analyzed for selected heavy metals. The average values of Cd, Cr and Ni in soil were 0.17 to 0.2, 0.18 to 0.33 and 0.005 to 0.009 mg kg^{-1}, respectively. The average cadmium, chromium, nickel concentration in different parts of plant i.e. stems, leaves, seeds and roots were

(0.124, 0.120, 0.117, 0.08), (0.005, 0.015, 0.008, 0.015), (0.03, 0.002, 0.003, 0.144) mg kg^{-1} respectively. The concentration sequence was in order of stem > seed > leaf > root, for Cd and root > stem > leaf > seed for Ni and leaf > root > seed > stem for chromium.

Payus *et al*. (2014) assessed heavy metals accumulation in rice (*Oryza Sativa)*. Paddy soils and rice plants were sampled along seven transverse lines of the paddy field before the harvesting time. The plant roots accumulated relatively large amount of lead, cadmium, chromium and copper, while zinc was the highest in the stem. The correlation test showed that there was a strong correlation for zinc and cadmium concentrations with the paddy soil. Enrichment factor (EF) showed that lead, cadmium and copper were concentrated in the root, while chromium and zinc metals were more concentrated in the shoot part. Translocation factor (TF) showed that rice was able to transfer zinc and chromium from root to the shoot part of paddy.

Satpathy *et al*. (2014) assessed the effects of chemical fertilizers on heavy metal acuumulation in paddy. Mn and Cd were found to be accumulated more in shoot than in root other metals accumulated more in the roots than in other plant parts such as shoots, and grains and ranged from 14.4–21.9 for Mn, 4.7–16.9 Zn, 6.6–5.3 Pb, 0.6–1.7 Cr, 0.2–0.5 Cu, and 0.1-0.2 g g^{-1} for Cd. In shoot accumulation of metal was in order of 25–32.9 (Mn), 2.3–6 (Zn), 0.4−0.9 (Cr), 0.3– 1.2 (Pb), 0.2-0.3 and 0.05–0.3 g g^{-1} for Cu. Metals accumulation in grain were found in the ranges of 5.6–7.5 Mn, 3.2–7.2 Zn, 0.1–0.6 Cr, 0.1–0.3 Cu, 0.02–0.05 Cd and 0.01– 1 g g^{-1} Pb. The content of Mn and Zn was higher in the roots of paddy plants, which were followed by Pb, Cr, Cu, and Cd. There was accumulation of heavy metals such as Cd and Pb and micronutrients such as Zn, Cu, and Mn in the soil of paddy fields which was higher than that of the control soil.

Mahale *et al*. (2012) evaluated the effect of fly ash in agriculture and on the growth and accumulation of heavy metal in wheat (*Triticum aestivu*m), mung bean (*Vigna radiata*) and urad bean (*Vigna mungo*). The fine fly ash was mixed with soil in the ratios of 10%, 20%, 30%, 40%, 50%, and 60% in w/w proportion. It was found that the application of fly ash enhanced the seed germination rate considerably, whereas in the absence of fly ash (control), rate of seed germination was very slow. The use of fly ash as an admixture in agriculture up to 60% for wheat (*Triticum aestivum*), 10-20% for mung bean (*Vigna radiate*) and 20% for urad bean (*Vigna mungo*) was suitable for growth and yield. Elements such as Cd, Cu, Fe, Mn, Mg, Ni, Pb and Zn were accumulated in plants but at very low concentration and below the permissible limits provided for human consumption.

Kingsawat and Roachanakana (2011) study to determine concentrations of heavy metals (Cd, Cu, and Zn) in the water, soil, and rice in paddy fields and to compare heavy metal concentrations in the water, soil and four parts of the rice plant (root, shoot, grain, and husk) between organic paddy fields and conventional paddy fields. The results showed the accumulation of heavy metals in the water, paddy soil and four parts of the rice plant to be as follows descending order Zn > Cu > Cd. The concentration of heavy metals in samples was also found to be as follows paddy soil > rice root > rice shoot > rice grain > rice husk > water. When compare the heavy metal concentration in conventional paddy field and organic paddy field, it was found that heavy metal concentration in conventional paddy field was higher than organic paddy field.

Mishra (2011) conducted experiment was assess the mobility of heavy metals in selected crops grown in fly ash amended soil. Fly ash was applied to the fields in the range of 10-20 t ha^{-1}. Metal content in soil as well as plant materials increased with increased application of ash. Al, Cu, Cr and Pb contents were 9.9, 81.0, 89.0 and16.0 mg ug^{-1} in soil with 20 t ha^{-1} fly ash as against 0.6, 5.0, 3.6 and 5.0 mg kg^{-1} respectively in control soil (with no ash application). However, at 20 t ha^{-1} application higher accumulation of all the four metals were recorded even in the grains. In general the accumulation of metals was in the order of root>shoot>grain.

Sharma *et al*. (2010) studied bioaccumulation of Heavy Metals in Pea (*Pisum sativum L.*) growing in different fly ash soil ratios i.e. 0, 5, 10, 15, 20 and 25%. The results showed heavy metals contents significantly increasing growth media and plant different level of with level fly ash. Translocation factor indicated that toxic heavy metals like Cd, Ni and Pb retained in the below ground while micronutrients like Cu, Zn and Fe translocated to above ground parts. Hence, it is evident that pea plants may be a good metal accumulator which be could used for restoration of waste land having high alkalinity and low nutrient values.

Singh *et al*. (2010) deals with the accumulation of heavy metals in fields contaminated with fly ash from a thermal power plant and subsequent uptake in different parts of naturally grown plants. Results revealed that in the contaminated site, the mean level of all the metals (Cd, Zn, Cr, Pb, Cu, Ni, Mn and Fe) in soil and different parts (root and shoots) of plant species were found to be significantly higher than the uncontaminated site. The enrichment factor (EF) of these metals in contaminated soil was found to be in the sequence of Cd (2.33) > Fe (1.88) > Ni (1.58) > Pb (1.42) > Zn (1.31) > Mn (1.27) > Cr (1.11) > Cu (1.10). Whereas, enrichment factor of metals in root and shoot parts was found to be in the order of Cd (7.56) > Fe (4.75) > Zn (2.79) > Ni (2.22) > Cu (1.69) > Mn (1.53) > Pb (1.31) > Cr (1.02) and Cd (6.06) ~ Fe (6.06) > Zn (2.65) > Ni (2.57) > Mn (2.19) > Cu (1.58) > Pb (1.37) > Cr (1.01), respectively. In contaminated site, translocation factor (TF) of metals from root to shoot was found to be in the order of Mn (1.38) > Fe (1.27) > Pb (1.03) > Ni (0.94) > Zn (0.85) > Cd (0.82) > Cr (0.73).

Rahman *et al.* (2010) reported heavy metals can have a serious impact if released into the environment even in trace quantities. These can enter into the food chain from aquatic and agricultural ecosystems and threaten human health indirectly. A field experiment was carried out to investigate the uptake of heavy metals by paddy crop. The distribution of heavy metals in the different parts was investigated. The order of average contents of metals in rice was Zn > Rb > Se > Sc > Cr >Cs. The concentrations were Se 1.92–7.78 ppm, Cr BDL (Below Detection Limit), Sc 0.01–0.04 ppm, Rb 2.25–16.1 ppm, Fe–BDL, Zn 62.7–102.5 ppm and Co–BDL. Average contents of metals in rice was Zn > Rb> Se > Sc > Cr >Cs, in husk Fe > Zn >Rb > Se > Cr > Cs > Co > Sc, in leaf Fe > Zn > Se > Rb > Cr > Co> Cs > Sc, in stem Zn > Fe > Rb > Se > Cr > Co > Cs > Sc, in root Fe > Zn > Cr > Se > Rb > Co > Sc > Cs and in the surface soil it was Fe > Zn > Cr > Rb > Se > Co > Sc > Cs.

Yeledhalli *et al*. (2009) studied heavy metal elements and radio nuclides of crops grown on soils amended with fly ash. Total content of the toxic elements i.e., Pb, As and Se was 14.8, 1.40 and 1.20 mg kg^{-1} and natural radio nuclides were 291.30, 38.50 and 60.10 with 40K, 226Ra and 228Ac in Alfisol respectively. The concentration of heavy metals i.e. Se, As and Pb (0.24, 0.32 and 0.78 mg kg^{-1}) elements in sunflower seeds in red soils increased due to application of fly ash @ 40 t ha^{-1}. However, the combined application of fly ash @ 30 t ha $^{-1}$ and FYM @ 20 t ha^{-1} resulted in lower concentration and was comparable with that in control in spite of their increase in concentration. The concentration of Se, As and Pb in groundnut kernel was 0.27, 0.36 and 0.84 mg kg^{-1} in control, which increases to 0.29, 0.40 and 0.88 mg kg^{-1}, respectively due to application of fly ash @ 40 t ha^{-1}. Further, application of fly ash at maximum dose @ 40 t ha^{-1} increased the concentration of heavy metal elements and activity of natural radionuclide (40 K, 226 Ra and 228 Ac) in edible parts of crops viz, Sunflower, Groundnut and Maize grown on Alfisol and vertisol. However, combined application of fly ash and FYM did not increase the heavy metal elements and radio nuclide activity in seeds or stover of crops.

Gupta *et al*. (2007) study metal accumulation and growth performance of *Phaseolus Vulgaris* grown in fly ash amended soil. Amendments used as 10% FA (10% FA+90% soil), 25% FA (25% FA+75% soil) and garden soil (GS) alone served as control. The pH and electrical conductivity (EC) increased and cation exchange capacity (CEC), organic carbon (OC) and organic matter (OM) of different amendments decreased with the addition of FA in the soil. The level of diethylene triamine penta acetic acid (DTPA) extractable metals increased with increase in FA amendments up to 25%. However, Cr was found below detection limit in both the amendments. The metal accumulation in the plant tissues was found in the order of Fe> Zn>Mn>Co> Ni>Pb >Cu >Cd at 25% FA. Accumulation of Fe, Mn, Ni, Cu and Co was found more in the roots while Zn, Pb and Cd were more in the aerial parts.

CHAPTER-III

MATERIALS AND METHODS

The present investigation entitled **"Study of fly ash incorporation on yield and partitioning of heavy metals in rice"** was carried out during *kharif* season of 2016 and 2017. The materials used for the experiment and methods employed for the analysis of soil and crop samples have been briefly described in the following sub sections.

3.1 Geographical situation

Geographically, Janjgir-Champa is situated in North Mahanadi delta at centre of Chhattisgarh state and lies between 21.06 to 22.04^0 North latitude and 82.03 to 83.02^0 East longitudes with an altitude of 294.4 meters above the mean sea level.

3.2 Experimental site

The field experiment was laid out in a clay loam soil with randomized block design at the Research Farm of Krishi Vigyan Kendra, Janjgir – Champa. The site selected for experiment had assured irrigation and drainage facilities.

3.3 Climate and weather

The region comes under sub-humid climate and the general climate of this region is dry moist, sub humid and the region receives 1200-1400 mm rainfall annually, out of which about 88 per cent is received during rainy season (June to September) and 8 per cent during winter season (October to February). May is the hottest and December is the coolest month of the year. The rainfall pattern has great variations during rainy season from year to year. Average maximum, minimum temperature and rainfall (mm) was 32.18, 20.23^{o}C and 31.75 during *kharif* season of 2016. Average maximum, minimum temperature and rainfall (mm) was 33.39, 23.94^{o}C and 37.13 during *kharif* season of 2017. The meteorological data of rainfall, temperature, relative humidity, vapor pressure, evaporation and sunshine from July to November in 2016 and 2017 are furnished in Appendix-A and B and depicted in Fig. 3.1 and 3.2.

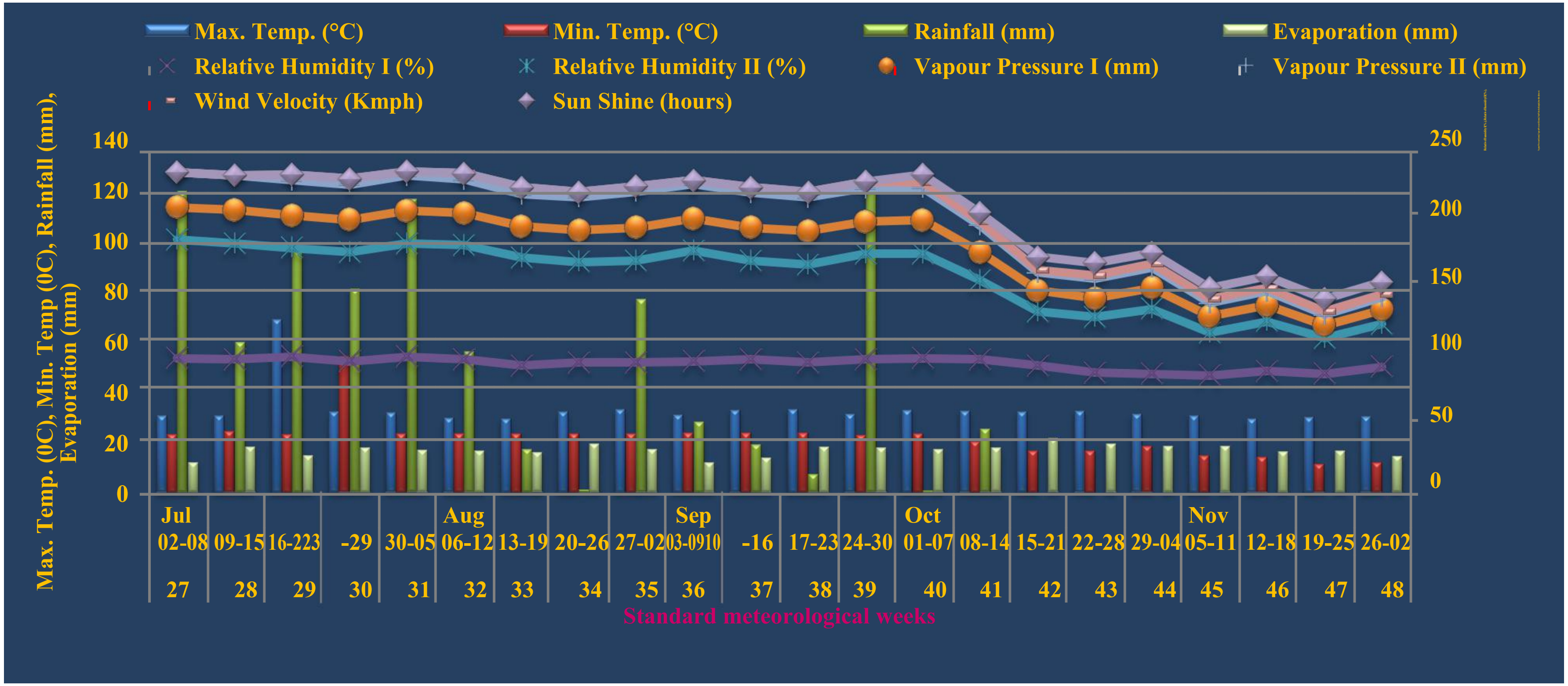


Fig. 3.1 Meteorological data during the crop growth period (weekly) of 2016

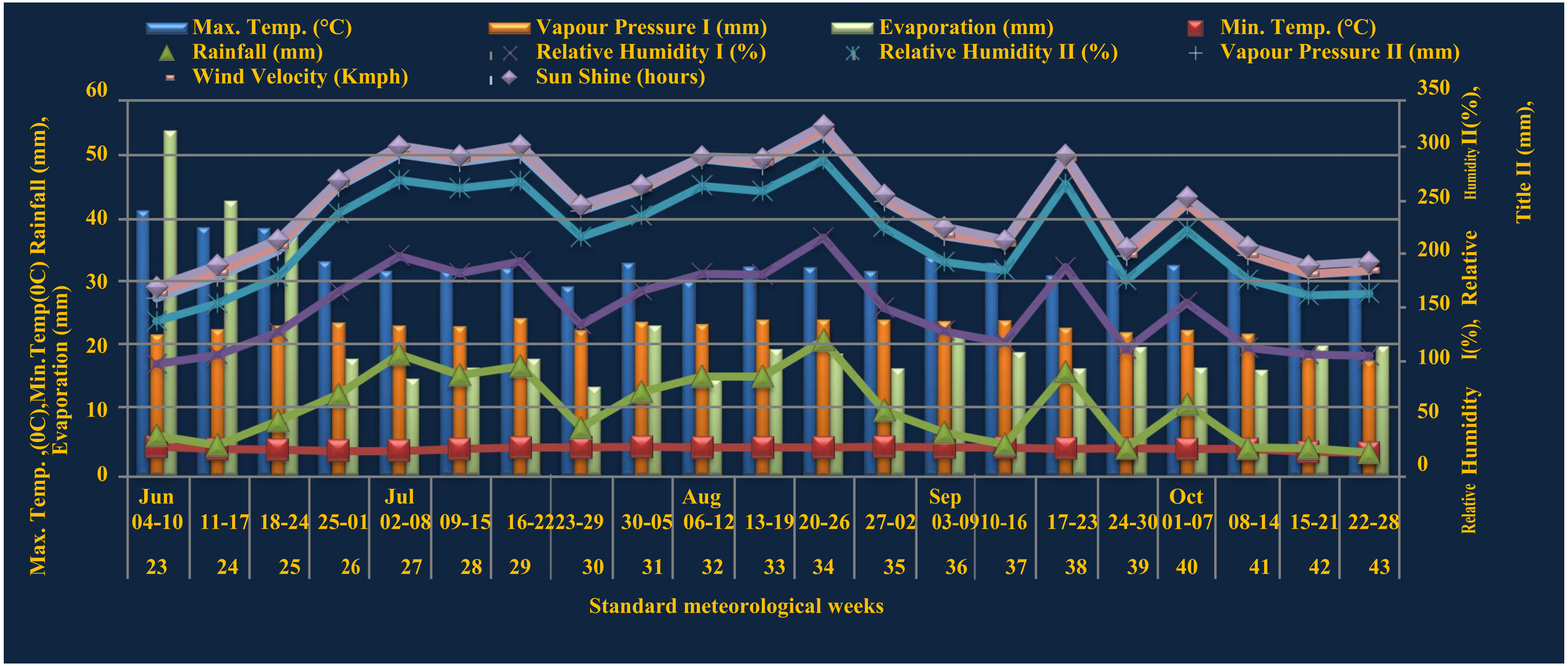


Fig. 3.2 Meteorological data during the crop growth period (weekly) of 2017

3.4 Basic properties of experimental soil

For the assessment of various properties of the experimental soil. Soil samples were collected from surface (0-15 cm) and sub-surface (15-30 cm) depths with the help of auger and representative composite samples were prepared. The soil samples were air dried, grinded, passed through 2 mm sieve and used for various physical and chemical analysis.

The initial properties of soil are presented in table 3.2 Soil contains 30% sand, 30% silt and 40% clay and characterized clay loam in texture. The soil was neutral in reaction (pH 7.5) and low in electrical conductivity (0.13 dS m^{-1}) while soil organic carbon was in medium range. The experimental soil was low in available nitrogen and phosphorus content and high in potassium. Soil available micronutrients i.e. Fe, Mn, and Cu were 21.28, 19.42 and 1.14 mg kg^{-1}, respectively which are above the critical levels, while available Zn concentration (0.42 ppm) was below the critical limit.

Status of soil available heavy metal i.e. Cr, Pb, Ni, Co and Cd content was 1.83, 1.14, 0.98, 0.94 and 0.22 ppm, respectively. The maximum permissible limit (MPL) and safe limit (SF) of different metals in soil plant system are given in table 3.1

Table 3.1 Maximum permissible limit and safe limit of heavy metals in soil plant system

Elements	Soil			Plant		Water	
	WHO (MPL*) (mg kg^{-1})	Indian Standard (SF**) (ug g^{-1})	European Union Standards (SF**) (EU 2000) (ug g^{-1})	WHO (MPL*) (mg kg^{-1})	Indian Standard (SF**) (ug g^{-1})	WHO (MPL*) (ug ml^{-1})	Indian Standard (SF**) (ug ml^{-1})
Fe	150[b]			425[g]		2.0[g]	
Mn	80[a]			500[g]		0.4[g]	0.10 [d]
Zn	200 [a]	360-600 [d]	300 [e]	50 [g]	50 [d]	3.0[g]	5.0 [d]
Cu	30 [a]	135-270 [d]	140 [e]	40 [i]	30 [d]	2.0[g]	0.05 [d]
Cd	3 [a]	3-6 [d]	3.0 [e]	5-10 [g]	1.5 [d]	0.003[g]	0.01 [d]
Pb	10 [a]	300 [d]	300 [e]	5.0 [f]	2.5 [d]	0.01[g]	0.10 [d]
Ni	80 [a]	75-100[d]	75 [e]	20-30[h]	1.5 [d]	0.07[g]	-
Co	17 [a]			50 [f]		0.05-1.5[g]	
	10[c]						
Cr	65[b]		150[e]	-	20 [d]	-	0.05 [d]

*MPL (Maximum permissible limit) **SF (Safe limit)

Table 3.2 The initial soil physical and chemical properties of experimental soil

Particulars	Analysis value	Soil type
Soil texture		
Sand (%)	30	
Silt (%)	30	Clay loam
Clay (%)	40	
Soil reaction (pH)	7.5	
Electrical conductivity (dS m^{-1})	0.13	
Organic carbon (%)	0.44	
Available N (kg ha^{-1})	176.89	
Available P (kg ha^{-1})	5.56	
Available K (kg ha^{-1})	348.25	
Available Fe (mg kg^{-1})	21.28	*150 mg.kg^{-1}
Available Zn (mg kg^{-1})	0.42	*80 mg.kg^{-1}
Available Cu (mg kg^{-1})	1.19	*200 mg.kg^{-1}
Available Mn (mg kg^{-1})	19.42	*30 mg.kg^{-1}
Available Cr (mg kg^{-1})	1.83	*65 mg.kg^{-1}
Available Pb (mg kg^{-1})	1.14	*10 mg.kg^{-1}
Available Ni (mg kg^{-1})	0.98	*80 mg.kg^{-1}
Available Co (mg kg^{-1})	0.94	*17 mg.kg^{-1}
Available Cd (mg kg^{-1})	0.22	*3 mg.kg^{-1}

* MPL (Maximum permissible limit)

3.5 Physico-chemical characteristics of fly ash and FYM

The fly ash used in the experiment was collected from, Madhya Bharat Paper Ltd. Village – Birgahni Champa, Dist. - Janjgir Champa, Chhattisgarh. The different physical and chemical properties of fly ash and FYM applied in the experiment are given in table 3.3

Table 3.3 Physical and chemical properties of fly ash and FYM

Particulars		Fly ash	FYM
Particle size distribution	(0.02- 2 mm)	50	
	(0.002-0.02mm)	33	
	(< 0.002 mm)	17	
Soil reaction (pH)		7.90	-
Electrical conductivity (dS m^{-1})		0.21	-
Organic carbon (%)		0.23	1.62
Total N (%)		0.071	0.46
Total P (%)		0.049	0.21
Total K (%)		0.31	0.59
Total Fe (mg kg^{-1})		4132.00	325.75
Total Mn (mg kg^{-1})		125.00	52.52
Total Zn (mg kg^{-1})		70.00	18.32
Total Cu (mg kg^{-1})		24.00	12.00
Total Cr (mg kg^{-1})		41.50	14.85
Total Co (mg kg^{-1})		29.20	17.32
Total Ni (mg kg^{-1})		31.80	13.00
Total Pb (mg kg^{-1})		16.52	10.21
Total Cd (mg kg^{-1})		13.50	1.60

3.6 Experimental details and lay out plan

Location : Krishi Vigyan Kendra, Research Farm, Janjgir – Champa (C.G.).

Season : *Kharif*, 2016 and 2017

Soil : Vertisols

Crop & variety : Paddy & Rajeshwari (IGKV R-1)

Establishment method : Transplanting

Net Plot Size : 24 m_2 (8m x 3m)

Row spacing : 20 cm

Plant spacing : 10 cm

Experimental Design : Randomized Block Design

Treatment : Eight

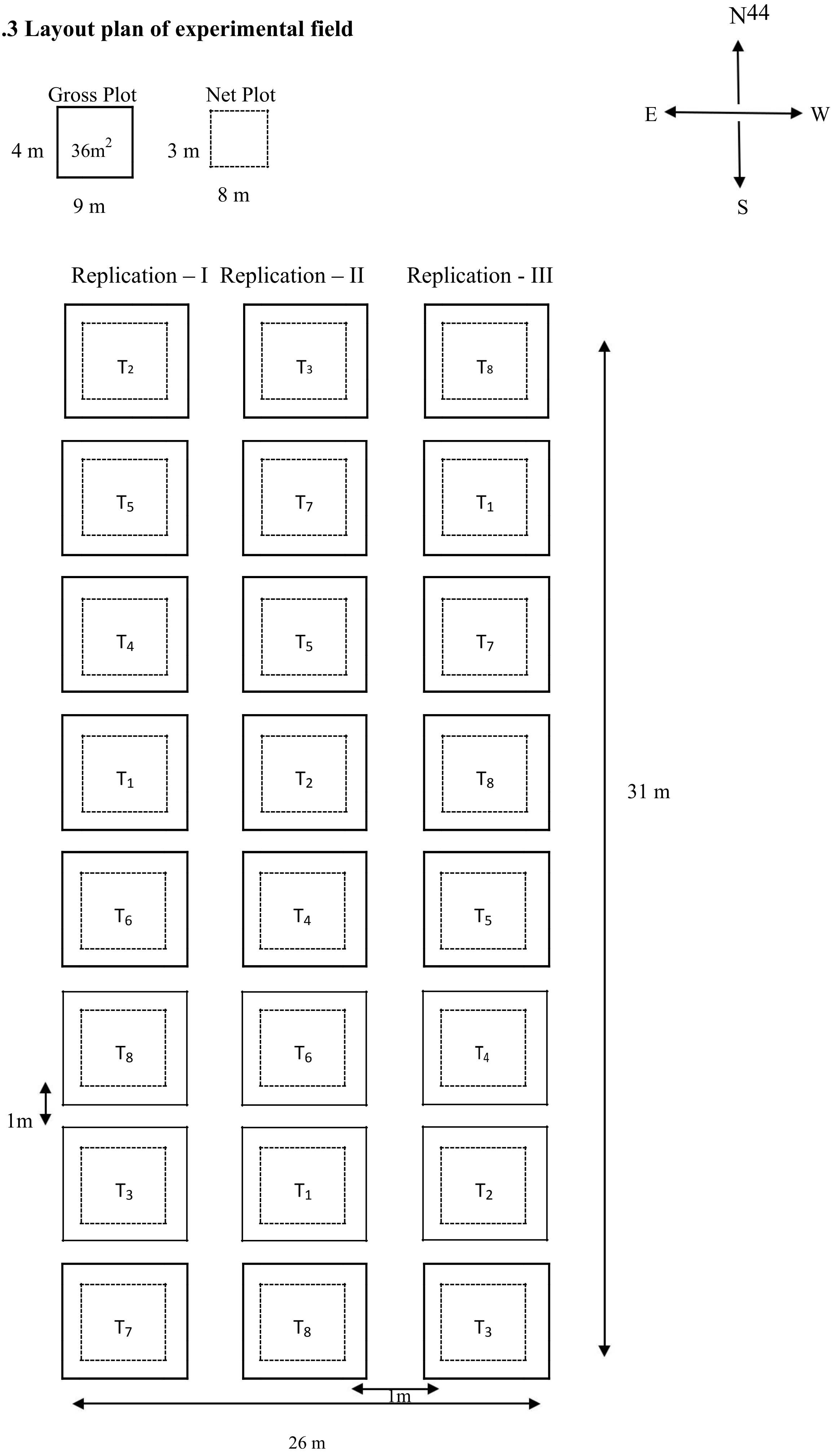
Replications : Three

The details of the treatments imposed in experiment are given in table 3.4

Table 3.4 Treatment details

S.N.	Treatments	Short Name
1	Control	T_1
2	GRD (100:60:40)	T_2
3	75% GRD + 20 t ha^{-1} fly ash	T_3
4	75% GRD + 40 t ha^{-1} fly ash	T_4
5	75% GRD + 60 t ha^{-1} fly ash	T_5
6	75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1}FYM	T_6
7	75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	T_7
8	75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1} FYM	T_8

Fig: 3.3 Layout plan of experimental field



3.7 Field preparation

The field was prepared by ploughing and cross ploughing with the cultivator. The field was puddled by tractor drawn puddler in presence of standing water and was levelled to obtain good tilth for better germination and growth. The layout plan of the treatments in given figure 3.3

3.8 Test crop

The paddy cv. Rajeshwari also known as IGKV R 1 was taken for the experiment. This variety matures in 120 days with high yield potential and exhibit resistance to gall midge biotypes 1 and 6 and leaf blast. It is recommended for irrigated and rainfed ecology of Chhattisgarh, Madhya Pradesh and Orissa. Its average yield is 5 to 5.5 t ha^{-1}.

3.9 Transplanting

Seedlings were carefully uprooted from the nursery at 21 days of nursery establishment and transplanted at a spacing of 20 x 10 cm.

3.10 Nutrients management practices

Nutrients management practices (Chemical fertilizers, fly ash and farm yard manure) were applied as per the treatments given in table 3.4. Nutrients were applied through urea, DAP, muriate of potash and FYM. The whole amount of P and K was applied as basal dressing, while nitrogen was applied in three equal splits as basal and remaining in two equal splits at active tillering and panicle initiation stage as per the treatment dose. The required quantity of basal doses of FYM, fly ash and chemical fertilizers were broadcasted in the field before transplanting.

3.11 Harvesting

When the central grain in the head was fully matured, the heads of rice were harvested manually from the net plot and border area separately .The stalk was harvested with the help of sickle at 3-4 cm from ground surface. Crop was threshed and winnowed manually after sun drying and yield per plot was recorded.

3.12 Observations

3.12.1 Total tillers

The total numbers of tillers were counted from five marked hills from each plot and its average value was presented.

3.12.2 Effective tillers

Effective tillers were counted from five marked hills from each plot and its average value was presented.

3.12.3 Test weight (1000-grain weight)

Dry clean grain samples were taken randomly from each plot separately and thousand seeds were counted from each plot and then weight was recorded on electronic balance.

3.12.4 Panicle length

The length of panicle was measured from five marked hills from each treatment. It was measured from the neck-node to the tip of the apical grains. After this, average length of panicle was determined.

3.12.5 Number of filled grains per panicle

It was counted from marked five hills of middle row of each plot and also chaffy grains per panicle were counted. After this, average no. of filled grain was calculated.

3.12.6 Grain yield

Grain yield of the net plot was recorded after threshing, winnowing and drying, which was then converted in q ha^{-1} by multiplying with appropriate multiplication factor.

3.12.7 Straw yield

The weight of dried straw yield of each net plot was recorded and converted into q ha^{-1} by multiplying with appropriate multiplication factor.

3.13 Soil analysis

3.13.1 Sample preparation

The soil samples were taken from 0-15 cm and 15-30 cm soil depths from each plot before applying the treatments and after crop harvest .The soil samples were air dried, grinded, sieved (2 mm sieve) and used for the following soil physical and chemical analysis.

3.13.2 Soil reaction (pH)

Soil pH was determined by glass electrode pH meter in 1:2.5 soil water suspension as described by Black (1965)

3.13.3 Electrical conductivity

Electrical conductivity was determined by taking supernatant liquid of soil water suspension prepared for pH determination by using electrical conductivity meter (Black, 1965).

3.13.4 Mechanical analysis (soil texture)

The mechanical analysis of soil was carried out by International Pipette Method as described by Piper (1966).

3.13.5 Organic carbon

Organic carbon was determined by Walkley and Black rapid titration method as described by Black (1965).

3.13.6 Available nitrogen

Available nitrogen was determined by alkaline permanganate method as described by Subbiah and Asija (1956).

3.13.7 Available phosphorus

Available phosphorus was extracted using $NaHCO_3$ (pH 8.5) by the method described by Olsen *et al.* (1954)

3.13.8 Available potassium

Available potassium was extracted by neutral normal ammonium acetate (pH-7) and determined with the help of Flame Photometer as described by Jackson (1967).

3.13.9 Available micronutrients

Micronutrients, i.e. Fe, Mn, Cu and Zn were extracted by using 0.005 M diethylene triamine penta acetic acid (DTPA), 0.01 M calcium chloride dihydrate and 0.1 M triethanol amine (TEA) buffered at pH 7.3 and the concentrations of the nutrients in the filtrate were analyzed by atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.13.10 Available heavy metals

Heavy metals, i.e. Co, Cr, Ni, Pb and Cd were extracted by using 0.005 M diethylene triamine penta acetic acid (DTPA), 0.01 M calcium chloride dihydrate and 0.1 M triethanol amine (TEA) buffered at pH 7.3.The concentrations of the nutrients in the filtrate were analyzed by atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.14 Plant chemical analysis

3.14.1 Sample preparation and digestion

Plant (Root, grain, leaf and stem), fly ash and FYM samples were dried in oven at 45^{0}C until constant dry weight obtained. The plant samples were taken used for macro, micro and heavy metal analysis. During plant sampling, it was ensured that plant samples were of the same physiological age and identical size. Paddy crop plants were collected and washed thoroughly with deionized water. Paddy plant was cut and separated into root, leaf, stem and grain subsamples. All subsamples were oven dried at $60_{\circ}^{C}$ for 24 h and were grinded and used for the analysis. Samples were first digested by different acids or acid and salt mixture and the total contents of N, P, K, Fe, Mn, Cu, Zn, Co, Cr, Ni, Pb and Cd were estimated by adopting standard procedures as per details given below.

3.14.2 Total nitrogen content

Nitrogen content analysis of grain and straw sample was done by taking 0.5 gm uniform by prepared sample in digestion tube to which 1 gm salt mixture (K_2SO_4 and $CuSO_4.5H_2O$ in the ratio of 10:1) and 10 ml. of concentrated H_2SO_4 was added. It was digested at 350 ^{o}C in digestion block till the solution becomes colourless. Then the nitrogen content in digested material was determined through distillation by automatic KEL plus system.

3.14.3 Phosphorus and Potassium

One gram of grain, root, leaf and stem samples was taken in digestion tube and 10 ml of di-acid mixture (Concentrated HNO_3 and $HClO_4$ in the ratio of 9:4) was added. The material was digested at 150 ^{0}C in KEL plus digestion block till the material became colourless. The digested material was transferred in to 100 ml volumetric flask by repeated washing with distilled water and made up the volume up to the mark. This digested material was used for the estimation of P and K content analysis as given below.

Phosphorus content

Phosphorus content was determined by Vanadomolybdo-phosphoric acid yellow colour complex method as described by Jackson (1967). An aliquot of 10 ml was taken, 10 ml of Vanado-molybdate yellow reagent was added and volume was made up to 50 ml. After half an hour color intensity was measured by Spectrophotometer at 420 nm wavelength.

Potassium content

Potassium content was determined by flame photometer as described by Chapman and Pratt (1961). An aliquot of 5 ml was taken and volume of made up to 25 ml in volumetric flask and potassium content was determined by flame photometer.

3.14.4 Total micronutrients

One gram of oven dried plant sample (root, stem, leaf and grain) and fly ash was digested with 10 ml of acid mixture (HNO_3 and $HCLO_4$ in 9:4 ratio) and final volume was made to 100 ml with deionized water. Total concentration of zinc, copper, iron and manganese were analyzed by atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.14.5 Total heavy metals

One gram oven dried plant sample (root, stem, leaf and grain) and fly ash was digested with 10 ml of acid mixture (HNO_3 and $HCLO_4$ in 9:4 ratio) and final volume was made to 100 ml with deionized water. From the aliquots, after suitable dilution, samples were analyzed by Atomic Absorption Spectrophotometer using respective hollow cathode lamps at desired wave lengths.

3.15 Statistical analysis

ANOVA TABLE

Source of variation	D.F.	S.S.	M.S.S.	Fcal	F tab%
Replication	(r-1)	RSS	RMS	RMS/EMS	
Treatment	(t-1)	TrSS	TMS	TMS/EMS	
Error	(r-1)(t-1)	ErSS	EMS		
Total	rt-1	TSS			

Data obtained from all observation were statistically analyzed by applying Randomized block design (RBD). Least significant difference (LSD) value were obtained to test the significance of treatment difference and least significant difference values were evaluated at 5% level of significance (Gomez & Gomez, 1984).

To test the significance of treatment differences, calculated value of 'F' was compared with tabular value of 'F' at 5 and 1 per cent levels of significance, against error degree of freedom, i.e. (r-1) (t-1).

In order to compare the mean value of treatments, standard error and critical values were calculated as follows:

(a) Standard error of mean S.Em± = √

(b) Critical difference (C.D.) = SE (d) x t value at 5% error degree of freedom

(c) Coefficient of variation (C.V. %) = x 100

Where,

D.F.	=	Degree of freedom
S.S.	=	Sum of square
M.S.S.	=	Mean sum of square
R	=	Replication
Gm	=	General mean
EMS	=	Error mean square

CHAPTER-IV

RESULTS AND DISCUSSION

A field experiment was conducted to study the integrated effects of FYM, fly ash (FA), a by-product collected from Madhya Bharat Paper Ltd. Village – Birgahni Champa, Dist. - Janjgir Champa, Chhattisgarh on soil fertility, toxic metal accumulation and rice productivity. The field experiment was conducted at the Krishi Vigyan Kendra Research Farm, Janjgir – Champa (C.G.) during *kharif* seasons of 2016 and 2017.

The experimental soil was clay loam in texture having 30% sand, 30% silt and 40% clay. The soil was neutral in reaction (pH 7.5) and normal in EC (0.13 dSm^{-1}). The experimental soil was low in available nitrogen and phosphorus and high in potassium. Soil available micronutrients Fe, Mn, and Cu were 21.28, 19.42 and 1.14 mg kg^{-1}, respectively, which were designated above the critical levels, while available Zn concentration in soil was below the critical value (0.42 ppm). The available heavy metals i.e. Cr, Pb, Ni Co and Cd content in soil was 1.83, 1.14, 0.98, 0.94 and 0.22 ppm, respectively, which was below the maximum permissible limit (MPL).

The influence of various combinations of fly ash applied on rice productivity, partitioning of heavy metals and changes in soil nutrient availability was studied for two years. The results obtained are presented through appropriate table and graphs are briefly discussed with reference to earlier work done under the following heads.

4.1 Physical and chemical properties of fly ash and FYM

4.2 Yield attributing character and yield of rice crop

4.3 Soil reaction, electrical conductivity and organic carbon of soil

4.4 Available major nutrients of soil

4.5 Available micronutrients of soil

4.6 Available heavy metals of soil

4.7 Partitioning of major nutrients in different rice plant parts

4.8 Partitioning of micro nutrients in different rice plant parts

4.9 Partitioning of heavy metals in different rice plant parts

4.1 Physico-chemical properties of fly ash and FYM

Physical and chemical properties of fly ash collected from Madhya Bharat Paper Ltd. Village – Birgahni Champa, Dist. - Janjgir Champa, Chhattisgarh are presented in table 3.3.

The mineralogical, chemical and physical properties of fly ash varied with the nature of parent material, condition of combustion, type of emission control device and storage and handling methods and therefore ash produced by burning has different characteristics (Kishore *et al*., 2009).

Thus use of fly ash should be site specific, depending on soil characteristics, agro ecology, type of crop etc**.** for sustainable agriculture production system.

4.1.1 Physical properties of fly ash

4.1.1.1 Particle size distribution and Texture

Fly ash used in experiment was found to be dominated by particle size equal to sand (0.02-2.0 mm) followed by silt (0.002-0.02mm) and clay (<0.002 mm) fractions, their respective contents being 50, 33 and 17 per cent (Table 3.3). The texture of fly ash was loamy sand and such type of texture materials application require less energy for tillage operations and facilitate good drainage and aeration if applied in heavy or degraded soils. The study carried out by Wigley and Williamson (1998) indicated 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.

Jala and Goyal (2010) reported bulk density of soil increases with increasing fly ash addition and leads to improve soil, workability of the soil, root penetration and increased moister retention capacity of the soil. This ultimately results in better availability of plant nutrient and enhances plant root proliferation in the soil.

Chandraka *et al*. (2015) reported that particle size distribution of fly ash i.e. sand (0.02- 2 mm), silt (0.002-0.02mm) and clay (<0.002 mm) percentage is 41.2, 49.6 and 9.2 and pH, EC (d Sm^{-1}) and organic carbon (g kg^{-1}) are 6.76, 0.16 and 1.55. Similar results were also recorded by Karmakar *et al*. (2010) and Kishor *et al*. (2009).

The texture class of fly ash under loam sandy was observed due to the dominance of the sand and silt sized fraction. The sandy loam type of texture of fly ash was also reported by Rai *et al*. (2011).

4.1.2 Chemical properties of fly ash and FYM

The pH, EC, organic carbon, total major, micro and heavy metal content in fly ash and FYM are given in table 3.3

4.1.2.1 pH, EC and organic carbon

Fly ash was mildly alkaline in reaction (pH 7.9), medium in soluble salt content (EC 0.21 dS m^{-1}) and very low in organic carbon content (0.23 %) (Table 3.5). The pH, EC and organic carbon value of fly ash reported in the literature varied from 5 to 9.5, 0.18 to 5.2 dS m^{-1} and 0.009- 0.36%, respectively. This variation is due to the difference in parent material of the various works as reported by Wearing *et al.* (2002) and Kumar *et al*. (2005)

4.1.2.2 Major Nutrients (N, P, K)

The total nitrogen, phosphorus, potassium content in fly ash and FYM was 0.071, 0.052, 0.39% and 0.86, 0.21, 0.59%, respectively (Table 3.3). The lower concentration of total organic carbon (TOC) and N in FA may be due to the oxidation of C and N during coal combustion which reduces their quantity in ash. The fly ash can be potential supplemental source of major plant nutrients for agriculture and related applications but also a amendment for improving the acid and degraded soils.

Malakar *et al*. (2016) also recorded that total N, P and K content in fly ash and FYM were 0.10, 0.08 and 0.02 % and 0.56, 0.37 and 0.67% respectively and was alkaline in nature. Kumar *et al*. (2000) reported that fly ash consists of all elements present in soil except organic carbon and nitrogen. However, similar findings regarding major nutrient status in fly ash was observed by Kumar *et al*. (2010) and Basu *et al*. (2009).

4.1.2.3 Micronutrients (Fe, Mn, Zn and Cu)

Total micronutrients content in fly ash was in order of Fe> Mn> Zn> Cu and was 4132, 125, 70 and 24 mg kg^{-1}, respectively. The total Fe, Mn, Zn and Cu content in FYM was 325.75, 52.52, 18.32 and 12.00 mg kg^{-1}, respectively (Table 3.3).

Yeledhalli *et al*. (2008) reported higher contents of Fe, Mn, Zn and Cu as 18600, 210.30, 156.2 and 72.65 mg kg^{-1} and in FYM 2800, 200, 20 and 30 mg kg^{-1}, respectively. Similar results regarding micronutrients status in fly ash were also reported by Kumar *et al.* (2005) and Sajwan *et al.* (2006).

Maiti and Prasad (2016) reported that contents of Fe, Mn, Zn and Cu are in the range of 60-68, 500-739, 52-230 and 40-80 mg kg^{-1}, respectively in fly ash and 3040,53.2, 24.7 and 44.1 mg kg^{-1}, respectively in FYM.

4.1.2.4 Heavy Metals (Ni, Co, Pb, Cr and Cd)

Table 3.3 revealed that total heavy metals present in fly ash was in order of Cr> Ni> Co> Pb>Cd and the value were 41.50, 31.80, 29.20, 16.52 and 13.50 mg kg^{-1}, respectively. The total Cr, Ni, Co, Pb and Cd content in FYM was 14.85, 13.00, 17.32, 10.21 and 1.60 mg kg^{-1} respectively.

Ratanasthien *et al.* (1996) revealed that the fly ash contains several elements namely Si, Fe, Al, Ca, K, Mg and Na at concentration of 17%, 11%, 9.8%, 6.4%, 1.4%, 1.2% and 0.4% respectively and also the concentration of heavy metals such as Mn, Ni, Co, Cr and Mo were reported as 582, 53, 34, 67, and 20 mg kg^{-1}, respectively. Similar findings of heavy metals concentration were also concluded by Basu *et al.* (2009) and Jala (2005).

Maiti and Prasad (2016) reported that content of Ni, Cr, Co, Pb, Cd, As and Al were in the range of 50-204.8, 38.2-303, 21.1-58, 3-5000, 5-43, 1-4 and 4.8-312 mg kg^{-1}, respectively in fly ash.

Presence of macro and micronutrients improves the fertility of soil. It significantly supplements the utility of chemical fertilizers. In view of above results we conclude that the fly ash can be used in agriculture field as valuable secondary source of fertilizer. However, various scientists have reported large variation in concentration of metals in fly ash. Therefore its use in agriculture needs to be monitored periodically when used on long term basis.

4.2 Yield attributing character and yield of rice crop

The yield attributing characters of rice i.e. effective tillers, numbers of grain per panicle, panicle length and grain and straw yield were significantly influenced by different treatments except total tillers and seed test weight (Table 4.2.1 to 4.2.3 and Figure 4.2.1 to 4.2.2).

4.2.1 Total tillers

Application of different doses of fly ash combined with and without organic manure and fertilizer did not influence number of total tillers (Table 4.2.1 Fig.4.2.1). Application of 75% GRD + 40 t FA ha^{-1} + 5 t FYM ha^{-1} (T_7) produced higher number of tillers though the effect was non significant.

4.2.2 Effective tillers

Influence of treatments on effective tillers is presented in table 4.2.1 and fig.4.2.1. The treatments had significantly increased effective tillers as compared to control. Application of 75% GRD + 40 t FA ha^{-1} + 5 t FYM ha^{-1} (T_7) produced highest number of effective tillers and the control showed lowest. The overall mean of effective tillers was found to be 5.20 and ranged from 3.83 to 6.0. The treatments were in the order of $T_7 \sim T_6 \sim T_5 \sim T_4 > T_8 > T_3 > T_2 > T_1$. The data indicated application of FA alone with fertilizer and manures resulted better in terms of effective tillers.

4.2.3 Panicle length

Significantly effect of different treatments on panicle length was observed (Table 4.2.2 Fig.4.2.1). The overall pooled mean of panicle length was 21.36 cm which ranged from 18.00 to 24.08 cm. The treatments 75% GRD + 20 t ha^{-1}fly ash + 5 t ha^{-1}, 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} and 75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1} FYM significantly improved over GRD (100:60:40). However, highest panicle length was observed in 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1}. Application of fly ash beyond 40 t ha^{-1} did not show any significant increase in panicle length. Rather, a significant decrease was observed in T_8 as compared to T_7.

4.2.4 Numbers of grains per panicle

The data on number of grains per panicle in table 4.2.2 fig.4.2.1 showed that all the treatments had significantly higher number of grains per panicle as compared to control. However, application of 75% GRD + 40 t FA ha^{-1} + 5 t FYM ha^{-1} (T_7) produced highest numbers of grains per panicle. The overall mean of number of grains per panicle was found 77.77 and ranged from 48.82 to 88.50. Fly ash applied @ 20, 40 and 60 t ha^{-1} with and without FYM significantly increased number of grains per panicle as compare to 100% recommended dose of NPK.

4.2.5 Test weight

Test weight was not significantly influenced by application of different doses of fly ash with and without FYM and fertilizers as presented in table 4.2.2 and fig.4.2.1. The polled mean of test weight was found 26.36 g and ranges from 25.08 to 26.83 g.

The increase in yield attributes may be due to combined application of fly ash and chemical fertilizer with FYM helped in promoting tiller numbers and dry matters when fly ash conjunction with FYM and chemical fertilizer helped in nutrient supplying capacity of soil and significant positive correlation between growth parameters and nutrient uptake.

Field and greenhouse studies conducted by Singh *et al.* (1997) concluded that many chemical constituents presence in fly ash benefit plant growth and can improve the properties of the soils. Application of fly ash (5–10%) at lower doses in soils enhances seed germination as well as seedling growth, although higher application (20–30%) either delays or drastically inhibits plant growth, development and other specific parameters. Significant increase in growth and seedling vigour (including plant pigment and dry matter accumulation) at lower fly ash levels 15 % could be due to nutrient readily available on fly ash nutrients

Table 4.2.1 Effect of fly ash doses applied with and without FYM on total tillers and effective tillers of paddy at harvest

Treatment	Total tiller/hill			Effective tiller/hill		
	2016	**2017**	**Pooled**	**2016**	**2017**	**Pooled**
T_1-Control	6.00	5.00	5.50	4.00	3.67	3.83
T_2- GRD (100:60:40)	5.67	5.33	5.50	5.00	4.67	4.83
T_3- 75% GRD + 20 t ha^{-1} fly ash	5.33	6.00	5.67	4.67	5.33	5.00
T_4- 75% GRD + 40 t ha^{-1} fly ash	6.00	5.67	5.83	5.67	5.67	5.67
T_5- 75% GRD + 60 t ha^{-1} fly ash	5.67	6.00	5.83	5.00	6.00	5.50
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	6.33	6.67	6.50	5.67	5.67	5.67
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	6.67	7.00	6.83	6.00	6.00	6.00
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	6.00	5.67	5.83	5.33	5.00	5.17
SEm±	**0.46**	**0.54**	**0.34**	**0.22**	**0.42**	**0.25**
CD (P=0.05)	**NS**	**NS**	**NS**	**0.67**	**1.37**	**0.76**

Table 4.2.2 Effect of fly ash doses applied with and without FYM on panicle length, number of grains per panicle and test weight of paddy at harvest

Treatment	Panicle length (c.m.) per panicle			Number of grains per panicle			Test weight (g.)		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	19.33	16.67	18.00	50.33	47.33	48.83	26.00	26.17	25.08
T_2- GRD (100:60:40)	20.00	19.83	19.92	73.67	71.67	72.67	26.00	27.33	26.67
T_3- 75% GRD + 20 t ha^{-1} fly ash	21.33	22.33	21.83	77.67	78.00	77.83	26.33	26.00	25.67
T_4- 75% GRD + 40 t ha^{-1} fly ash	22.00	22.67	22.33	84.33	86.67	85.50	26.67	26.33	26.83
T_5- 75% GRD + 60 t ha^{-1} fly ash	21.00	21.83	21.42	80.00	79.33	79.67	26.67	27.00	27.50
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	22.33	21.67	22.00	83.33	83.67	83.50	27.33	25.67	25.67
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	23.00	25.17	24.08	87.00	90.00	88.50	27.00	27.33	27.17
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	21.33	22.50	21.92	85.00	86.33	85.67	26.33	26.67	26.33
SEm±	**0.92**	**1.40**	**0.64**	**1.89**	**2.54**	**1.54**	**0.56**	**1.50**	**0.52**
CD (P=0.05)	**NS**	**4.27**	**1.95**	**5.74**	**7.71**	**4.67**	**NS**	**NS**	**NS**

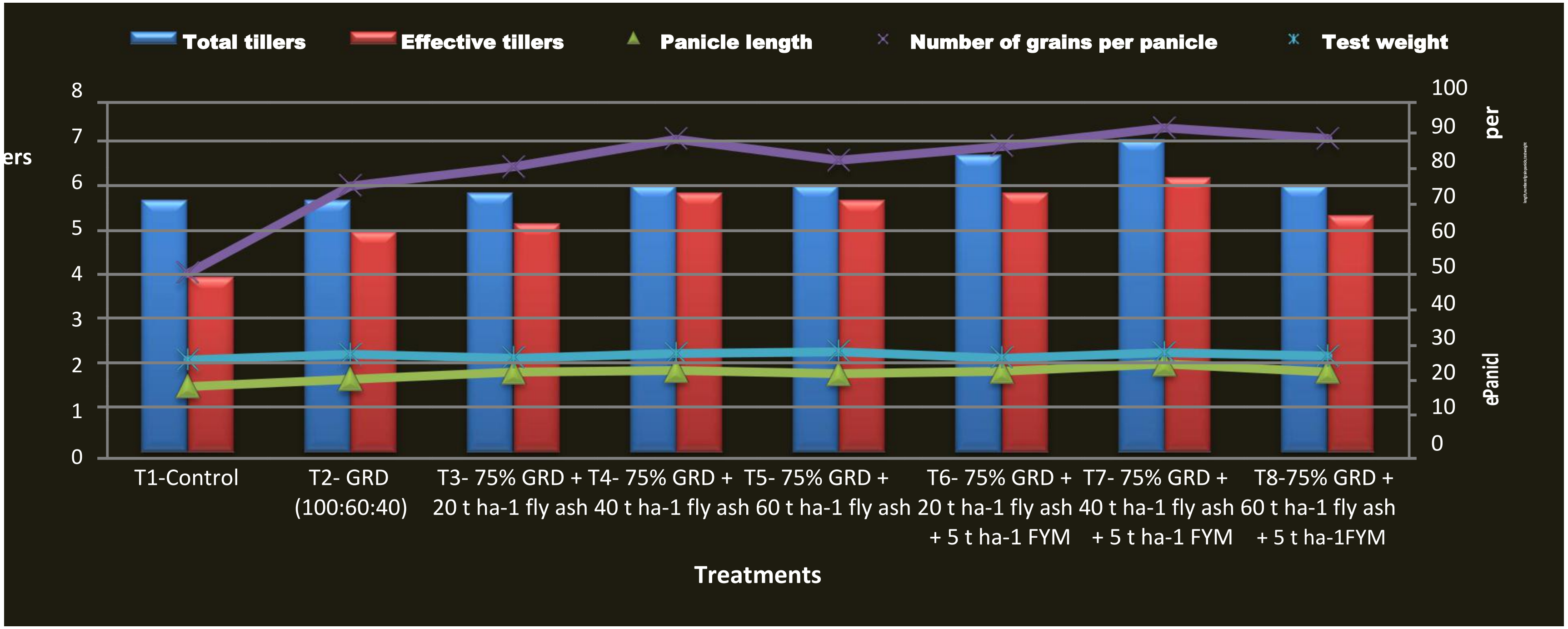


Fig.4.2.1 Effect of fly ash doses applied with and without FYM on total tillers, effective tillers, panicle length, and number of grains per panicle and test weight of paddy at harvest

but at higher fly ash application levels, the same parameters decline due to absorption of toxic elements as reported earlier in similar crops (Modgal and Singh 1990).

Increase in yield attributes by the application of fly ash with FYM might be due to improvement in physical and chemical properties that enhanced availability of various nutrients required for plant growth. Complementary effect of higher root growth and nutrient availability to plants might have resulted in higher number of grains per panicle. Thus synergistic effect from integration of fly ash with FYM and chemical fertilizer in terms of nutrient supply system might have resulted in better nutrient uptake which produced more numbers of yield attributes.

Significantly higher numbers of total tillers, effective tillers and higher number of grains per panicle was also reported by Yavarzadeh and Shamsadini (2012), Karmarkar *et al.* (2009), Khan and Qasim (2008), Sahu *et al.* (2007) and Totawat *et al.* (2002)**.**

4.2.6 Grain and straw yield

Influence of various doses of fly ash combined with and without FYM on grain and straw yields presented in table 4.2.3 and fig.4.2.2. The different doses of fly ash applied with and without FYM and fertilizer produced significantly higher grain yield as compared to GRD (100:60:40). However the highest (51.50 q ha^{-1}) yield was recorded with 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM and control showed the lowest (19.08 q ha^{-1}). The increase in the grain yield by application of 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM was 28.50 % when compared over GRD (100:60:40). The difference in grain yield among the various fly ash doses with and without FYM was non significant.

Influence of various doses of fly ash with and without FYM and fertilizer significantly increased straw yield (Table 4.2.1 and Fig.4.2.2). Application of 75% GRD + 40 t FA ha^{-1} + 5 t FYM ha^{-1} (T_7) produced the highest (79.33 q ha^{-1}) straw yield and control showed the lowest (32.58 q ha^{-1}). Fly ash applied @ 40 t ha^{-1} with FYM and 75% GRD significantly increased straw yield as compare to GRD (100:60:40) while, without FYM the effect was non significant.

Table 4.2.3 Effect of fly ash doses applied with and without FYM on grain and straw yield of paddy at harvest

Treatment	Grain Yield q ha^{-1}			Straw Yield q ha^{-1}		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	19.83	18.33	19.08	32.17	33.00	32.58
T_2- GRD (100:60:40)	39.50	40.62	40.08	65.00	66.33	65.67
T_3- 75% GRD + 20 t ha^{-1} fly ash	44.00	43.50	43.75	67.37	65.67	66.52
T_4- 75% GRD + 40 t ha^{-1} fly ash	47.17	48.00	47.58	71.50	70.00	70.75
T_5- 75% GRD + 60 t ha^{-1} fly ash	41.33	41.67	41.50	63.67	62.67	63.17
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	48.17	49.67	48.92	74.00	73.00	73.50
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	50.67	52.33	51.50	78.67	80.00	79.33
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	45.00	46.33	45.67	69.00	69.67	69.33
SEm±	**2.44**	**1.90**	**1.20**	**4.96**	**2.17**	**2.67**
CD (P=0.05)	**7.42**	**5.77**	**3.68**	**15.05**	**6.61**	**8.11**

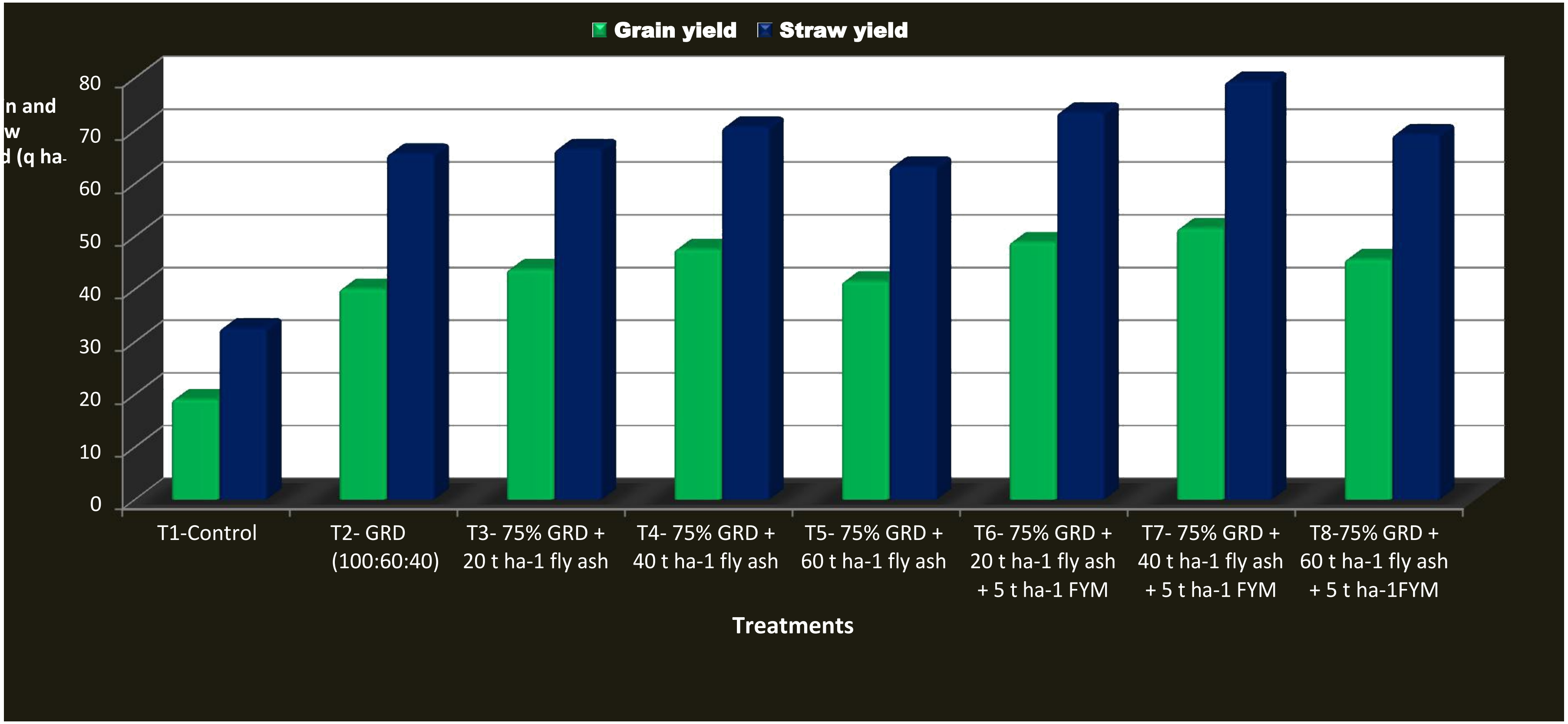


Fig.4.2.2 Effect of fly ash doses applied with and without FYM on grain and straw yield of paddy at harvest

The increase in straw yield by application of 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM was 19.0% when compared over GRD (100:60:40).

The results indicated that FA application along with 75% recommended dose of NPK and FYM had positive effects on yield and yield components which might be due to improvement in physical properties of soil accompanied with balanced availability of applied nutrients.

The increase in grain and straw yield might be due to the presence of many chemical constituents of fly ash which has a beneficial effect on soil properties. Rautaray *et al.* (2003) concluded that the dry matter production of rice is an important character which indicating the extent of accumulation of photosynthates and an indirect indication of photosynthetic activity.

Yeledhalli *et al.* (2008) reported that fly ash brings about improvement in various soil physical and chemical properties such as bulk density, porosity, water holding capacity and hydraulic conductivity. Application of fly ash /pond ash altered the textural class of the soil towards increasing sand and silt content, consequently the soil porosity and WHC increased significantly, improving the root and shoot development of crops and yield.

The increase in yield might be attributed due to increasing the water holding capacity of the soil. The increased water holding capacity supports the crop growth even under moisture stress conditions. Further availability of major and micro nutrients in the soil increased their uptake by the crop hence higher dry matter production. The above results are in conformity with those reported by several workers viz. Das *et al*. (2013), Dange and Nalge (2010) , Yeledhalli *et al*. (2008) and Lal *et al*. (1996) who observed superior growth and yield of crop due to application of fly ash.

Integration of fly ash with inorganic fertilizer and FYM producing considerably higher grain and straw yield was reported by Reddy *et al*. (2010) and Yelendhalli *et al*. (2008).

Selvakumari *et al*. (2000) also reported higher yield in rice when fly ash was applied in combination with compost, fertilizer and Azospirillum. Thus might due to the higher supply of nutrients, conducive physical environment leading to better aeration, increase in soil moisture holding capacity, root activity and nutrient absorption.

The increase in yield of maize from 36-40%, red gram from 55-58%, mustard from 28-32% and potato from 25-37% over control due to application of fly ash @ 50 t ha^{-1} was also reported by Arivazhagan *et al*. (2011) and Kumar *et al*. (2005).

4.3 Soil reaction, electrical conductivity and organic carbon content of soil

Influence of different doses of fly ash with and without FYM and fertilizer on pH, EC and organic carbon in 0-15 cm and 15-30 cm soil depths is presented in table 4.3.1 to 4.3.3 and fig. 4.3.1 to 4.3.3

4.3.1 Soil reaction (pH)

The treatment did not show any significant influence on soil pH at different depths (Table 4.3.1 & Fig 4.3.1). It was due to the fact that pH of experimental soil and fly ash used was almost similar. Moreover, the clay soils have inherent buffering power which could also resist changes in pH due to application of amendments. The Khan and Qasim (2008) and Yadav (2006) also observed non significant effect of fly ash on soil reaction.

Fly ash application can change soil pH either increase or decrease depending on fly ash pH. Acidic nature of fly ash decreased soil pH while alkaline fly ash can raise pH of acidic soils (Pathan *et al*., 2003 and Skousen *et al*., 2013).

However, Tripathy *et al*. (2005) reported that fly ash application was found to enhance the soil pH of acid soil which could be due to high content of CaO and MgO. Khan and Khan (1996) also found increase in soil pH of acid soil which might be due to the neutralization of H^+ by alkali salts and also due to solubilisation of basic metallic oxides of fly ash in soil.

4.3.2 Electrical conductivity

The results of electrical conductivity measured at harvest in 0-15 cm and 15-30 cm soil depths are presented 4.3.2 and fig 4.3.2. The addition of different dose of fly ash with different combination of organic and inorganic fertilizer did not influence soil electrical conductivity. One possible reason for this may be that salts might have move down at lower depth with water and resulting in no significant influence on electrical conductivity of the soil. These observation corroborate with the earlier work reported by James *et al.* (2014). In both 0-15 cm and 15-30 cm soil depth marginal increase compare than initial value (0.13 dS m^{-1}).

Increased levels of fly ash added to soil increased the soil electrical conductivity due to soluble major and minor inorganic constituents and the binding of metal ions occurred readily to soil.

Khan and Qasim (2008), Sikka and Kansal (1995) and El-Mogazi *et al.* (1988) also reported that effect of fly ash application on soil electrical conductivity was non significant.

4.3.3 Organic carbon

Results on organic carbon content is presented in table 4.3.3 and fig 4.3.3 the data showed significant influence of application of different combinations of fly ash treatments. All the treatments of fly ash showed higher organic carbon content in surface (0-15 cm) and subsurface (15-30 cm) soil. The increase in the treatments was higher in surface than subsurface soil depth. Fly ash applied @ 40 t ha^{-1} combined with 5 t ha^{-1} FYM and 75% (GRD) recorded the highest organic carbon content in 0-15 and 15-30 cm soil depths (0.65% and 0.42%) and control showed the lowest.

In surface soil fly ash applied @ 20, 40 and 60 t ha^{-1} with chemical fertilizer and FYM significantly increased the organic carbon content. The treatments of 20 and 60 t ha^{-1} of fly ash with 75% chemical fertilizer were statistically at par as compared to GRD (100:60:40), as revealed from the year wise data in both soil depts.. .

Table 4.3.1 Effect of fly ash doses applied with and without FYM on soil pH of different depth at harvest

Treatment	pH (1:2.5)					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	7.69	7.56	7.63	7.91	7.46	7.69
T_2- GRD (100:60:40)	7.77	7.66	7.72	7.97	7.52	7.75
T_3- 75% GRD + 20 t ha^{-1} fly ash	7.93	7.78	7.86	8.05	7.57	7.81
T_4- 75% GRD + 40 t ha^{-1} fly ash	7.79	7.75	7.77	7.92	7.94	7.93
T_5- 75% GRD + 60 t ha^{-1} fly ash	7.87	7.72	7.79	7.93	7.81	7.87
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	7.76	7.77	7.76	8.06	7.83	7.95
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	7.81	7.78	7.79	8.09	7.80	7.94
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	7.95	7.82	7.88	7.94	7.95	7.95
SEm±	**0.18**	**0.08**	**0.10**	**0.20**	**0.06**	**0.10**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**0.18**	**NS**
Non amended soil (Near by)		**7.29**			**7.51**	

Table 4.3.2 Effect of fly ash doses applied with and without FYM on soil EC of different depth at harvest

Treatment	EC dS m^{-1}					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	0.12	0.11	0.12	0.12	0.13	0.13
T_2- GRD (100:60:40)	0.13	0.12	0.12	0.13	0.13	0.13
T_3- 75% GRD + 20 t ha^{-1} fly ash	0.13	0.13	0.13	0.14	0.12	0.13
T_4- 75% GRD + 40 t ha^{-1} fly ash	0.14	0.12	0.13	0.13	0.14	0.14
T_5- 75% GRD + 60 t ha^{-1} fly ash	0.12	0.13	0.13	0.15	0.15	0.15
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.13	0.14	0.13	0.13	0.14	0.14
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.14	0.13	0.14	0.15	0.16	0.16
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	0.13	0.15	0.14	0.13	0.15	0.14
SEm±	**0.008**	**0.01**	**0.008**	**0.007**	**0.01**	**0.006**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Non amended soil (Near by)		**0.13**			**0.12**	

Table 4.3.3 Effect of fly ash doses applied with and without FYM on soil organic carbon of different depth at harvest

Treatment	Organic carbon (%)					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	0.41	0.43	0.42	0.28	0.25	0.27
T_2- GRD (100:60:40)	0.49	0.54	0.52	0.30	0.33	0.32
T_3- 75% GRD + 20 t ha^{-1} fly ash	0.50	0.53	0.52	0.31	0.30	0.30
T_4- 75% GRD + 40 t ha^{-1} fly ash	0.54	0.59	0.56	0.33	0.40	0.37
T_5- 75% GRD + 60 t ha^{-1} fly ash	0.51	0.49	0.50	0.32	0.36	0.34
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.57	0.58	0.57	0.32	0.35	0.33
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.61	0.68	0.65	0.39	0.45	0.42
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	0.58	0.63	0.61	0.33	0.34	0.33
SEm±	**0.01**	**0.02**	**0.01**	**0.03**	**0.01**	**0.01**
CD (P=0.05)	**0.04**	**0.06**	**0.03**	**NS**	**0.04**	**0.05**
Non amended soil (Near by)		**0.51**			**0.22**	

In sub surface soil application of fly ash @ 40 t ha^{-1} combined with and without FYM significantly increased the organic carbon content as compared to GRD (100:60:40). The OC content in fly ash treatment @ 20 and 60 t ha^{-1} integrated with and without FYM were statistically at par with 100% recommended dose of NPK.

The increase in organic carbon content with increase in fly ash dose over control. This might be due to faster oxidation (decomposition) of fly ash under the influence of chemical fertilizer and FYM which have resulted in accumulation of organic matter in contrast to the former. The results on increased soil organic carbon with fly ash application was also reported by Das *et al.* (2013), Jala (2005), Totawat *et al*. (2002), Maiti (2003) and Sarangi *et al*. (2001).

The organic carbon content varied with depth and higher organic carbon was observed in surface soils and it general decreases with the increase in depth. It is due to luxurious vegetation added more organic residues on the surface and higher root growth leading to accumulation of higher organic matter at the upper soil. The higher C/N ratios occur in the surface soil and the ratio tends to decline with depth. Wider C/N ratio indicates the slow rate of N-mineralisation. These findings are supported by Sharma *et al*. (2005) and Minhas and Bora (1982).

4.4 Available major nutrients of soil

Available major nutrients status (N, P and K) in surface (0-15) and subsurface (15-30) soil depths as influenced by different doses of fly ash combined with without FYM is given in table 4.4.1 to 4.4.3 and figure 4.4.1 to 4.4.3.

4.4.1 Soil available nitrogen

Table 4.4.1 & Fig. 4.4.1 revealed that available soil nitrogen in 0-15 cm and 15-30 cm soil depths was significantly affected by different doses of fly ash. All the treatments showed significantly higher available soil nitrogen as compared to control in surface and surface soil. Among the treatments, 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM recoded highest available soil nitrogen in 0-15 cm (228.79 kg ha^{-1}) and 15-30 cm (158.11 kg ha $^{-1}$) and control showed lowest (175.97 and 133.52 kg ha^{-1}). Fly ash applied @ 20, 40 and 60 t ha^{-1} combined with and without FYM significantly increased available N as compared to GRD in 0-15 cm soil depth.

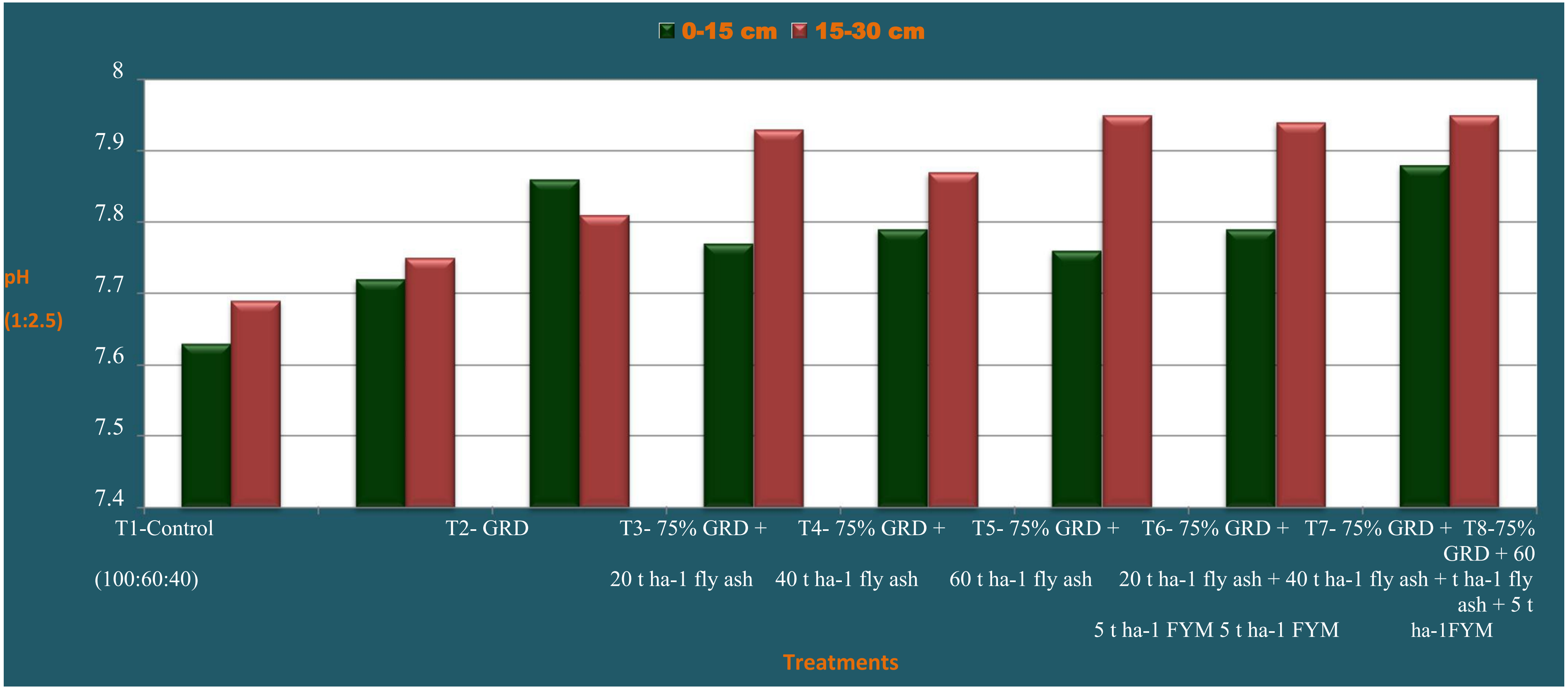


Fig.4.3.1 Effect of fly ash doses applied with and without FYM on soil pH of different depth at harvest

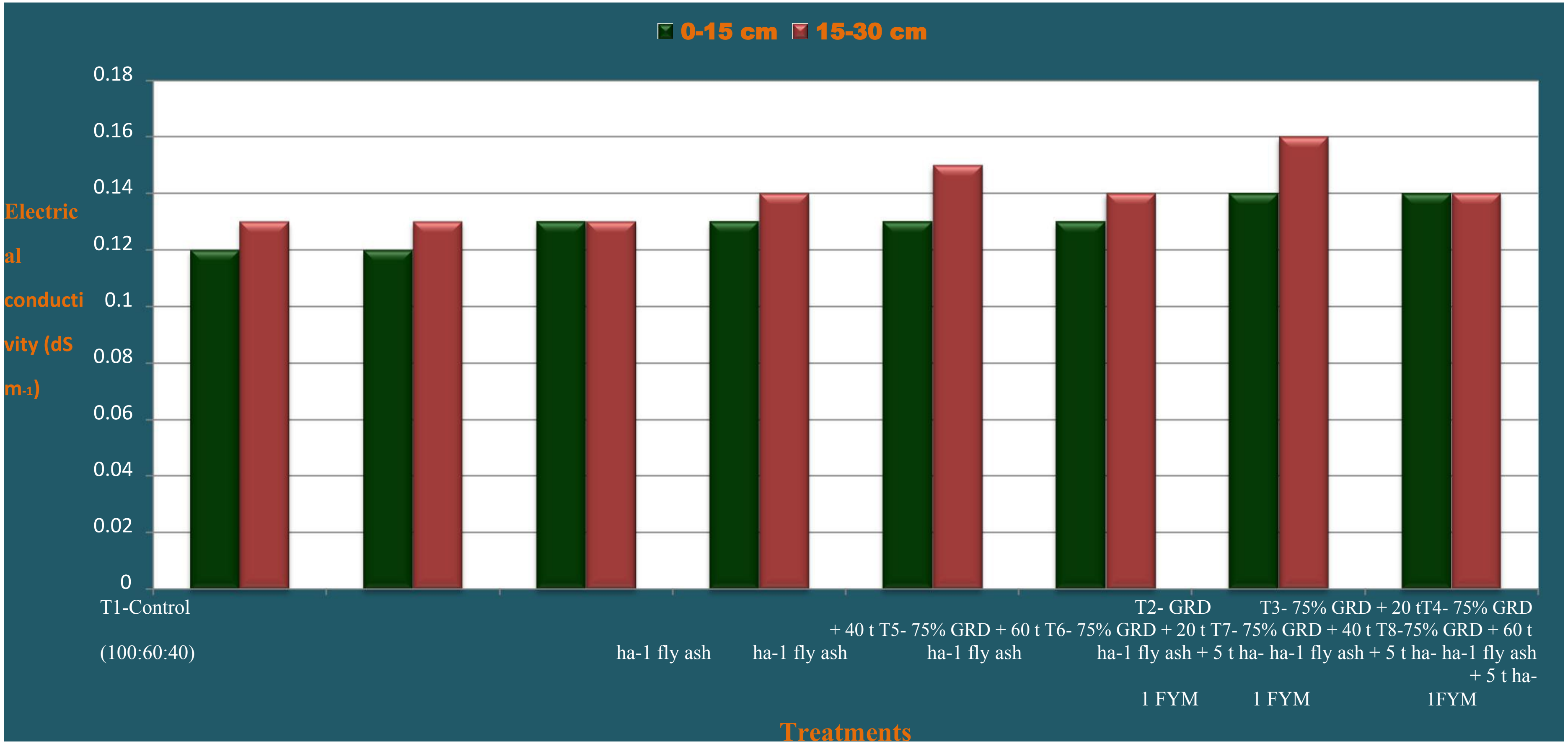


Fig.4.3.2 Effect of fly ash doses applied with and without FYM on soil EC of different depth at harvest

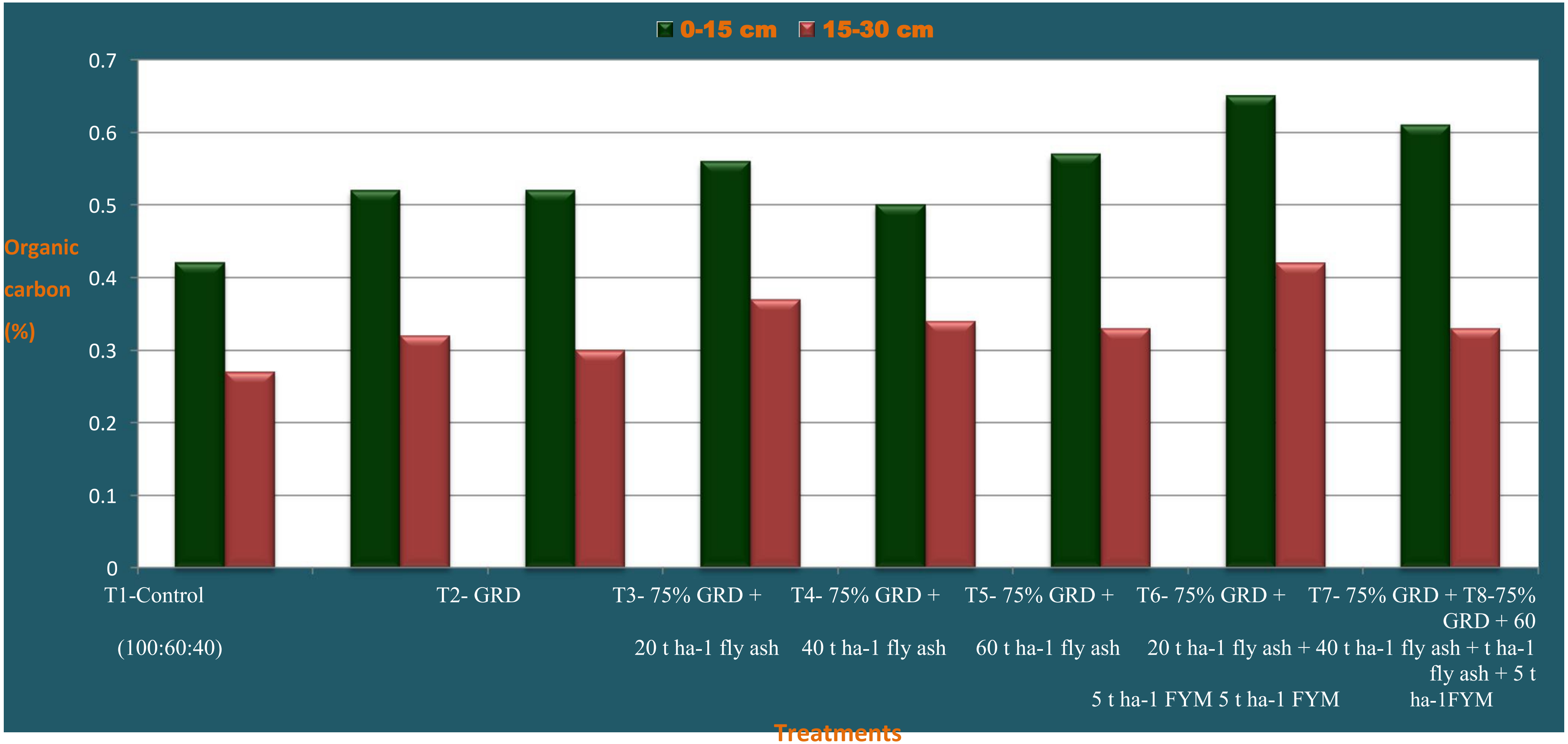


Fig.4.3.3 Effect of fly ash doses applied with and without FYM on soil organic carbon of different depth at harvest

In 15-30 cm soil depth, fly ash application at 20 and 60 t ha^{-1} with FYM significantly increased available soil nitrogen whereas, all other treatments of fly ash were statistically at par with 100% recommended dose of NPK (100:60:40).

4.4.2 Soil available phosphorus

The data pertaining to mean soil available phosphorus in 0-15 cm and 15-30 cm soil depths are presented in table 4.4.2 and fig. 4.2.2. The results showed that in surface soil (0-15 cm) it was significantly influenced by different treatments. Fly ash application @ 20, 40 and 60 t ha^{-1} combined with and without FYM significantly increased soil available phosphorus as compared to GRD. The treatment T_8 (75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1} FYM) recorded the highest (9.25 kg ha^{-1}) and control the lowest (5.70 kg ha^{-1}) soil available phosphorus.

Soil available phosphorus at subsurface soil depth (15-30 cm) was not influenced by treatments. The T_7 treatment (75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM) showed higher (5.72 kg ha^{-1}) as compared to control (3.60 kg ha^{-1}).

4.4.3 Soil available potassium

The two year pooled mean of soil available potassium in 0-15 and 15-30 cm soil depths was significantly influenced by different doses of fly ash (Table 4.4.3 and Fig. 4.4.3).

Application of fly ash @ 20, 40 and 60 t ha^{-1} in combination with or without FYM increased soil available potassium significantly over GRD and control. The T_8 treatment (75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1} FYM) recorded the highest available soil potassium (442.30 kg ha^{-1}) and control showed the lowest (355.96 kg ha^{-1}) in 0-15 cm soil depth. In the subsurface soil, all the treatments of fly ash combined with and without FYM significantly increased soil available potassium as compared to control but were similar to GRD, The treatment T_8 (75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1} FYM) recorded the highest (292.20 kg ha^{-1}) and control the lowest (241.23 kg ha^{-1}) available K.

Table 4.4.1 Effect of fly ash doses applied with and without FYM on soil available N of different depth at harvest

Treatment	Available N (Kg ha^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	178.01	173.93	175.97	132.90	134.13	133.52
T_2- GRD (100:60:40)	198.13	200.80	199.46	141.26	140.63	140.95
T_3- 75% GRD + 20 t ha^{-1} fly ash	212.62	214.17	213.39	145.44	147.73	146.59
T_4- 75% GRD + 40 t ha^{-1} fly ash	215.24	222.77	219.01	153.80	157.30	155.55
T_5- 75% GRD + 60 t ha^{-1} fly ash	211.09	210.33	210.71	145.44	147.70	146.57
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	219.00	226.03	222.52	153.80	151.63	152.72
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	225.41	232.17	228.79	156.16	160.07	158.11
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	220.77	223.77	222.27	157.98	156.73	157.36
SEm±	**1.95**	**3.28**	**1.96**	**8.49**	**2.84**	**4.94**
CD (P=0.05)	**5.92**	**9.95**	**5.95**	**NS**	**8.63**	**14.98**
Non amended soil (Near by)		**221.25**			**165.98**	

Total N (%): Fly ash -0.071 FYM- 0.86

Table 4.4.2 Effect of fly ash doses applied with and without FYM on soil available P of different depth at harvest

Treatment	Available P (Kg ha^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	5.81	5.59	5.70	3.94	3.35	3.63
T_2- GRD (100:60:40)	5.90	5.75	5.83	4.12	4.80	4.46
T_3- 75% GRD + 20 t ha^{-1} fly ash	6.64	6.03	6.33	5.09	5.19	5.14
T_4- 75% GRD + 40 t ha^{-1} fly ash	7.28	7.32	7.30	5.26	5.46	5.36
T_5- 75% GRD + 60 t ha^{-1} fly ash	6.96	7.16	7.06	5.16	5.07	5.12
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	8.09	8.28	8.18	5.39	5.40	5.39
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	8.29	9.10	8.69	5.41	6.02	5.72
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	9.27	9.23	9.25	5.25	5.38	5.32
SEm±	**0.31**	**0.08**	**0.14**	**0.63**	**0.59**	**0.45**
CD (P=0.05)	**0.94**	**0.26**	**0.42**	**NS**	**NS**	**NS**
Non amended soil (Near by)		**10.35**			**6.25**	

Total P (%): Fly ash -0.049 FYM- 0.21

Table 4.4.3 Effect of fly ash doses applied with and without FYM on soil available K of different depth at harvest

Treatment	Available K (Kg ha^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	351.78	360.15	355.96	243.98	238.48	241.23
T_2- GRD (100:60:40)	366.40	361.58	363.99	283.19	275.08	279.14
T_3- 75% GRD + 20 t ha^{-1} fly ash	392.08	398.10	395.09	285.51	281.27	283.39
T_4- 75% GRD + 40 t ha^{-1} fly ash	413.33	410.79	412.06	287.84	290.82	289.33
T_5- 75% GRD + 60 t ha^{-1} fly ash	407.18	400.37	403.78	272.62	288.37	280.50
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	436.80	432.33	434.57	284.31	288.23	286.27
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	439.18	440.25	439.72	291.44	292.95	292.20
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	445.41	439.18	442.30	292.12	290.52	291.32
SEm±	**4.57**	**5.57**	**3.69**	**10.60**	**3.57**	**5.39**
CD (P=0.05)	**13.88**	**16.90**	**11.22**	**NS**	**10.85**	**16.35**
Non amended soil (Near by)		**375.21**			**298.31**	

Total K (%): Fly ash -0.31 FYM- 0.59

The increase in available nutrients in soil after harvest of rice might be due to chelating effect of FYM and FA which did not allow the nutrients to be lost or adsorbed to the soil. Mineralization of nutrients from fly ash and organic manure provides the major and micro-nutrients during the crop growth at later stages.

Available N content was maximum in surface horizon and found to decreasing with increasing depth which might be due to decreasing content of organic carbon with depths (Table 4.4.1). The variation of phosphorus content which could be attributed to high organic matter content leading to formation of organo-complexes of the nutrients with humus coating of iron and aluminium particles. These is findings are also supported by the research work carried out by Thangasamy *et al*. (2005) and Gupta *et al*. (1990).

Patil *et al*. (1996) also found increase in available N content of soil with application of fly ash which might be due to the contribution of N made through fly ash.

The increase in soil available nutrient status in the treatments may be associated with the content of fly ash and FYM applied. It may also be due to the improved physico-chemical and biological properties of soil.

The increased soil nutrient status can also be attributed to decomposition of crop residues resulting in enzyme-aided nutrient mineralization carried out by the native microbial population present in the soil. The favorable effect of fly ash on nutrient availability was ascribed to its effect on biotic activity and the nutrient release via biotic activity.

The silica which is present in fly ash would also have played a major role in releasing the P to available pool from the insoluble sources in fly ash as well as soil. The increase may be due to the hydrolysis of iron, aluminum and magnesium compound in fly ash and released inorganic acid by fly ash. The liberated acids might have helped in the release of available phosphate from the unavailable form without affecting the pH as organic matter present in the soil has a buffering capacity in maintaining the pH. Selvakumari *et al*. (1999) also found increased nutrient availability due to application of fly ash and FYM.

The significant increase in available K status of soil was due to the addition of K to soil through fly ash. Increased availability of potassium could be due to breakdown of minerals by several organic and inorganic acids (Grewal *et al*., 1998). The available potassium status of soils under study was high and it did not show any definite trend in its depth-wise distribution, which could be due to presence of high clay content and illitic nature of these clays. The result obtained is also supported by the findings of Najar (2002) and Talib (1984).

Lee *et al.* (2005), Bhoyar (1998), Matte and Kene (1995) and Stevenson (1994) also reported increased availability of major nutrients due to fly ash addition.

4.5 Available micronutrients in soil

The pooled data of available micronutrients (Fe, Mn, Cu and Zn) in 0-15 and 15-30 cm soil depths as influenced by grades doses of fly ash at harvest of the rice crop are presented in table 4.5.1 to 4.5.4 & fig. 4.5.1 to 4.5.4.

4.5.1 Soil available iron

The average iron status in surface and subsurface depths is shown in table 4.5.1 and fig. 4.5.1. The effect of different treatments on the status of available Fe was found significant at both the depths.

In surface soil, application of different treatments significantly increased the Fe status except in 20 t ha^{-1} fly ash without FYM when compared with control and 100% recommended dose of NPK (GRD). Integration of fly ash @ 60 t ha^{-1} with FYM showed the highest Fe content in 0-15 cm (40.31 mg kg^{-1}) and 15-30 cm (27.55 31 mg kg^{-1}) soil depths whereas control recorded the lowest.

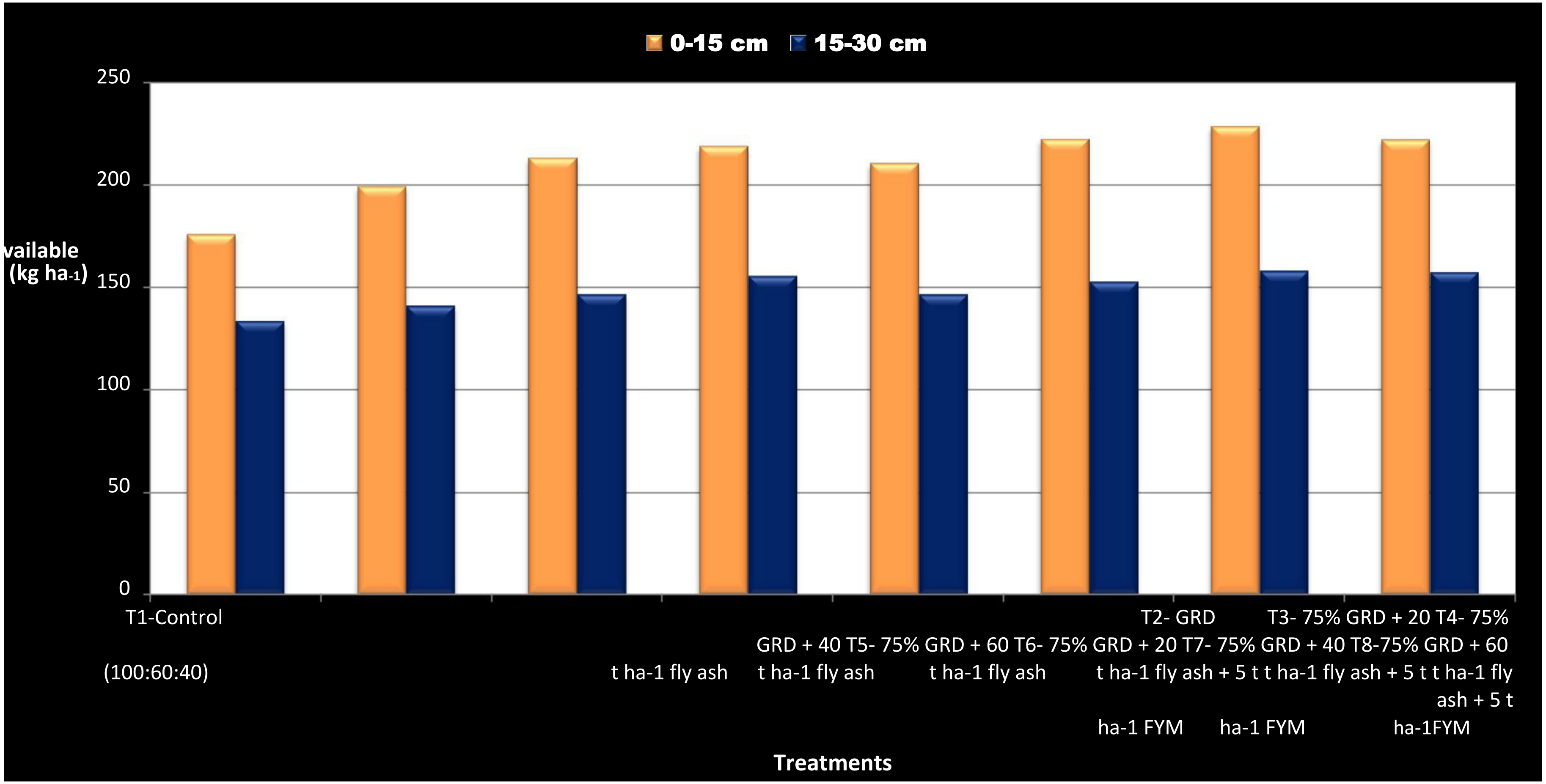


Fig.4.4.1 Effect of fly ash doses applied with and without FYM on soil available N of different depth at harvest

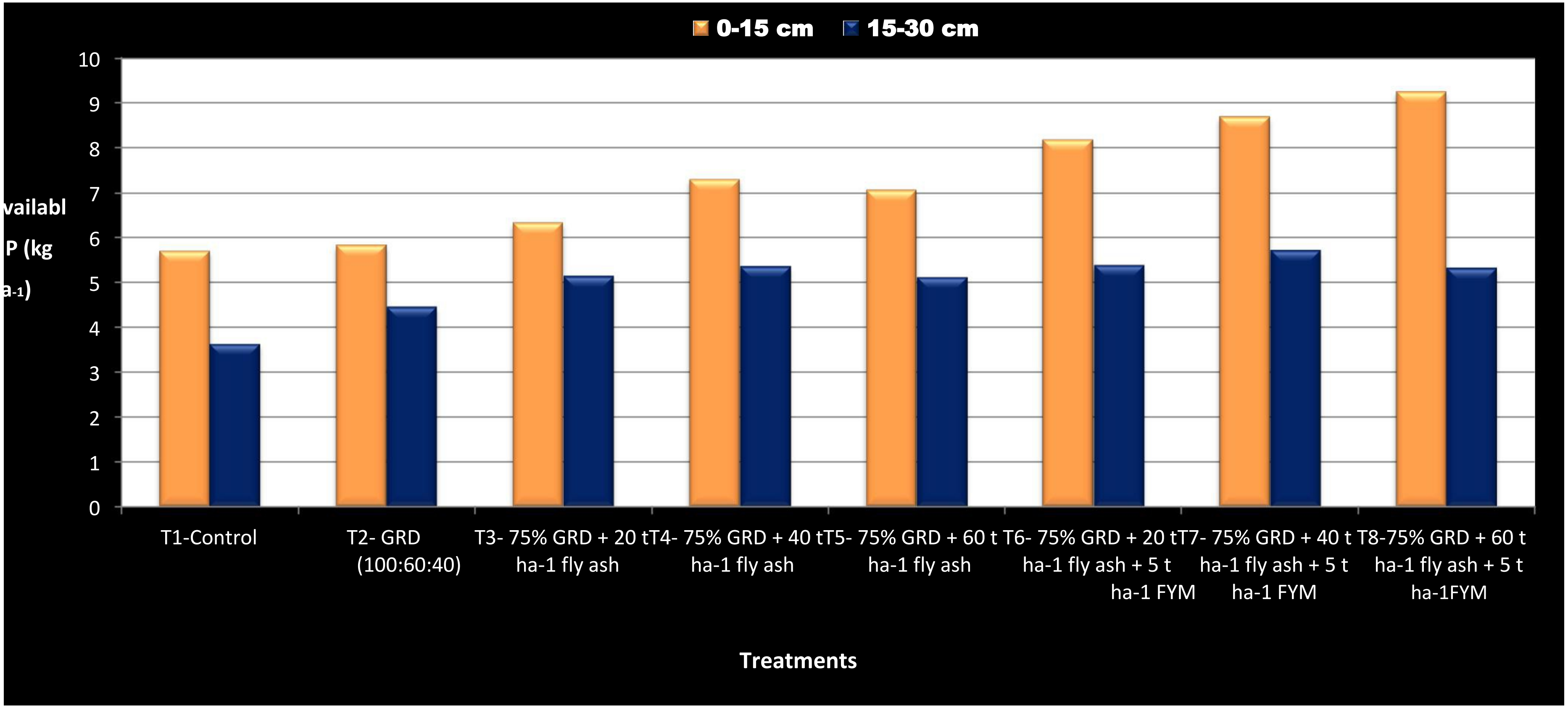


Fig.4.4.2 Effect of fly ash doses applied with and without FYM on soil available P of different depth at harvest

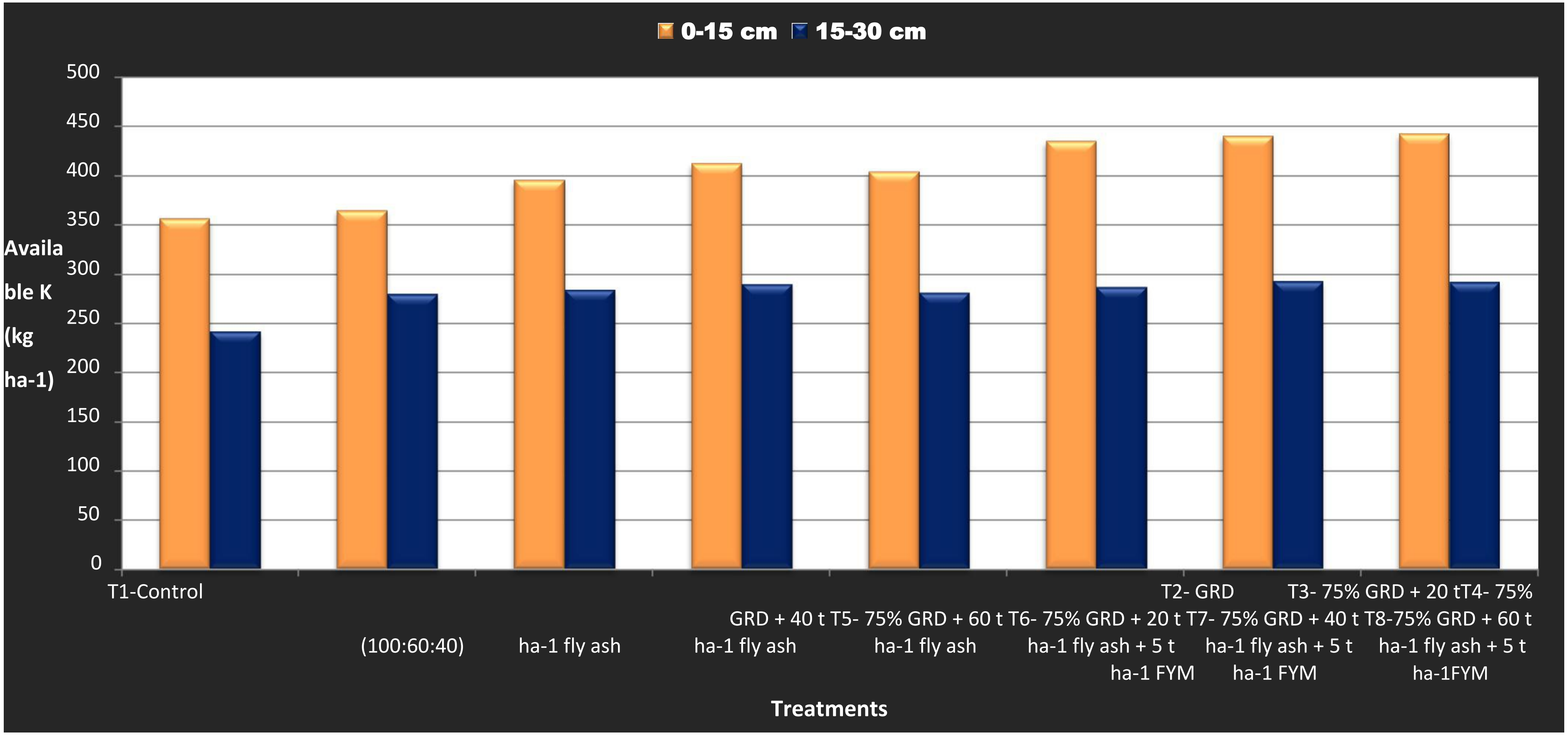


Fig.4.4.3 Effect of fly ash doses applied with and without FYM on soil available K of different depth at harvest

Similar trend in available Fe content was also observed in 15-30 cm soil depth, except T_3 (75% GRD+20 t ha^{-1} fly ash), there was a significant increase in available fe content under all the treatments as compared to control and GRD.

Increasing doses of fly ash with and without FYM showed increasing status of Fe content. The Fe status was higher at the surface than the subsurface soil depth.

4.5.2 Soil available manganese

The average manganese status in surface and subsurface soil depths is shown in table 4.5.2 and fig. 4.5.2. The effect of different treatments on the status of available Mn was found significant at both the depths.

In surface soil, application of different treatments significantly increased the Mn status except 20 t ha^{-1} fly ash without FYM, when compared with control and GRD. Application of fly ash @ 60 t ha^{-1} + 75% GRD with FYM showed the highest (33.59 mg kg^{-1}) available Mn status while the control showed the lowest (18.74 mg kg^{-1}).

In 15-30 cm soil depth increasing doses of fly ash significantly increased the Mn status in soil but the application of only 40 and 60 t ha^{-1} fly ash + 75% GRD with FYM was found superior over 100% GRD. Application of fly ash @ 40 t ha^{-1} + 75% GRD with FYM showed the highest (20.49 mg kg^{-1}) available Mn status while the control showed the lowest (13.79 mg kg^{-1})

Increasing doses of fly ash with and without FYM showed increase in Mn content. Mn availability was higher at the surface than the subsurface soil.

4.5.3 Soil available zinc

The average zinc status in surface and sub-surface depths is shown in table 4.5.3 and fig. 4.5.3.The data revealed application of the different treatments was significantly increased at 0-15 cm depth but non significant increase was observed in 15-30 cm soil depth.

Table 4.5.1 Effect of fly ash doses applied with and without FYM on soil available Fe of different depth at harvest

Treatment	Available Fe (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	20.14	22.40	21.27	12.17	15.76	13.97
T_2- GRD (100:60:40)	22.09	21.63	21.86	12.97	18.57	15.77
T_3- 75% GRD + 20 t ha^{-1} fly ash	24.60	23.98	24.29	16.25	19.86	18.06
T_4- 75% GRD + 40 t ha^{-1} fly ash	30.52	37.24	33.88	18.31	24.01	21.16
T_5- 75% GRD + 60 t ha^{-1} fly ash	32.59	37.66	35.13	17.32	28.14	22.73
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	28.87	33.01	30.94	22.30	25.01	23.65
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	33.18	39.07	36.12	23.21	28.49	25.85
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	36.31	40.31	40.31	23.83	31.27	27.55
SEm±	**1.38**	**1.99**	**1.24**	**1.52**	**3.32**	**1.66**
CD (P=0.05)	**4.21**	**6.05**	**3.77**	**4.62**	**NS**	**5.02**
Non amended soil (Near by)		**15.6**			**12.42**	

Total Fe (mg kg^{-1}): Fly ash - 4132 FYM- 325.75 **MPL (mg kg^{-1}):** 150

Table 4.5.2 Effect of fly ash doses applied with and without FYM on soil available Mn of different depth at harvest

Treatment	Available Mn (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	19.66	17.83	18.74	13.24	14.33	13.79
T_2- GRD (100:60:40)	22.82	21.26	22.04	14.29	17.92	16.10
T_3- 75% GRD + 20 t ha^{-1} fly ash	24.35	22.89	23.62	14.46	17.75	16.11
T_4- 75% GRD + 40 t ha^{-1} fly ash	28.52	27.55	28.04	15.10	20.79	17.95
T_5- 75% GRD + 60 t ha^{-1} fly ash	27.59	27.27	27.43	14.87	19.78	17.33
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	27.66	30.04	28.85	15.37	20.05	17.71
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	31.75	32.56	32.16	17.06	23.92	20.49
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	32.77	34.40	33.59	17.12	23.53	20.32
SEm±	**0.82**	**1.47**	**1.02**	**0.31**	**1.55**	**0.70**
CD (P=0.05)	**2.41**	**4.46**	**3.11**	**0.95**	**4.71**	**2.15**
Non amended soil (Near by)		**18.23**			**14.35**	

Total Mn (mg kg^{-1}): Fly ash – 125.0 FYM- 52.52 **MPL (mg kg^{-1}):** 80

Table 4.5.3 Effect of fly ash doses applied with and without FYM on soil available Zn of different depth at harvest

Treatment	Available Zn (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	0.28	0.26	0.27	0.22	0.19	0.21
T_2- GRD (100:60:40)	0.34	0.30	0.32	0.22	0.23	0.22
T_3- 75% GRD + 20 t ha^{-1} fly ash	0.43	0.39	0.41	0.24	0.25	0.24
T_4- 75% GRD + 40 t ha^{-1} fly ash	0.50	0.51	0.51	0.24	0.29	0.26
T_5- 75% GRD + 60 t ha^{-1} fly ash	0.55	0.48	0.51	0.26	0.28	0.27
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.60	0.55	0.58	0.25	0.26	0.25
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.60	0.52	0.56	0.28	0.33	0.30
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	0.56	0.58	0.57	0.26	0.32	0.29
SEm±	**0.01**	**0.09**	**0.04**	**0.02**	**0.03**	**0.02**
CD (P=0.05)	**0.04**	**NS**	**0.14**	**NS**	**NS**	**NS**
Non amended soil (Near by)		**0.33**			**0.29**	

Total Zn (mg kg^{-1}): Fly ash – 70.0 FYM- 18.32 **MPL (mg kg^{-1}):** 200

Table 4.5.4 Effect of fly ash doses applied with and without FYM on soil available Cu of different depth at harvest

Treatment	Available Cu (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	1.10	1.04	1.07	0.83	0.78	0.81
T_2- GRD (100:60:40)	1.32	1.18	1.25	0.88	0.82	0.85
T_3- 75% GRD + 20 t ha^{-1} fly ash	1.48	1.44	1.46	0.87	0.81	0.84
T_4- 75% GRD + 40 t ha^{-1} fly ash	1.59	1.59	1.59	0.90	0.89	0.90
T_5- 75% GRD + 60 t ha^{-1} fly ash	1.63	1.60	1.62	1.15	0.91	1.03
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	1.81	1.78	1.80	0.99	0.90	0.95
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	1.97	1.85	1.91	1.10	0.96	1.03
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	2.00	1.81	1.92	1.01	0.98	1.00
SEm±	**0.03**	**0.03**	**0.02**	**0.04**	**0.06**	**0.03**
CD (P=0.05)	**0.10**	**0.10**	**0.07**	**0.12**	**NS**	**0.09**
Non amended soil (Near by)		**1.12**			**0.59**	

Total Cu (mg kg^{-1}): Fly ash – 24.0 FYM- 12.0 **MPL (mg kg^{-1}):** 30

In surface soil, application of different treatments significantly increased the Zn status, except 20 t ha^{-1} fly ash without FYM, when compare with control and 100% recommended dose of NPK. The maximum zinc (0.58 mg kg^{-1}) content was recorded in treatment 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM and minimum in (0.27 mg kg^{-1}) in control.

Increasing doses of fly ash with and without FYM showed increasing status of Zn content. The Zn status was higher at the surface than the subsurface depth.

4.5.4 Soil available copper

The average copper status in surface and subsurface soil depths is shown in table 4.5.4 and fig. 4.5.4.The effect of different treatments on the status of available Cu was found significant at both the depths.

In surface soil, application of different treatments was significantly increased the Cu status when compared with control and 100% recommended dose of NPK. Higher dose of fly ash @ 60 t ha^{-1}+ 75% GRD with FYM showed the highest (1.92 mg kg^{-1}) available Cu status while the control showed the lowest (1.07 mg kg^{-1}) Cu content availability.

All the treatments of fly ash applied along with FYM significantly increased soil available copper content over the 100% recommended dose of NPK at 15-30 cm soil depth. Application of 75% GRD + 60 t ha^{-1} fly ash recorded the highest (1.03 mg kg^{-1}) Cu status while control showed the lowest (0.81 mg kg^{-1}).

Increasing doses of fly ash with and without FYM showed increasing status Cu availability. Higher Cu content was observed when the fly ash was applied with FYM in 0-15 cm soil depth as compared without FYM, while reversed trend subsurface soil.

The distribution of micronutrients in paddy field soils was in the ranking order of Fe>Mn >Cu> Zn in both depths. The content of maximum under the treatments of different doses of fly ash with 75% recommended dose of NPK and FYM compare to without FYM. Available micronutrient status of soil showed that it increased with increasing doses of fly ash with and without combination of

FYM. It might be due to the fact that fly ash and FYM contains sufficient amount of the micronutrients, hence serving of good source of micro nutrients (Table 3.3). The above results are in conformity with that of Reddy *et al*. (2010), Deshmukh *et al*. (2000) and Kuchanwar *et al*. (1997).

Organic matter, crop residues, and manure application affect the immediate and potential availability of micronutrient cations (Rengel 2007). The cationic micronutrients react with certain organic molecules to form organometallic complexes as chelates and the soluble chelates can increase the availability of the micronutrient and protect it from precipitation reactions. These chelates may be synthesized by plant roots and released to the surrounding soil, may be present in the soil humus or may be synthetic compounds added to the soil to enhance micronutrient availability.

The status of available micronutrients in soil was above the critical limit of the soil indicating adequate supply of nutrients to the plants.

In the surface soil horizon, micronutrient distribution was not only controlled by soil physical and chemical properties but also by rate and characteristics of fly ash and FYM. Fly ash and FYM contains considerable amount of Fe, Mn, Cu and Zn which might have increased the status of micronutrients in soil measured at the crop harvest (Table 4.5.1 to 4.5.4). Jiang *et al.* (2006) also reported increase in micronutrients content due to fly ash application.

Plant cycling exerts dominant control on the vertical distribution of micronutrients. Generally, biological cycling moves nutrients upwards because some proportion of the nutrients absorbed by plants are transported aboveground and then recycled to the soil surface by litter fall and microbial activity. (Jobbáge and Jackson 2001).

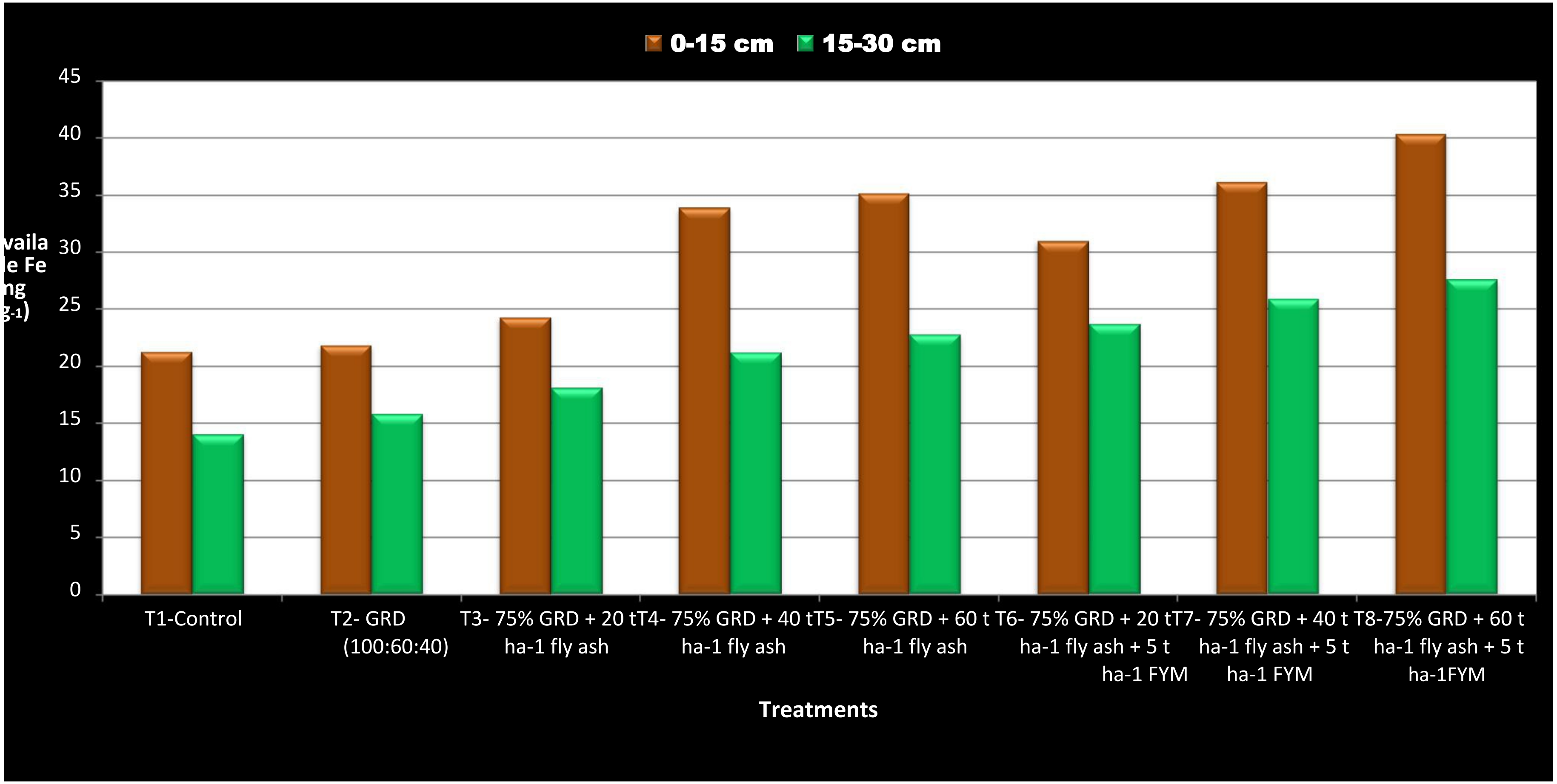


Fig.4.5.1 Effect of fly ash doses applied with and without FYM on soil available Fe of different depth at harvest

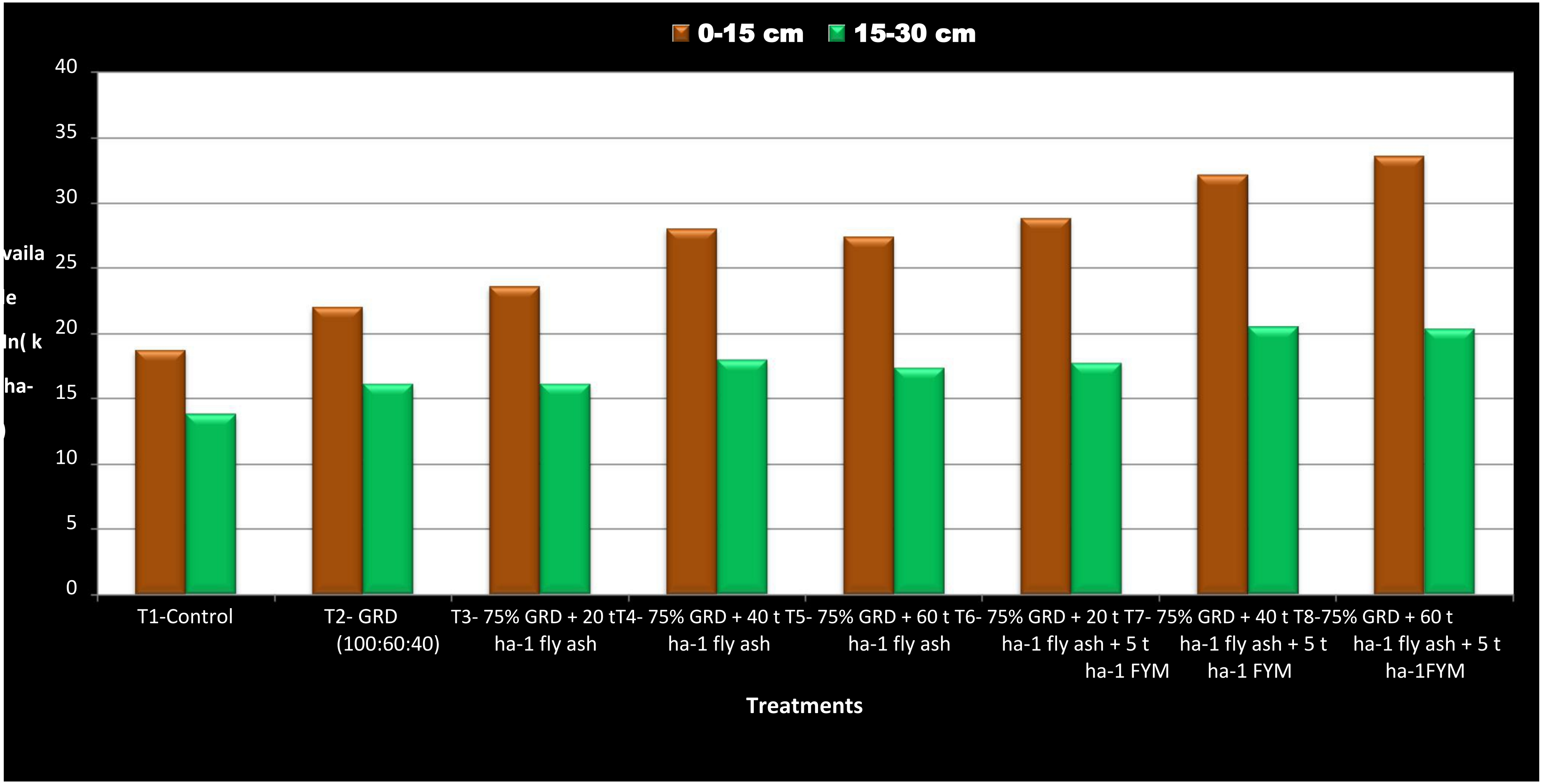


Fig.4.5.2 Effect of fly ash doses applied with and without FYM on soil available Mn of different depth at harvest

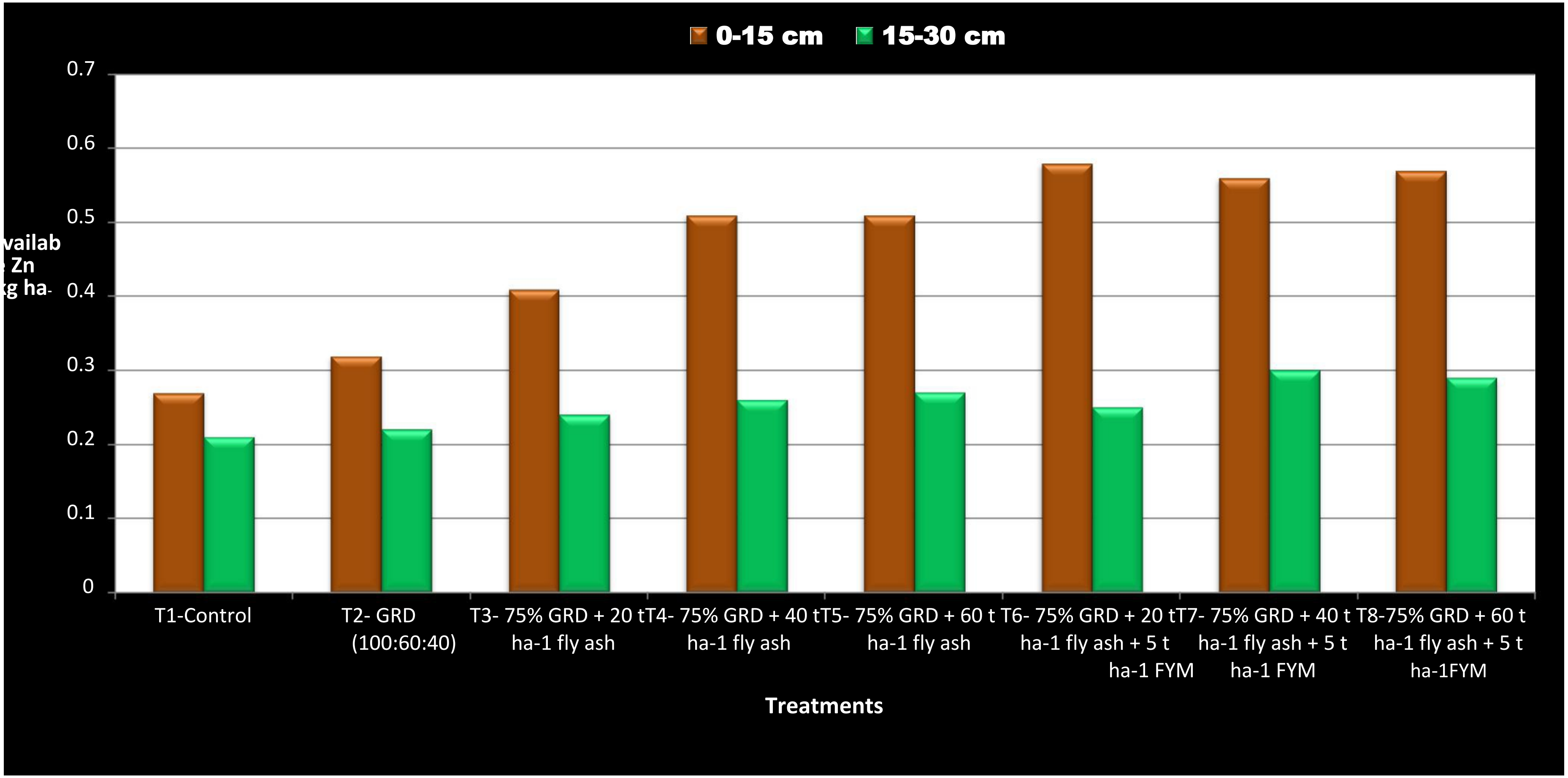


Fig.4.5.3 Effect of fly ash doses applied with and without FYM on soil available Zn of different depth at harvest

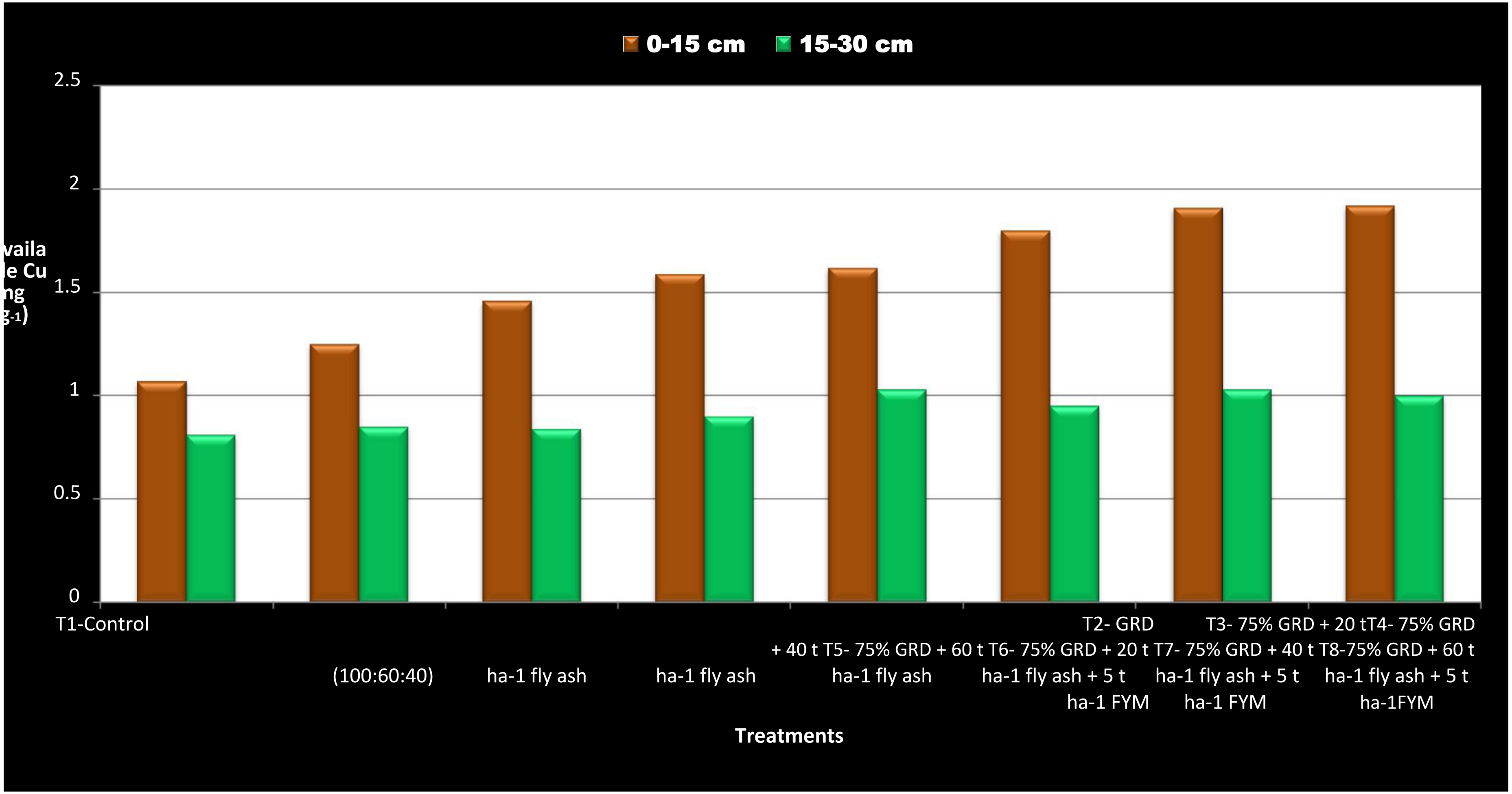


Fig.4.5.4 Effect of fly ash doses applied with and without FYM on soil available Cu of different depth at harvest

4.6 Available heavy metals in soil

Influence of the different treatments doses of fly ash combined with and without FYM on availability of heavy metals (Ni, Co, Cr, Pb and Cd) in 0-15 and 15-30 cm soil depths is presented in table 4.6.1 to 4.6.5 and fig. 4.6.1 to 4.6.5.

4.6.1 Soil available chromium

The average chromium content pooled over the two year of experiment at different depths is shown in 4.6.1 and fig. 4.6.1. The effect of different treatments on the status of soil available Cr was found significant only at surface soil. Application of fly ash with and without FYM significantly increased Cr status when compared with control and 100% recommended dose of NPK (100:60:40). The available Cr status was the highest (2.61 mg kg^{-1}) in 0-15 cm and (2.04 mg kg^{-1}) in 15-30 cm soil depth with the application of 60 t ha^{-1} fly ash + 75% GRD without FYM.

Increasing doses of fly ash with and without FYM showed increasing status of soil available Cr content. Higher Cr content was observed when the fly ash was applied without FYM than with FYM in 0-15 cm soil depth with similar trend in subsurface soil.

4.6.2 Soil available cobalt

The average cobalt status at both the soil depths is shown in table 4.6.2 and fig.4.6.2. The effect of different treatments on the status of soil available cobalt was found significant at both the depths.

At 0-15 soil depth, application of different treatments significantly increased the cobalt availability with and without FYM when compared with control and 100% recommended dose of NPK. Application of fly ash @ 60 t ha^{-1}+75% GRD without FYM showed the highest (1.29 mg kg^{-1}) available cobalt content while the control showed the lowest (1.00 mg kg^{-1}).

In 15-30 cm soil depth, T_4, T_5 and T_8 treatments showed significant increase in the cobalt status when compare with control and 100% recommended dose of NPK. Highest (0.97 mg kg^{-1}) cobalt content was observed with 60 t ha^{-1} fly ash along with 75% GRD application.

The increasing doses of fly ash with and without FYM showed increasing status of cobalt content. It was higher at the surface than the subsurface soil depth. The higher cobalt content was observed when the fly ash was applied without FYM.

4.6.3 Soil available nickel

The average nickel status in surface and subsurface soil depths is shown in table 4.6.3 & fig.4.6.3.The effect of different treatments on the status of available Ni was found significant at both the depths.

In surface soil, application of different treatments significantly increased the Ni status except in 20 t ha^{-1} fly ash with and without FYM when compare with control and 100% recommended dose of NPK. Application of fly ash @ 60 t ha^{-1}+ 75% GRD without FYM showed the highest (1.20 mg kg^{-1}) available Ni status, while the control showed the lowest (0.97 mg kg^{-1}).

In 15-30 cm soil depth, all the treatments significantly increased the Ni status except 20 t ha^{-1} fly ash with and without FYM when compare with control and 100% recommended dose of NPK. The highest (0.82 mg kg^{-1}) Ni content was observed with 40 t ha^{-1} fly ash and FYM.

The increasing doses of fly ash with and without FYM showed increasing status of Ni content. The Ni status was higher at the surface than the subsurface depth. Higher Ni content was observed when the fly ash was applied without FYM.

4.6.4 Soil available lead

The average lead status in surface and subsurface soil depths is shown in 4.6.4 and fig. 4.6.4. The effect of different treatments on the status of available Pb was found significant at surface soil depth but no significant change was observed in sub-surface soil through there was a marginal increase over control and GRD. In surface soil, application of different treatments significantly increased the Pb status with and without FYM when compared with control and GRD (100:60:40). The application of fly ash @ 60 t ha^{-1}+ 75% GRD with FYM showed the highest (1.45 mg kg^{-1}) Pb status while the control showed the lowest (1.00 mg kg^{-1}).

In 15-30 cm soil depth, increasing dose of fly ash with and without FYM showed increasing status of Pb content. The application of 75% GRD +60 t ha^{-}

Table 4.6.1 Effect of fly ash doses applied with and without FYM on soil available Cr of different depth at harvest

Treatment	Available Cr (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	1.88	1.81	1.85	1.36	1.34	1.35
T_2- GRD (100:60:40)	1.95	1.90	1.93	1.47	1.52	1.50
T_3- 75% GRD + 20 t ha^{-1} fly ash	2.36	2.34	2.35	1.70	1.66	1.68
T_4- 75% GRD + 40 t ha^{-1} fly ash	2.53	2.57	2.55	1.82	1.73	1.78
T_5- 75% GRD + 60 t ha^{-1} fly ash	2.59	2.64	2.61	1.97	2.12	2.04
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	2.30	2.24	2.27	1.68	1.60	1.64
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	2.49	2.42	2.46	1.79	1.59	1.69
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	2.51	2.36	2.44	1.84	1.71	1.77
SEm±	**0.04**	**0.17**	**0.09**	**0.19**	**0.28**	**0.22**
CD (P=0.05)	**0.12**	**NS**	**0.29**	**NS**	**NS**	**NS**
Non amended soil (Near by)		**1.79**			**1.39**	

Total Cr (mg kg^{-1}): Fly ash – 41.50 FYM- 14.85 **MPL (mg kg^{-1}):** 65

Table 4.6.2 Effect of fly ash doses applied with and without FYM on soil available Co of different depth at harvest

Treatment	Available Co (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	1.05	0.95	1.00	0.85	0.76	0.81
T_2- GRD (100:60:40)	1.11	0.91	1.01	0.88	0.77	0.82
T_3- 75% GRD + 20 t ha^{-1} fly ash	1.24	1.09	1.16	0.92	0.86	0.89
T_4- 75% GRD + 40 t ha^{-1} fly ash	1.28	1.17	1.23	0.94	0.95	0.95
T_5- 75% GRD + 60 t ha^{-1} fly ash	1.28	1.30	1.29	0.97	0.97	0.97
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	1.19	1.16	1.18	0.90	0.82	0.86
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	1.21	1.18	1.19	0.91	0.85	0.88
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	1.25	1.21	1.23	0.92	0.96	0.94
SEm±	**0.02**	**0.03**	**0.02**	**0.06**	**0.02**	**0.03**
CD (P=0.05)	**0.08**	**0.09**	**0.07**	**NS**	**0.07**	**0.10**
Non amended soil (Near by)		**0.89**			**0.78**	

Total Co (mg kg^{-1}): Fly ash – 70.0 FYM- 17.32 **MPL (mg kg^{-1}):** 17

Table 4.6.3 Effect of fly ash doses applied with and without FYM on soil available Ni of different depth at harvest

Treatment	Available Ni (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	1.00	0.95	0.97	0.68	0.65	0.67
T_2- GRD (100:60:40)	1.09	0.97	1.03	0.70	0.62	0.66
T_3- 75% GRD + 20 t ha^{-1} fly ash	1.13	1.05	1.09	0.77	0.62	0.69
T_4- 75% GRD + 40 t ha^{-1} fly ash	1.19	1.15	1.17	0.78	0.69	0.73
T_5- 75% GRD + 60 t ha^{-1} fly ash	1.22	1.18	1.20	0.81	0.78	0.79
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	1.11	1.02	1.07	0.76	0.65	0.70
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	1.13	1.08	1.11	0.84	0.80	0.82
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	1.16	1.09	1.12	0.80	0.77	0.79
SEm±	**0.01**	**0.03**	**0.02**	**0.03**	**0.02**	**0.02**
CD (P=0.05)	**0.05**	**0.10**	**0.06**	**0.09**	**0.17**	**0.06**
Non amended soil (Near by)		**0.97**			**0.78**	

Total Ni (mg kg^{-1}): Fly ash – 31.80 FYM- 13.00 **MPL (mg kg^{-1}):** 80

^{1} FA without FYM (T_8) showed the highest (0.92 mg kg^{-1}) and control showed the lowest (0.72 mg kg^{-1}) Pb availability. Higher Pb content was observed when the fly ash was applied without FYM in 0-15 cm soil depth, while the trend was reversed in subsurface soil.

4.6.5 Soil available cadmium

The average cadmium status in surface and subsurface depths is presented in in table 4.6.5 and fig. 4.6.5.Effect of different treatments on the status of available Cd was non significant at both the depths. The application of fly ash @ 60 t ha^{-1} +75% GRD without FYM showed the highest available Cd status (0.52 and 0.31 mg kg^{-1}) in 0-15 and 15-30 cm soil depths, respectively, while the control showed the lowest.

Increasing doses of fly ash with and without FYM showed increasing status of Cd content. The Cd status was higher at the surface than the subsurface depth.

The occurrence of heavy metals in paddy field soils was in the order of Cr > Pb > Co >Ni> Cd at the surface and subsurface soil layers.

Eskew *et al*. (1983) and Marschner (2002) reported that the Nickel (Ni) is a major environmental contaminant and one of the wide spread heavy metals, defined as ultra micronutrient. It is considered to be essential for possibly all plant species in small quantity (0.01 to 5 µg g^{-1} dry wt.), being important component of many enzymes especially ureas. However, at higher concentrations this metal becomes toxic for majority of plant species.

The distribution pattern of metals is governed by various soil physical and chemical factors like particle size distribution, pH, EC, organic matter, $CaCO_3$, cation exchange capacity, exchangeable cations etc. Datta *et al*. (2000) reported that concentration of heavy metals declined with depth which might be due to lower permeability and vertical movement of the metals. The results also indicated that organic carbon plays a major role in mobility and transport of Cd, Ni, Cr and Pb in the soils. Immobilization of metals might have been due to adsorption and occulation on the surface by hydroxides and oxides in soils and tend to remain in the zone of incorporation. Similar observations have also been reported by Ciurl (2001) and Appavu and Sree Ramulu (1990).

Table 4.6.4 Effect of fly ash doses applied with and without FYM on soil available Pb of different depth at harvest

Treatment	Available Pb (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	1.02	0.98	1.00	0.72	0.73	0.72
T_2- GRD (100:60:40)	1.08	1.06	1.07	0.74	0.72	0.73
T_3- 75% GRD + 20 t ha^{-1} fly ash	1.35	1.37	1.36	0.78	0.85	0.81
T_4- 75% GRD + 40 t ha^{-1} fly ash	1.33	1.39	1.36	0.84	0.87	0.86
T_5- 75% GRD + 60 t ha^{-1} fly ash	1.39	1.38	1.38	0.90	0.94	0.92
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	1.31	1.22	1.27	0.70	0.77	0.74
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	1.36	1.25	1.31	0.78	0.83	0.80
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	1.48	1.42	1.45	0.86	0.82	0.84
SEm±	**0.03**	**0.08**	**0.04**	**0.05**	**0.05**	**0.04**
CD (P=0.05)	**0.09**	**0.25**	**0.12**	**NS**	**NS**	**NS**
Non amended soil (Near by)		**0.96**			**0.79**	

Total Pb (mg kg^{-1}): Fly ash – 16.52 FYM- 10.21 **MPL (mg kg^{-1}):** 10

Table 4.6.5 Effect of fly ash doses applied with and without FYM on soil available Cd of different depth at harvest

Treatment	Available Cd (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	0.26	0.24	0.25	0.20	0.21	0.21
T_2- GRD (100:60:40)	0.29	0.32	0.30	0.22	0.19	0.21
T_3- 75% GRD + 20 t ha^{-1} fly ash	0.41	0.35	0.38	0.26	0.24	0.25
T_4- 75% GRD + 40 t ha^{-1} fly ash	0.44	0.39	0.41	0.28	0.29	0.29
T_5- 75% GRD + 60 t ha^{-1} fly ash	0.54	0.50	0.52	0.29	0.33	0.31
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.37	0.34	0.36	0.22	0.20	0.21
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.37	0.35	0.36	0.25	0.23	0.24
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	0.41	0.44	0.43	0.24	0.33	0.29
SEm±	**0.06**	**0.04**	**0.05**	**0.01**	**0.03**	**0.02**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Non amended soil (Near by)		**0.29**			**0.21**	

Total Cd (mg kg^{-1}): Fly ash – 13.50 FYM- 1.60 **MPL (mg kg^{-1}):** 3

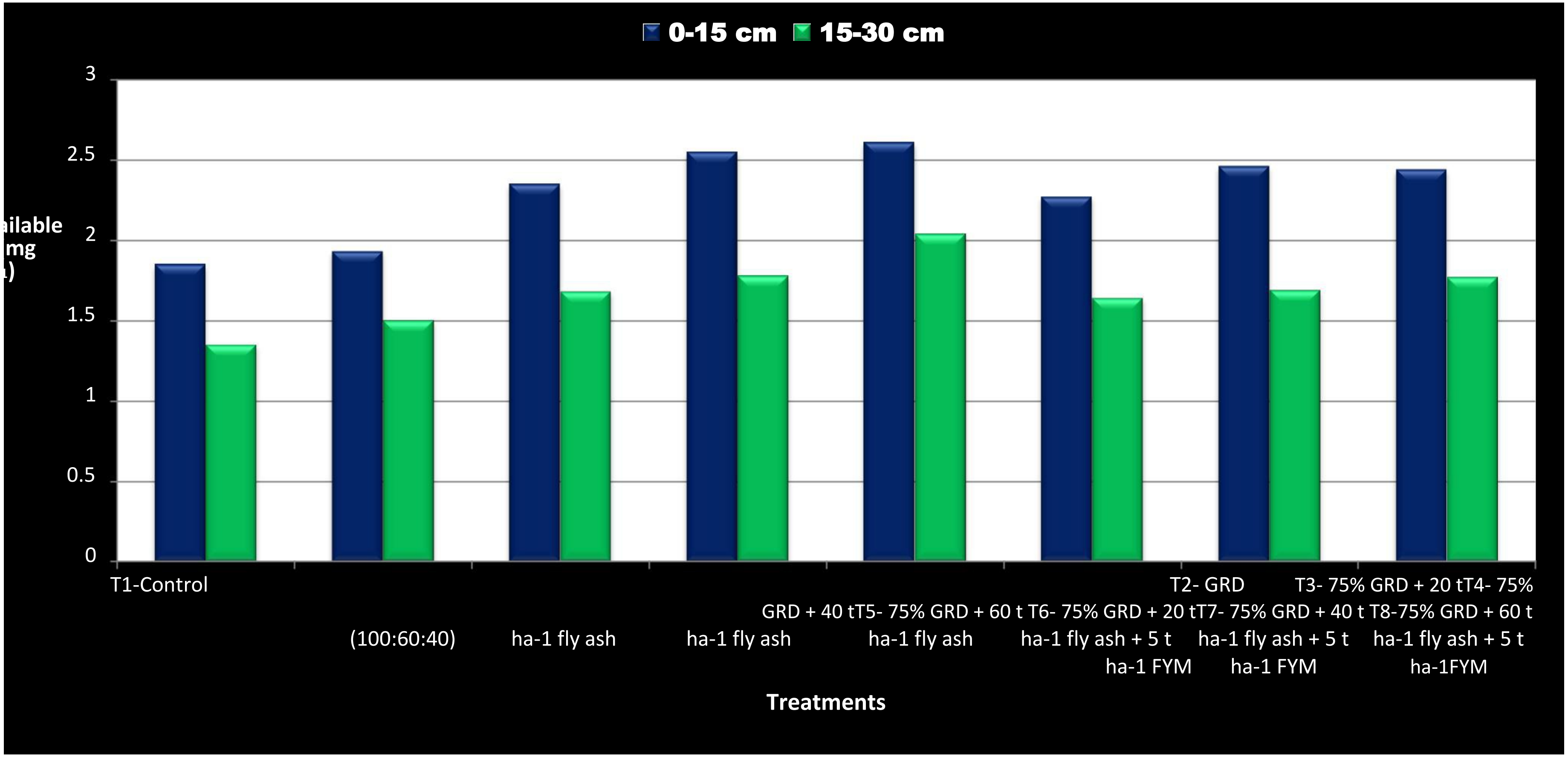


Fig.4.6.1 Effect of fly ash doses applied with and without FYM on soil available Cr of different depth at harvest

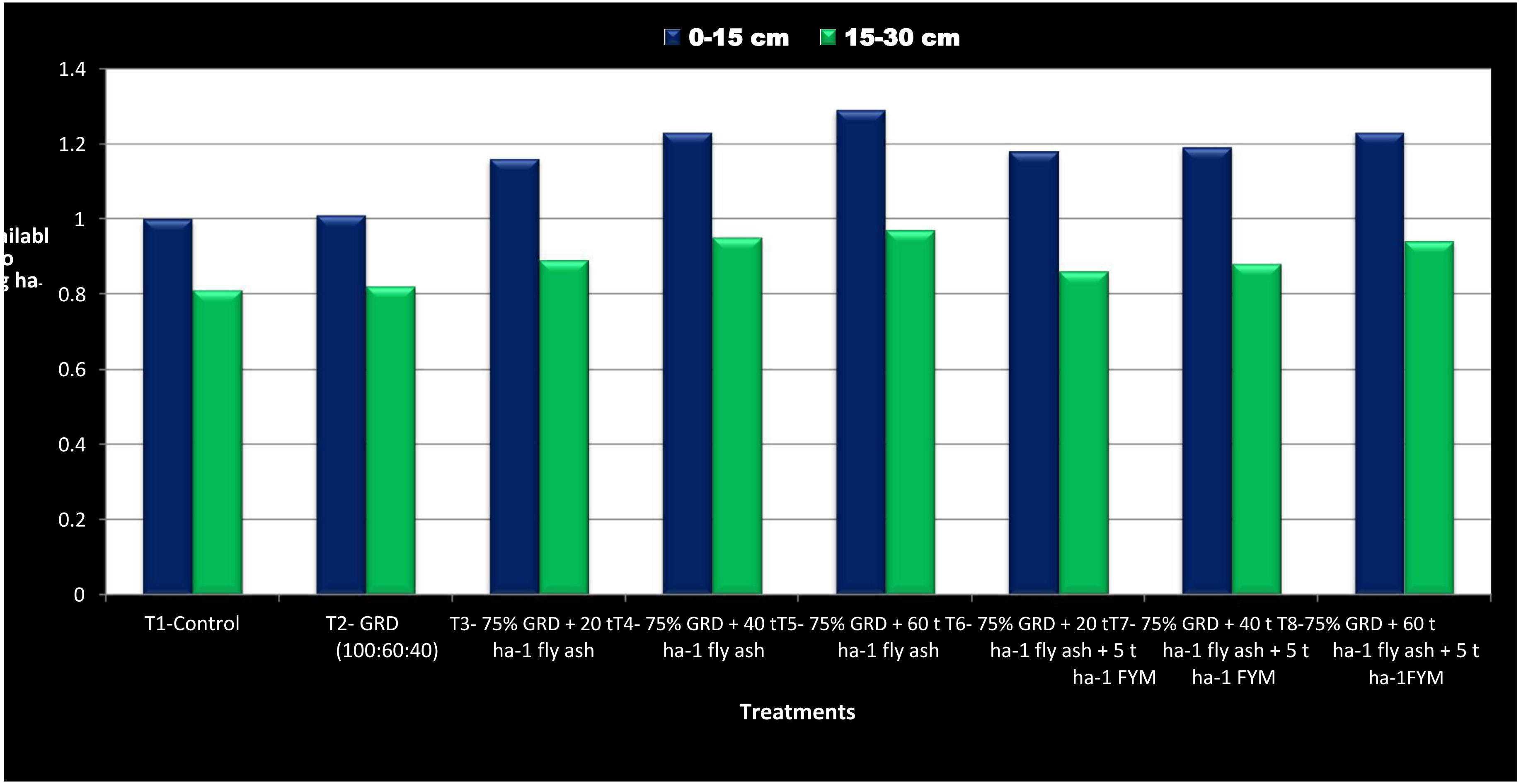


Fig.4.6.2 Effect of fly ash doses applied with and without FYM on soil available Co of different depth at harvest

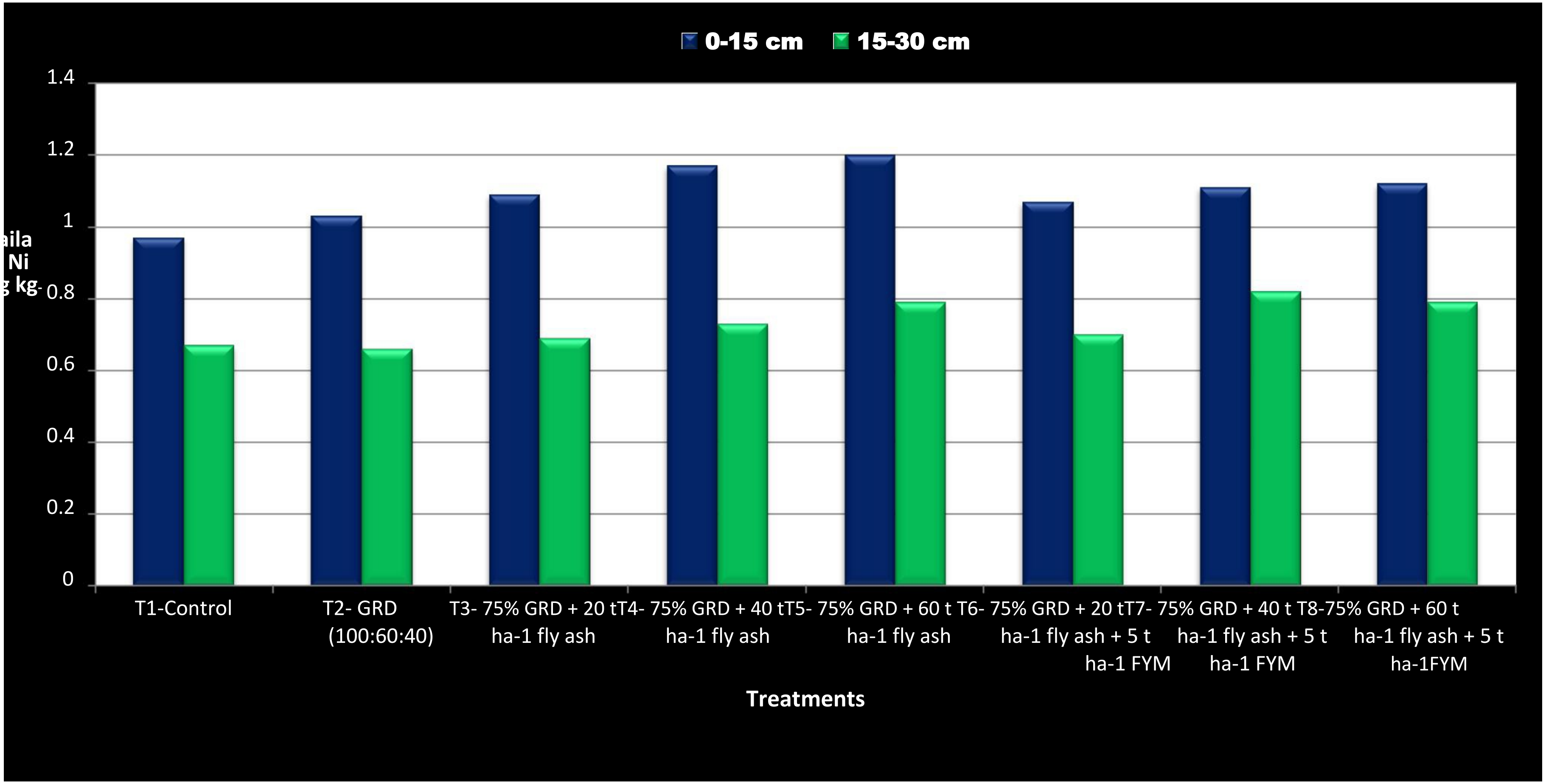


Fig.4.6.3 Effect of fly ash doses applied with and without FYM on soil available Ni of different depth at harvest

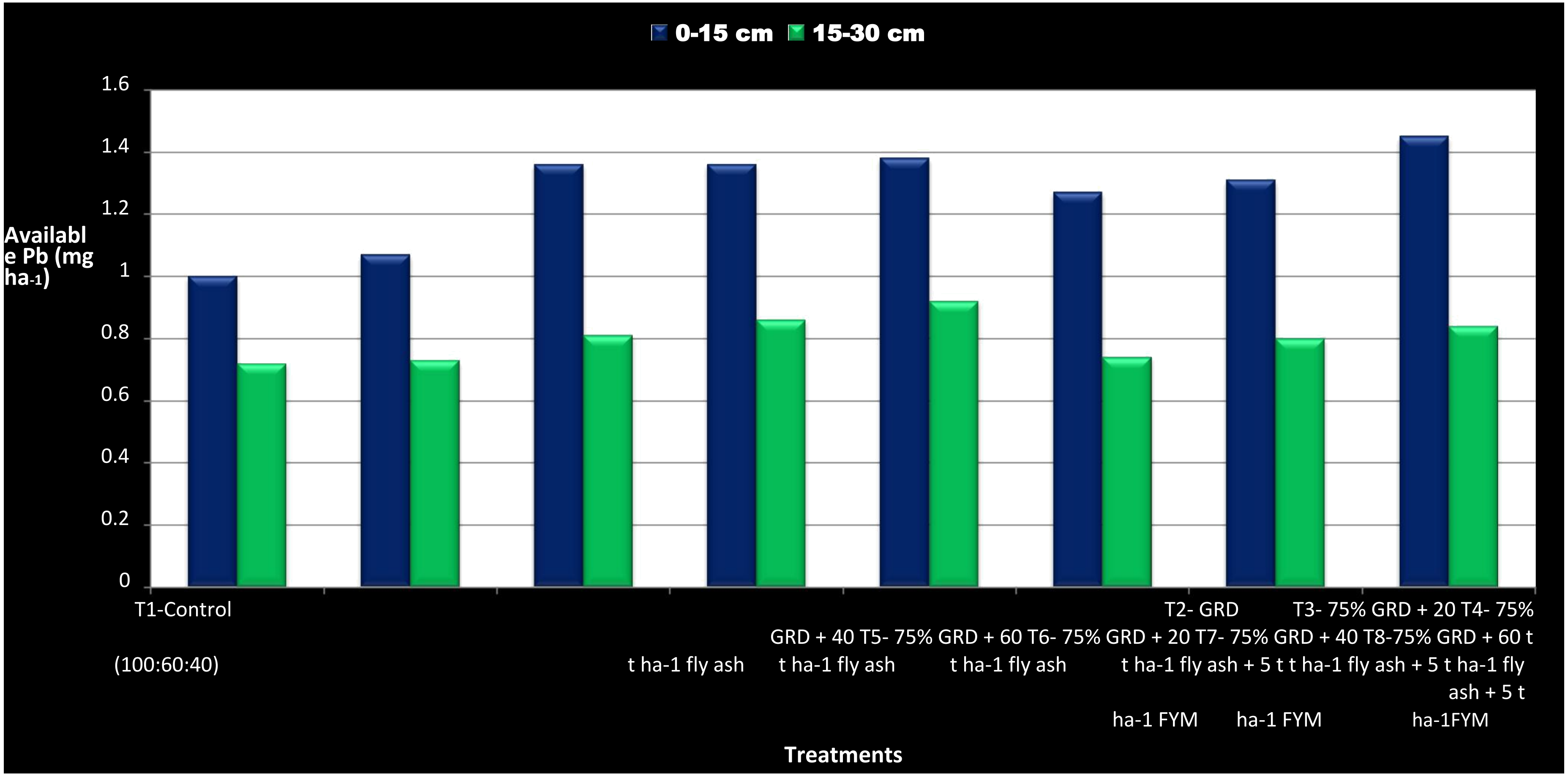


Fig.4.6.4 Effect of fly ash doses applied with and without FYM on soil available Pb of different depth at harvest

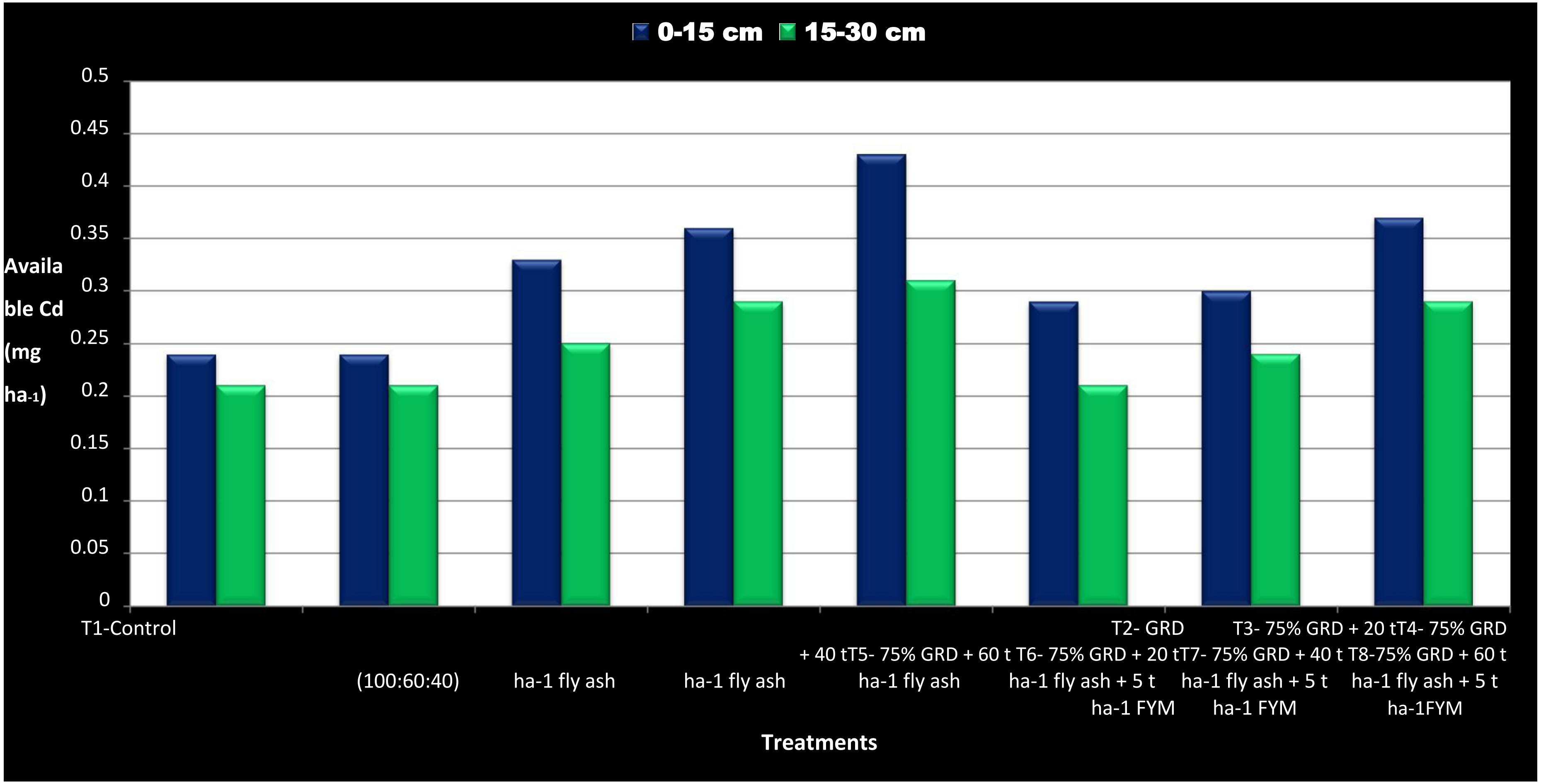


Fig.4.6.5 Effect of fly ash doses applied with and without FYM on soil available Cd of different depth at harvest

Heavy metals, such as Cr, Cd, Pb, As and Hg are often cited as primary contaminants of concern. The possibility of synergistic effect of two or more metals may be of considerable importance at some sites contaminated with heavy metals. These metals can be transferred and concentrated into plant tissues from the soil, and brought about significant reductions in both plant growth and grain yield of crops.

They can be toxic to photosynthetic activity, chlorophyll synthesis and antioxidant enzymes. Every metal and plant interacts in a specific way which depends on several factors such as soil type, plant, growth conditions and the presence of other ions. Metal uptake by grains was directly related to the applied heavy metal with greater concentrations of metals found in cases where added separately rather than in combinations (Athar and Ahmad, 2002 and Nan *et al*., 2002).

Application of fly ash without combination FYM increased the concentration of soil available toxic metal (Ni, Cr, Co, Pb and Cd) than in combination with FYM. Soil available toxic metals increased when increasing doses of fly ash with and without combination of FYM applied. This might be due to fact that fly ash contains these metals. Similar observation regarding the metal content in fly ash was reported by Gond *et al*. (2013), Yeledhalli *et al.* (2008), Singh and Agrawal (2007), Murzaeva (2004), Panda *et al*. (2003) and Rautary *et al.* (2003).

4.7 Partitioning of major nutrients in different rice plant parts

The major nutrients (N, P and K) concentration in different plant parts (root, grain, leaf and stem) of rice as influenced by different dose of fly ash applied with and without FYM are given in table 4.7.1 to 4.7.3 and figure 4.7.1 to 4.7.3

4.7.1 Nitrogen

Nitrogen accumulation in rice root, grain, leaf and stem are given in table 4.7.1 and figure 4.7.1.The data showed that imposition of the different treatments significantly increased the nitrogen content in root, grain and leaf but the effect wasnon significant in stem.

Nitrogen concentration in plant parts was in order of root> grain> leaf> stem in different fly ash treatments.

Application of fly ash with and without integration of FYM significantly increased N content in root over control and 100% recommended dose of NPK. Application of 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM showed highest (2.29 %) N content in root whereas control was observed in lowest (1.98 %).

Nitrogen concentration in rice grown also increased by different levels fly ash with and without FYM over GRD except, the treatment with 75% GRD + 20 t ha^{-1} fly ash. Among the treatments, 75% GRD + 60 t ha^{-1}fly ash + 5 t ha^{-1}FYM recorded highest (1.42 %) grain N and control the lowest (1.17 %).

Nitrogen accumulation in rice leaf significantly increased by the treatments of fly ash as compared to GRD. Application of 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM recorded maximum accumulation of nitrogen in leaf.

4.7.2 Phosphorus

The results on phosphorus content in different plant parts (root, grain, leaf and stem) is presented in table 4.7.2 and figure 4.7.2. Except 75% GRD + 20 t ha^{-1} fly ash treatment, all the treatments showed significantly higher P grain content as compared to control and 100% GRD. Application of fly ash with 75% recommended dose of NPK and integration of FYM showed significantly higher phosphorus concentration over without FYM and GRD.

Phosphorus distribution in plant parts was in order of root> grain>leaf>stem in different fly ash treatments.

Application of 20 and 40 t ha^{-1} fly ash without FYM showed similar P in leaf as compared to100% GRD, but all other fly ash treatments showed significantly higher P content. Integration of FA with chemical fertilizer and FYM showed maximum absorption of P by grain as compared to application of fly ash without FYM.

Phosphorus concentration in root and stem marginally increased but not significantly with the treatments as compared to GRD.

Table 4.7.1 Effect of fly ash doses applied with and without FYM on nitrogen content of different plant parts of paddy at harvest

Treatment	Nitrogen content (%)											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	2.03	1.92	1.98	1.17	1.20	1.18	0.33	0.30	0.32	0.25	0.23	0.24
T_2- GRD (100:60:40)	2.13	1.95	2.04	1.21	1.24	1.23	0.31	0.29	0.30	0.26	0.29	0.28
T_3 - 75% GRD + 20 t ha^{-1} fly ash	2.30	2.08	2.19	1.28	1.23	1.26	0.34	0.33	0.34	0.30	0.32	0.31
T_4 - 75% GRD + 40 t ha^{-1} fly ash	2.30	2.10	2.20	1.30	1.28	1.29	0.36	0.38	0.37	0.32	0.33	0.33
T_5 - 75% GRD + 60 t ha^{-1} fly ash	2.27	2.12	2.19	1.29	1.26	1.27	0.37	0.33	0.35	0.31	0.34	0.33
T_6 - 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	2.37	2.18	2.27	1.30	1.25	1.28	0.36	0.38	0.37	0.32	0.30	0.31
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	2.43	2.15	2.29	1.36	1.46	1.41	0.39	0.41	0.40	0.34	0.35	0.34
T_8 -75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	2.40	2.16	2.28	1.40	1.44	1.42	0.39	0.34	0.37	0.34	0.31	0.33
SEm±	**0.07**	**0.04**	**0.03**	**0.04**	**0.04**	**0.02**	**0.01**	**0.01**	**0.01**	**0.02**	**0.03**	**0.02**
CD (P=0.05)	**0.23**	**0.12**	**0.10**	**0.12**	**0.12**	**0.07**	**NS**	**0.05**	**0.03**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**1.98**			**1.21**			**0.45**			**0.32**	

Total N (%): Fly ash -0.071 FYM- 0.86

Table 4.7.2 Effect of fly ash doses applied with and without FYM on phosphorus content of different plant parts of paddy at harvest

Treatment	Phosphorus content (%)											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	0.28	0.36	0.32	0.20	0.33	0.27	0.11	0.12	0.11	0.11	0.12	0.11
T_2- GRD (100:60:40)	0.35	0.48	0.41	0.22	0.38	0.30	0.12	0.11	0.12	0.12	0.14	0.13
T_3- 75% GRD + 20 t ha^{-1} fly ash	0.35	0.52	0.43	0.25	0.38	0.32	0.11	0.14	0.13	0.13	0.14	0.13
T_4- 75% GRD + 40 t ha^{-1} fly ash	0.41	0.59	0.50	0.27	0.43	0.35	0.13	0.12	0.13	0.13	0.15	0.14
T_5- 75% GRD + 60 t ha^{-1} fly ash	0.35	0.60	0.47	0.29	0.47	0.38	0.16	0.14	0.15	0.15	0.12	0.13
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.37	0.47	0.42	0.27	0.47	0.37	0.14	0.15	0.15	0.16	0.14	0.15
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.42	0.56	0.49	0.32	0.51	0.42	0.16	0.19	0.18	0.18	0.15	0.16
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	0.39	0.57	0.48	0.36	0.49	0.42	0.18	0.15	0.17	0.19	0.14	0.17
SEm±	**0.03**	**0.05**	**0.03**	**0.01**	**0.02**	**0.01**	**0.01**	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**
CD (P=0.05)	**NS**	**NS**	**NS**	**0.04**	**0.06**	**0.04**	**NS**	**NS**	**0.03**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**0.53**			**0.31**			**0.35**			**0.28**	

Total P (%): Fly ash -0.049 FYM- 0.21

Table 4.7.3 Effect of fly ash doses applied with and without FTM on potassium content of plant different parts of paddy at harvest

Treatment	**Potassium content (%)**											
	Root			**Grain**			**Leaf**			**Stem**		
	2016	**2017**	**Pooled**	**2016**	**2017**	**Pooled**	**2016**	**2017**	**Pooled**	**2016**	**2017**	**Pooled**
T_1-Control	0.44	0.42	0.43	0.30	0.32	0.31	1.24	1.34	1.29	1.15	1.15	1.15
T_2- GRD (100:60:40)	0.52	0.53	0.52	0.32	0.35	0.34	1.28	1.36	1.32	1.16	1.18	1.17
T_3- 75% GRD + 20 t ha^{-1} fly ash	0.52	0.55	0.53	0.33	0.36	0.34	1.29	1.38	1.33	1.16	1.15	1.16
T_4- 75% GRD + 40 t ha^{-1} fly ash	0.53	0.53	0.53	0.38	0.38	0.38	1.33	1.40	1.37	1.19	1.20	1.19
T_5- 75% GRD + 60 t ha^{-1} fly ash	0.51	0.53	0.52	0.35	0.37	0.36	1.31	1.36	1.34	1.20	1.19	1.19
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.47	0.57	0.52	0.36	0.41	0.39	1.32	1.41	1.37	1.19	1.22	1.21
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	0.59	0.55	0.57	0.38	0.42	0.40	1.37	1.45	1.41	1.20	1.22	1.21
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	0.57	0.54	0.55	0.41	0.39	0.40	1.36	1.47	1.42	1.25	1.24	1.24
SEm±	**0.04**	**0.04**	**0.04**	**0.01**	**0.02**	**0.01**	**0.02**	**0.01**	**0.01**	**0.02**	**0.03**	**0.02**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**0.04**	**0.07**	**0.05**	**0.05**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**0.41**			**0.45**			**1.34**			**1.12**	

Total K (%): Fly ash -0.31 FYM- 0.59

4.7.3 Potassium

Table 4.7.3 and figure 4.7.3 showed that the effect of the treatments was significant on grain and leaf K content but non-significant in root and stem K content.

Increasing dose of fly ash applied with FYM showed significant increase in K content of rice grain when compared with GRD. However, it significantly increased in all other treatments as compared to control.

Potassium distribution in plant parts was in order of leaf> stem>root>grain in different fly ash treatments studied.

Potassium concentration in leaf increased significantly by increasing dose of fly ash combined with and without FYM over control. Maximum content of K in rice leaf was accumulated by application of fly ash @ 60 t ha^{-1} with 5 t ha^{-1} FYM and 75% recommended dose of NPK.

In general, major nutrients in different pant parts of rice were higher by application of increasing doses of fly ash with FYM than without FYM.

The increase in concentration was due to release of the nutrient via- bio activity to soil there by increasing the availability to the plants. Higher absorption of nutrients by rice is due to increase in availability of nutrients during crop growth due to beneficial effect of fly ash integration with FYM. It might have further helped in creating favourable soil physical condition (structure, pore space and water holding capacity etc.) for root proliferation and solubilisation of nutrients and availability in soil which led to higher uptake of nutrients and crop growth.

Sireesha *et al*. (2014) also reported increased nutrient uptake by the addition of fly ash, which provided conducive physical environment and essential nutrient elements especially Ca, Mg, S, B and Mo.

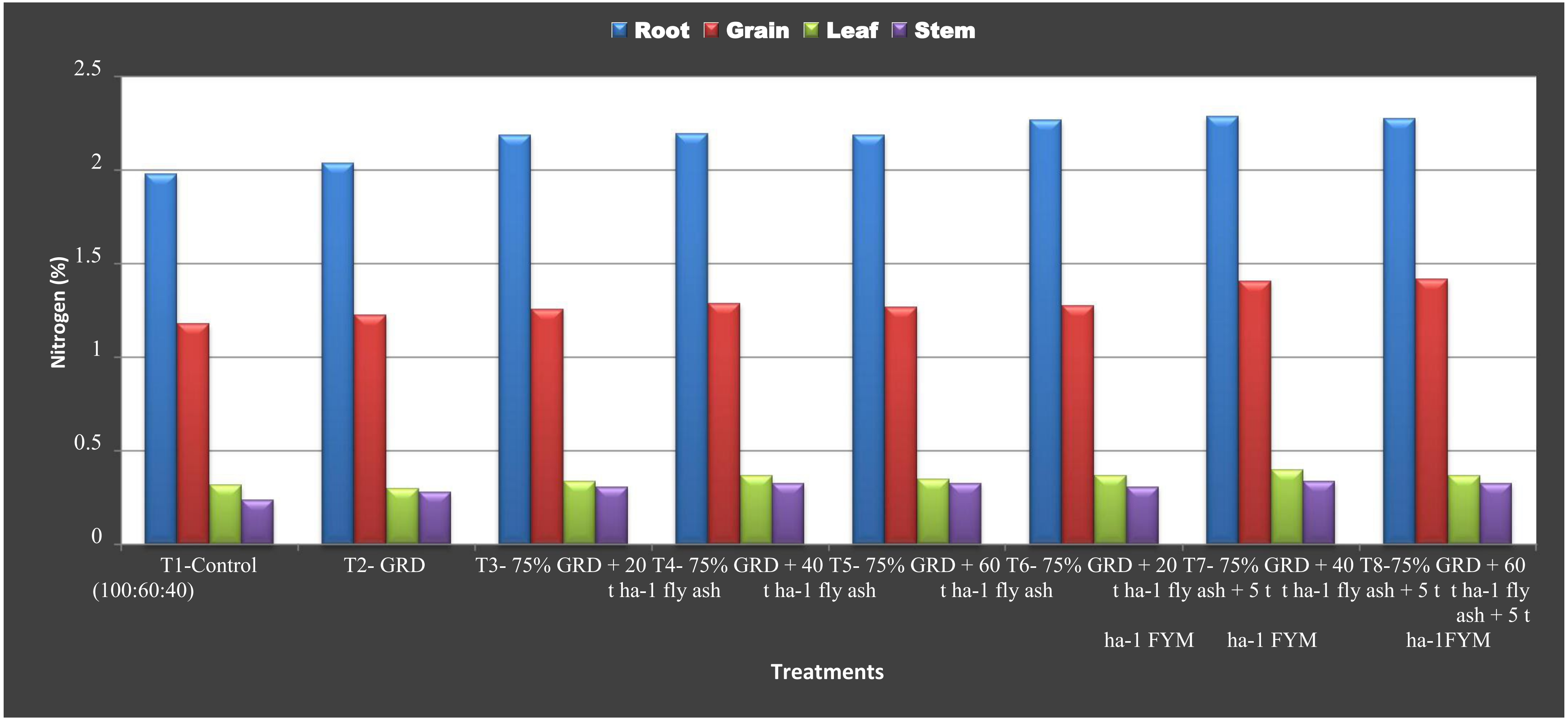


Fig.4.7.1 Effect of fly ash doses applied with and without FYM on nitrogen content of different plant parts of paddy at harvest

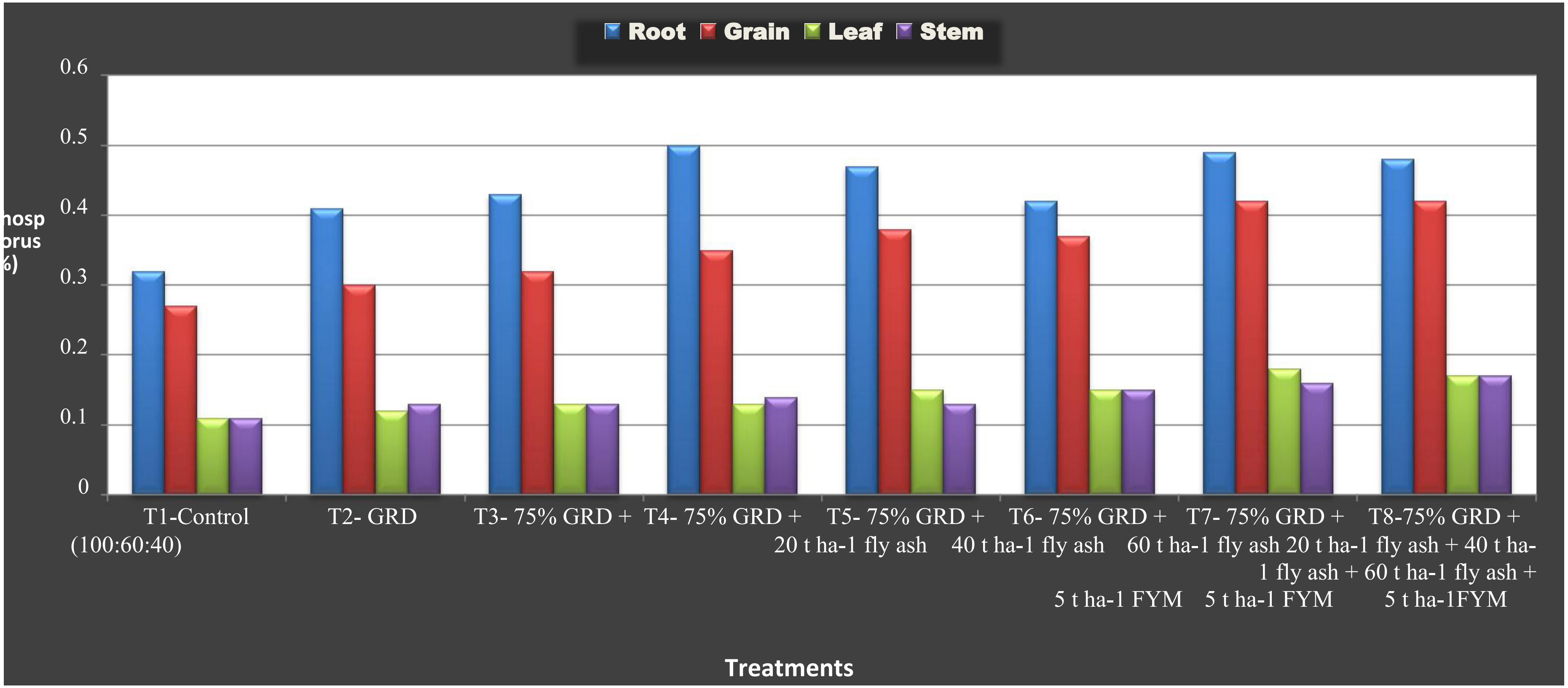


Fig.4.7.2 Effect of fly ash doses applied with and without FYM on phosphorus content of different plant parts of paddy at harvest

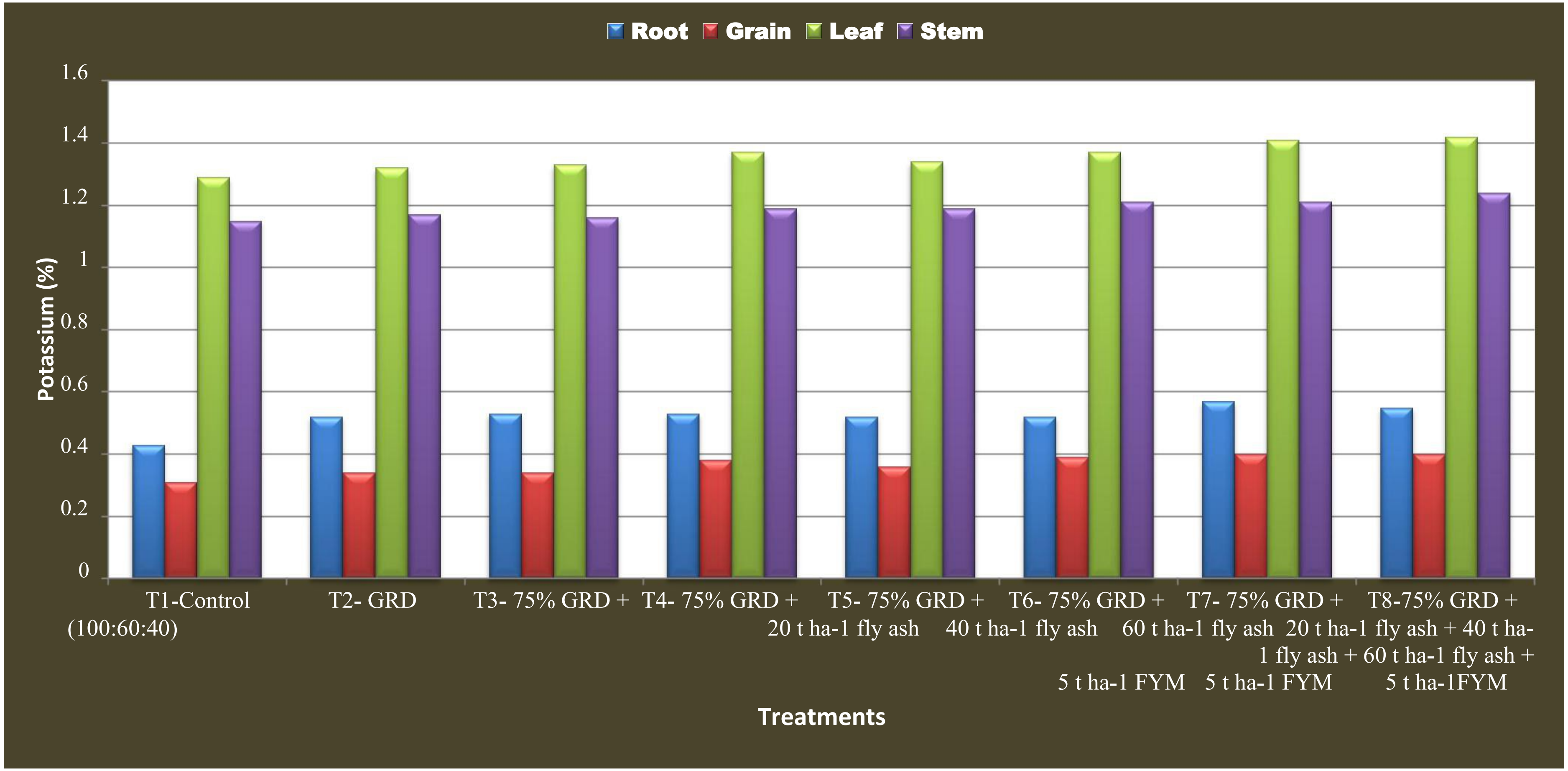


Fig.4.7.3 Effect of fly ash doses applied with and without FYM on potassium content of different plant parts of paddy at harvest

Selvakumari *et al*. (2000) also showed higher content and uptake of nutrients by rice when FA @ 40 t ha^{-1} was applied along with chemical fertilizers and compost.

The trend of nutrients concentration in different plant parts observed was also supported by the results of Brannvall *et al*.(2014), Zhao *et al*.(2010), Wang-da *et al*. (2005), Warambhe *et al.* (1993) and Jambagi *et al*. (1995).

4.8 Partitioning of micro nutrients in different rice plant parts

The micronutrient (Fe, Mn, Zn and Cu) concentration in the paddy plant parts is shown in table 4.8.1 to 4.8.4 and figure 4.8.1 to 4.8.4.

4.8.1 Iron

The average concentration of Fe in the paddy plant parts are presented in table 4.8.1 and figure 4.8.1. It can be seen that that the highest accumulation occurred in the roots by different treatments of fly ash. Fe concentration in roots as influenced by different doses of fly ash was significant. Fly ash applied with and without FYM significantly increased Fe content of root except 75% GRD + 20 t ha^{-1} fly ash treatment as compared GRD.

Grain Fe concentration was significantly influenced by all treatments of fly ash combined with or without FYM over the GRD except 75% GRD + 20 t ha^{-1} fly ash treatment. Among the treatments, 75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM showed the highest (124.67 mg kg^{-1}) concentration and control the lowest (110.65 mg kg^{-1}).

All the all treatments of fly ash significantly increased Fe concentration in leaf as compared to control. Application of 75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM significantly increased leaf Fe over 100% recommended dose of NPK. Integration of FA, chemical fertilizer and FYM showed maximum accumulation of Fe in leaf than application of fly ash without FYM.

The concentration iron (Fe) in stem of rice as influenced by different treatments was significantly influenced over control. Fly ash applied @ 20, 40 and 60 t ha^{-1} combination with 5 t ha^{-1} FYM and 75% recommended dose of NPK showed significantly higher Fe contentas compare to GRD. All other treatments were statistically at par.

Iron concentrations varied in order from root > leaf > stem> grain in the plant was due to the absorption by roots is higher from the plants surrounding soil.

4.8.2 Manganese

The results on concentration of manganese in the plants parts of rice as influenced by the different levels of fly ash are presented in table 4.8.2 and figure 4.8.2. Fly ash applied 20, 40 and 60 t ha^{-1} with and without FYM significantly increased Mn concentration in leaf except 75% GRD + 20 t ha^{-1} fly ash treatment over GRD. Integration of 60 t ha^{-1} fly ash + 75% GRD with FYM showed maximum (157.68 mg kg^{-1}**)** whereas control showed minimum (144.24 mg kg^{-1}**)** accumulation of Mn in leaf. Manganese content of leaf was higher than grain.

The distribution of Mn content in different plant parts was in the order of leaf>stem>root>grain.

Manganese concentration of root, grain and stem of rice increased but non significantly by the different treatments of fly ash with and without FYM. Different concentration of Mn between two levels of FA along with 75 % recommended dose of NPK and with and without organic fertilizer was not significant.

4.8.3 Zinc

Zinc concentration in plant parts in rice was influenced due to application of fly ash with and without organic manure (Table 4.8.3 and Figure 4.8.3). Zinc concentration in grain in different treatments of fly ash was increased as compared to control and 100% recommended dose of NPK. Fly ash applied @ 20 and 40 t ha^{-1} with and without FYM significantly increased Zn content over 100% GRD. Maximum accumulation of zinc in grain was when fly ash applied with FYM as compared to without FYM.

Table 4.8.1 Effect of fly ash doses applied with and without FYM on Fe content of different plant parts of paddy at harvest

Treatment	Fe content (mg kg^{-1})											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	311.00	313.33	312.17	109.33	112.00	110.65	221.33	224.00	222.67	214.67	211.33	213.00
T_2- GRD (100:60:40)	323.67	320.67	322.17	111.00	113.00	112.00	228.00	226.67	227.33	218.33	219.33	218.83
T_3- 75% GRD + 20 t ha^{-1} fly ash	331.00	328.33	329.67	107.33	118.33	112.83	229.67	230.67	230.17	218.00	221.33	219.67
T_4- 75% GRD + 40 t ha^{-1} fly ash	336.33	335.00	335.67	115.67	121.33	118.50	231.33	235.33	233.33	221.67	225.00	223.33
T_5- 75% GRD + 60 t ha^{-1} fly ash	339.00	328.33	333.67	120.00	117.00	118.50	234.67	231.33	233.00	223.00	219.33	221.17
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	323.00	333.33	328.17	118.00	124.67	121.33	226.00	231.67	228.83	222.67	229.00	225.83
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	337.00	341.33	339.17	121.00	125.67	123.33	228.33	238.33	233.33	225.67	231.33	228.50
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	343.00	336.67	339.83	124.57	124.77	124.67	241.00	234.67	237.83	226.33	230.00	228.17
SEm±	**6.28**	**3.56**	**3.09**	**2.87**	**2.47**	**1.77**	**5.56**	**3.10**	**3.39**	**3.38**	**3.50**	**2.28**
CD (P=0.05)	**19.05**	**10.79**	**9.38**	**8.71**	**7.52**	**5.37**	**NS**	**NS**	**10.25**	**NS**	**10.6**	**6.92**
Non amended plant (Near by)		**310.1**			**119.5**			**225.2**			**215.2**	

Total Fe (mg kg^{-1}): Fly ash - 4132 FYM- 325.75 **MPL (mg kg^{-1}):** 425

Table 4.8.2 Effect of fly ash doses applied with and without FYM on Mn content of different plant parts of paddy at harvest

Treatment	Mn content ($mg\ kg^{-1}$)											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	84.67	89.73	87.20	62.33	73.67	68.00	141.67	144.24	142.95	130.33	134.48	132.41
T_2- GRD (100:60:40)	89.00	92.72	90.86	66.67	72.67	70.17	141.33	150.36	145.85	131.00	136.14	133.57
T_3- 75% GRD + 20 t ha^{-1} fly ash	92.67	96.18	94.43	66.67	78.67	72.67	143.67	150.06	146.87	132.67	141.49	137.08
T_4- 75% GRD + 40 t ha^{-1} fly ash	96.00	100.33	98.16	68.00	84.00	76.00	155.00	152.28	153.64	134.00	145.35	139.68
T_5- 75% GRD + 60 t ha^{-1} fly ash	99.67	97.91	98.79	69.33	75.33	72.33	148.33	153.83	151.08	132.00	145.47	138.74
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	91.33	103.32	97.33	70.67	82.00	76.33	148.67	157.78	153.22	133.67	147.57	140.62
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	96.33	107.63	101.98	71.67	87.67	79.67	151.00	158.63	154.82	139.33	151.14	145.24
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	94.33	108.14	101.24	77.67	89.00	83.33	157.33	158.03	157.68	140.67	148.93	144.80
SEm±	**3.94**	**5.30**	**4.36**	**5.81**	**5.02**	**4.85**	**2.65**	**2.62**	**1.82**	**2.73**	**4.82**	**3.17**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**8.06**	**7.95**	**5.52**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**98.4**			**74.3**			**145.1**			**138.3**	

Total Mn ($mg\ kg^{-1}$): Fly ash – 125.0 FYM- 52.52 **MPL ($mg\ kg^{-1}$):** 500

Table 4.8.3 Effect of fly ash doses applied with and without FYM on Zn content of different plant parts of paddy at harvest

Treatment	Zn content (mg kg^{-1})											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	41.33	35.02	38.18	14.00	15.14	14.57	25.67	23.55	26.00	24.67	21.18	22.92
T_2- GRD (100:60:40)	38.00	42.32	40.16	14.33	14.06	14.20	27.67	25.97	28.12	25.00	22.95	23.97
T_3- 75% GRD + 20 t ha^{-1} fly ash	41.33	42.72	42.03	15.67	17.98	16.82	29.00	28.85	31.15	26.67	23.32	25.00
T_4- 75% GRD + 40 t ha^{-1} fly ash	42.33	48.82	45.58	16.33	20.84	18.59	28.00	32.37	30.92	27.00	24.24	25.62
T_5- 75% GRD + 60 t ha^{-1} fly ash	42.00	40.21	41.11	17.00	21.26	19.13	30.67	31.66	32.14	28.33	27.32	27.83
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	41.67	49.63	45.65	17.00	16.94	16.97	27.00	33.66	30.19	25.67	28.18	26.93
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	43.33	50.49	46.91	19.67	20.25	19.96	31.33	34.62	33.15	28.00	28.18	28.09
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	44.00	51.43	47.72	20.67	20.45	20.56	31.00	32.73	32.43	27.33	29.21	28.27
SEm±	**2.40**	**3.89**	**2.24**	**1.76**	**1.26**	**1.04**	**1.17**	**2.02**	**1.17**	**2.04**	**2.86**	**1.80**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**3.83**	**3.16**	**3.57**	**6.13**	**3.57**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**49.3**			**20.5**			**38.2**			**25.1**	

Total Zn (mg kg^{-1}): Fly ash – 70.0 FYM- 18.32 **MPL (mg kg^{-1}):** 50

Table 4.8.4 Effect of fly ash doses applied with and without FYM on Cu content of different plant parts of paddy at harvest

Treatment	**Cu content (mg kg^{-1})**											
	Root			**Grain**			**Leaf**			**Stem**		
	2016	**2017**	**Pooled**	**2016**	**2017**	**Pooled**	**2016**	**2017**	**Pooled**	**2016**	**2017**	**Pooled**
T_1-Control	28.33	26.67	27.50	10.00	12.33	9.67	17.00	17.50	16.25	13.00	13.50	11.58
T_2- GRD (100:60:40)	32.33	29.67	31.00	11.33	13.33	10.83	16.33	17.67	16.00	14.00	15.33	13.33
T_3- 75% GRD + 20 t ha^{-1} fly ash	33.67	31.33	32.50	11.67	15.67	12.17	18.33	20.50	18.42	13.67	16.43	13.22
T_4- 75% GRD + 40 t ha^{-1} fly ash	34.00	33.00	33.50	12.00	17.00	13.00	18.00	19.67	17.83	15.33	17.67	16.50
T_5- 75% GRD + 60 t ha^{-1} fly ash	32.67	30.00	31.33	11.33	17.00	12.67	19.33	21.83	19.58	14.67	17.00	15.50
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	33.00	31.67	32.33	12.67	15.00	12.33	18.00	18.40	17.20	13.67	19.33	16.67
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	35.00	34.00	34.50	13.00	19.33	14.67	20.00	19.00	18.50	17.67	22.80	18.23
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	35.33	33.33	34.33	16.00	20.33	16.67	21.67	21.47	20.57	20.67	23.00	21.33
SEm±	**1.54**	**3.36**	**1.71**	**1.02**	**1.74**	**0.97**	**1.51**	**2.17**	**1.22**	**2.67**	**3.03**	**2.19**
CD (P=0.05)	**NS**	**NS**	**NS**	**3.10**	**5.28**	**2.96**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**32.4**			**15.5**			**18.2**			**16.4**	

Total Cu (mg kg^{-1}): Fly ash – 24.0 FYM- 12.0 **MPL (mg kg^{-1}):** 40

Zinc concentration in different plant parts showed a decreasing pattern of root > leaf > stem > grain.

Zinc accumulation in leaf by different fly ash treatments increased significantly as compared to 100% GRD, except 75% GRD + 20 t ha^{-1} fly ash treatment. Among the treatments, 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM recorded higher absorption. Zinc content of leaf and stem was slightly higher than the grain.

Zinc concentration in stem and root was not significantly affected by increasing doses of fly ash with and without FYM. However, slightly higher Zn concentration was observed in treatments than the control and 100% recommended dose of NPK.

4.8.4 Copper

Influence of various doses of fly ash combined with and without FYM on concentration of copper in different plant parts is presented in table 4.8.4 and fig. 4.8.4. The copper concentration in grain was significantly influenced by different doses of fly ash as compared to control. Application of 20 and 40 t ha^{-1} fly ash with FYM significantly increased concentration in grain over GRD. Highest (16.67 mg kg^{-1}) concentration of Cu was observed with 60 t ha^{-1} fly ash + 75% GRD + 5 t ha^{-1} FYM and lowest (9.67 mg kg^{-1}) in the control.

Copper concentrations varied in descending order from root > leaf > grain> stem.

Copper accumulation in root, leaf and stem was non-significantly influenced by the fly ash treatments but marginal increase was noticed over control and GRD.

Copper is one of the nutrients needed to process a variety of enzyme activity and acts as an ‘electron carrier’ in an enzyme and brings redox reaction to regulate respiratory activity in plants. However, the presence of copper metal that exceeded the permissible limits or standards may cause stunted roots growth and plants**.**

The occurrence of micronutrients in different plant parts (root, grain, leaf and stem) of rice was in the order Fe>Mn >Zn> Cu.

The increased accumulation of micronutrients in different plant parts of rice due to fly ash treatments might be due to increased activity of ionic transporter in nutrients by increased doses of fly ash and FYM. Nutrient accumulation in leaf was higher than grain which was due to low mobility of these nutrients from the former to the later.

The trend in concentration of the nutrients accumulated in different plant parts observed in the experiment was also similar as observed by Tripathi *et al*. (1997) and Hopkins (1999). They reported that the Cu, Zn, and Mn accumulated at its highest concentration in roots of the rice plant and followed by leafs and grains. Most metals that were found abundantly in the paddy plants were nutrients like Fe, Mn, Zn, and Cu that are required for various enzyme activities and play an important role in photosynthesis and growth of the plant.

Accumulation of nutrient in the plant parts depend on the concentration of soil available micronutrient, solubility sequence and the plant species growing on these soils**.** Various findings also suggest that the micronutrients content was more in roots of the plants grown on FA amended soil.

In soil, iron and manganese have an oxidative or catalytic effect and maintain an optional nutritional balance for normal growth with increases in concentration of fly ash, the availability of micronutrients was increased.

Yap *et al*. (2009) also reported micronutrient content to be higher in root and leaf by integrated application of FA with recommended dose of NPK and FYM which might be due to creation of congenial environment around the rhizospheric zone, one of the causes may be reduction in bulk density of the soil due to which higher diffusion of nutrients occurring to root zone. The increase in micronutrient content in different plant parts was due to improve balance nutrient and their uptake.

The trend of micronutrient content in different plant parts was also supported by the results of Mongia *et al*. (2003), Singh *et al*. (1996), Milovsky and Konovnov (1992) and Bruggermann *et al*. (1990).

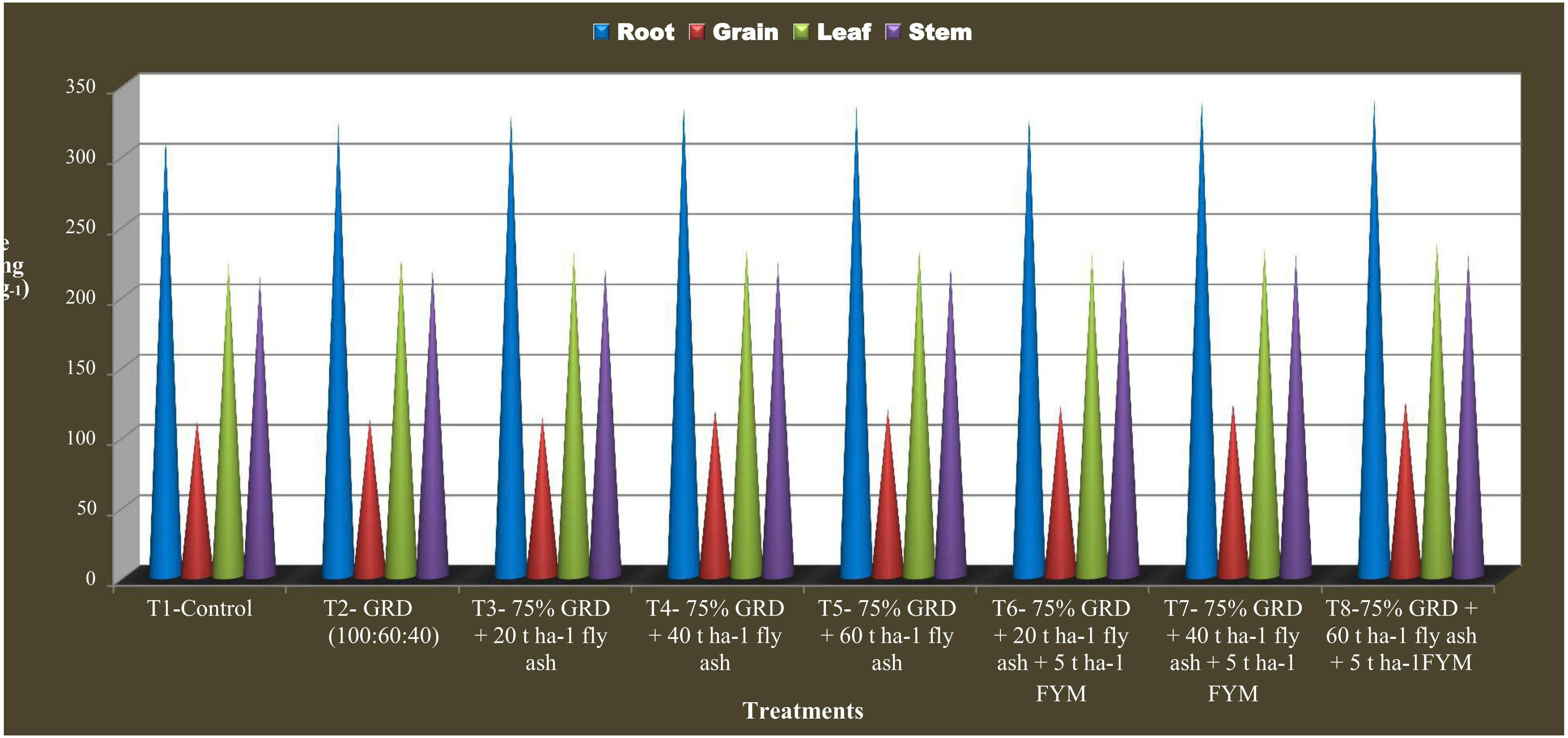


Fig.4.8.1 Effect of fly ash doses applied with and without FYM on Fe content of different plant parts of paddy at harvest

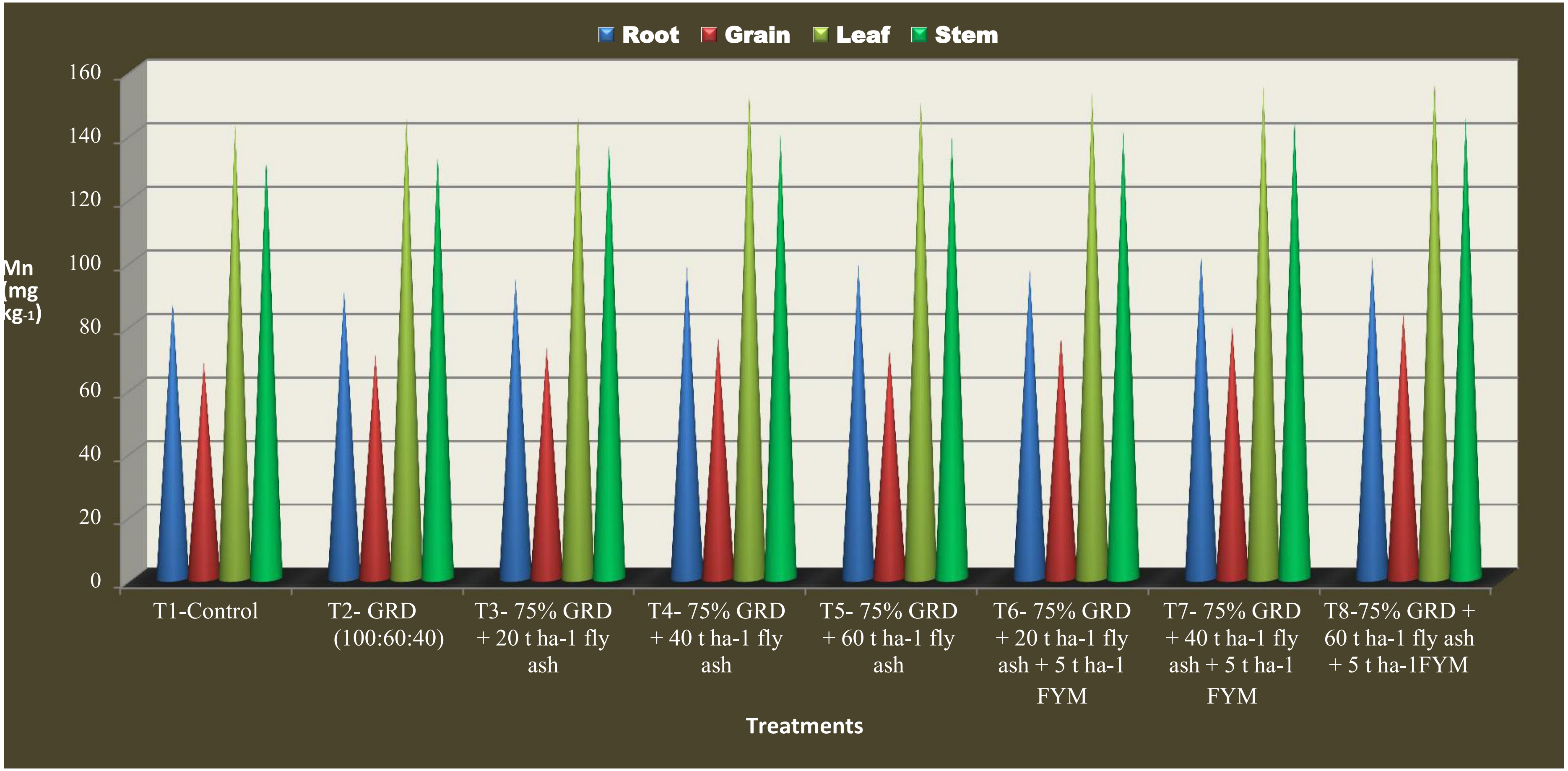


Fig.4.8.2 Effect of fly ash doses applied with and without FYM on Mn content of different plant parts of paddy at harvest

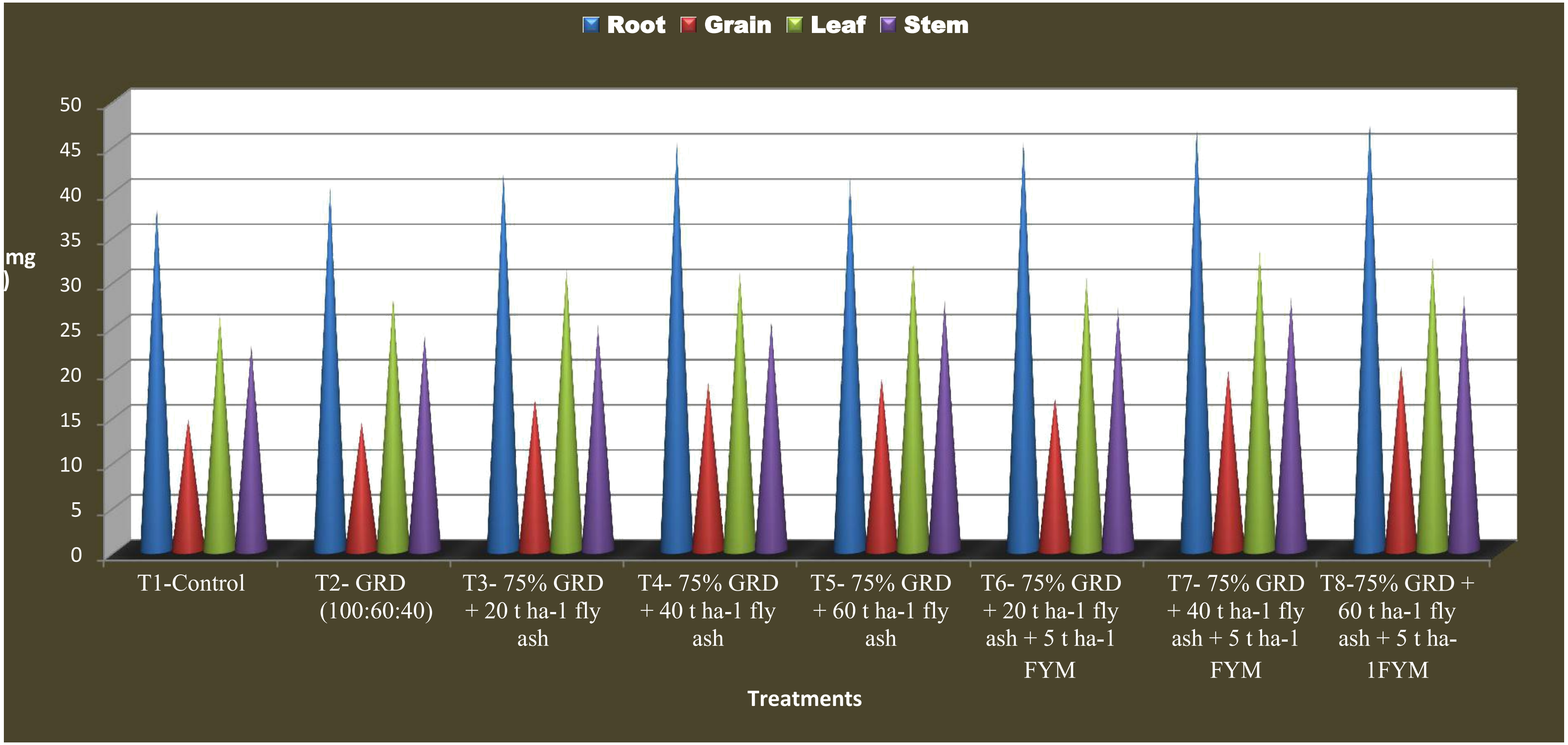


Fig.4.8.3 Effect of fly ash doses applied with and without FYM on Zn content of different plant parts of paddy at harvest

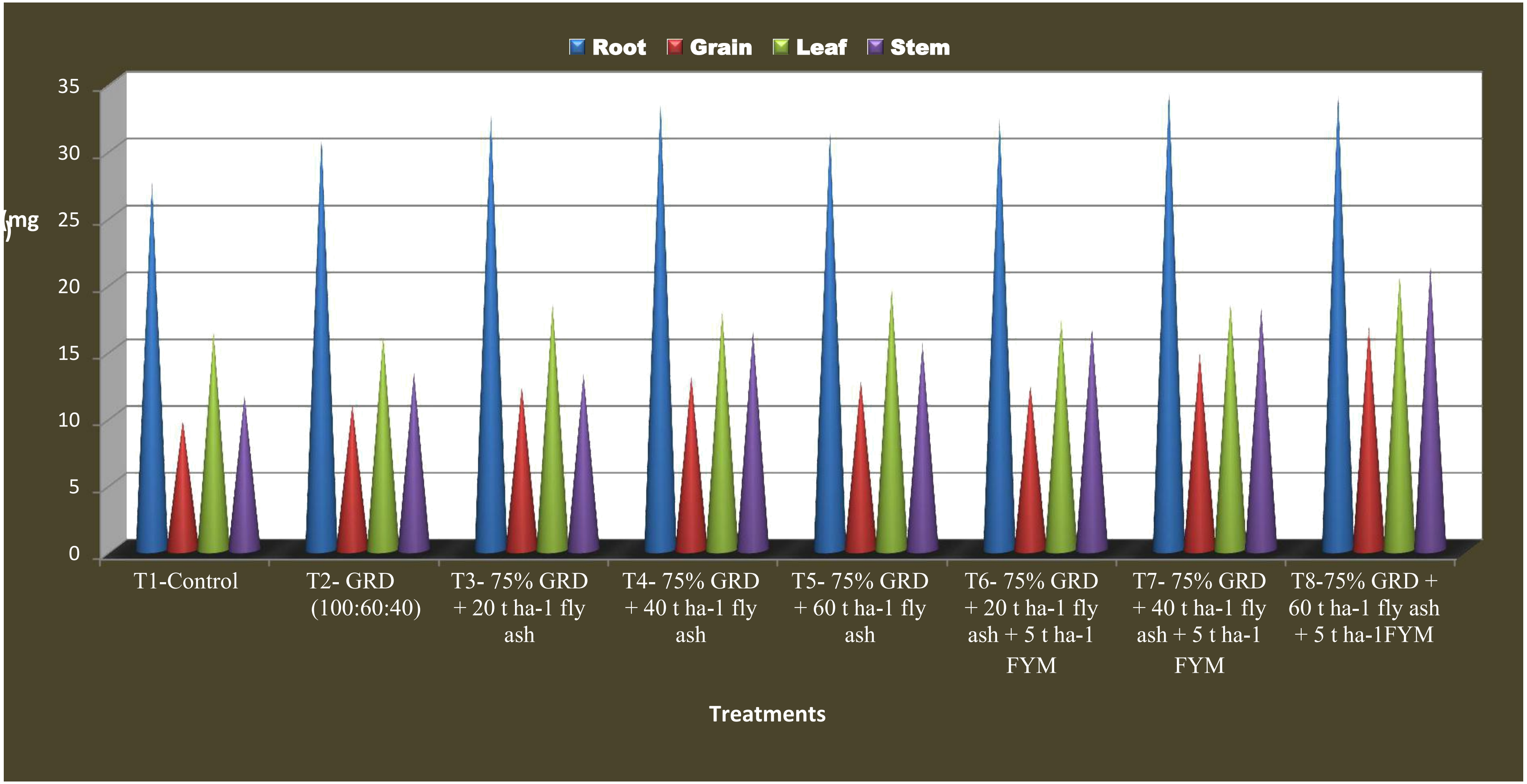


Fig.4.8.4 Effect of fly ash doses applied with and without FYM on Cu content of different plant parts of paddy at harvest

The result of micronutrient content is higher in rice root was also reported by Lee *et al*. (2006), Sinha and Gupta (2005), Hall and Williams (2003) and Srivastava and Chhonkar (2000).

4.9 Partitioning of heavy metals in different rice plant parts

The effect of the different doses fly ash integrated with and without FYM on chromium, cobalt, nickel, lead and cadmium concentration in different plant parts of rice is presented in table 4.9.1 to 4.9.5 and fig.4.9.1 to 4.9.5.

4.9.1 Chromium

The chromium concentration in grain and leaf was significantly increased due to the different fly ash treatments but non-significant in root and stem part of rice. (Table 4.9.1 and Fig.4.9.1).

Chromium concentration showed a decreasing pattern from root > leaf > stem > grain.

The various treatments of fly ash with and without FYM and fertilizer significantly increased concentration of Cr in grain over control but statistically at par over 100 % recommended dose of NPK. Among the treatments, 75% GRD + 60 t ha^{-1} fly ash recorded the highest (5.07 mg kg^{-1}) and control showed the lowest (3.19 mg kg^{-1}). It was higher when fly ash was applied without FYM as compare to with FYM.

Fly ash applied @ 40 and 60 t ha^{-1} with and without FYM significantly influenced chromium content in leaf over control and 100 % recommended dose of NPK. Its accumulation was also higher when fly ash was applied without FYM. Among the treatments, 75% GRD + 60 t ha^{-1} fly ash recorded the highest (7.55 mg kg^{-1}) content and control showed the lowest (6.74 mg kg^{-1}).

4.9.2 Cobalt

The cobalt accumulation in different plant parts of rice as influenced by the different doses of fly ash with and without organic manure are shown in table 4.9.2 and fig.4.9.2.

Cobalt concentrations varied in descending order from root > leaf > grain> stem.

Cobalt content in leaf is significantly influenced by the different fly ash treatments over control. Application of fly ash @ 40 and 60 t ha^{-1} without FYM recorded significantly higher Co content over 100% recommended dose of NPK. Application of 75% GRD + 60 t ha^{-1} fly ash recorded the highest Co content (5.24 mg kg^{-1}) and control showed the lowest (3.93 mg kg^{-1}).

Application of fly ash @ 40 and 60 t ha^{-1} without FYM and 60 t ha $^{-1}$ fly ash + 5 t ha^{-1} FYM recorded higher Co in the stem over 100 % recommended dose of NPK. Accumulation was highest with 60 t ha^{-1} of fly ash without FYM application.

In root and grain, the content was not affected by the different treatments of fly ash when compared to control and GRD.

4.9.3 Nickel

Table 4.9.3 fig.4.9.3 showed nickel concentration in different plant parts of rice as influenced by graded dose of fly ash. It increased significantly in leaf but not in root, grain and stem when compared to control and 100% GRD.

Application of 75% GRD + 60 t ha^{-1} fly ash recorded the highest accumulation while, control recorded the lowest. Nickel concentrations varied in descending order from root > leaf > grain> stem.

4.9.4 Lead

Influence of the various doses of fly ash with and without organic manure on the average lead content in different parts is presented in table 4.9.4 and fig.4.9.4

All the treatments of fly ash with and without FYM significantly influenced lead accumulation in root over control. Among the treatments 75% GRD + 60 t ha^{-1} fly ash treatment showed significantly higher content when compared to 100 % recommended dose of NPK. Application of 75% GRD + 60 t ha^{-1} fly ash recorded the highest (3.83 mg kg^{-1}) content and control showed the lowest (3.25 mg kg^{-1}).

Table 4.9.1 Effect of fly ash doses applied with and without FYM on Cr content of different plant parts of paddy at harvest

Treatment	Cr content (mg kg^{-1})											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	6.90	6.15	6.53	3.99	3.83	3.91	7.37	6.12	6.74	4.96	4.71	4.84
T_2- GRD (100:60:40)	7.20	6.87	7.04	4.52	4.46	4.49	7.56	5.78	6.67	5.63	4.89	5.26
T_3 - 75% GRD + 20 t ha^{-1} fly ash	7.21	7.11	7.16	4.62	4.61	4.62	7.87	6.19	7.03	5.65	5.52	5.59
T_4 - 75% GRD + 40 t ha^{-1} fly ash	7.38	7.29	7.33	5.17	4.71	4.94	8.02	6.29	7.16	5.76	5.68	5.72
T_5 - 75% GRD + 60 t ha^{-1} fly ash	7.66	7.30	7.48	5.11	5.03	5.07	8.10	6.98	7.55	6.02	6.10	6.06
T_6 - 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	6.86	6.98	6.92	4.61	4.10	4.36	7.43	6.20	6.82	5.66	5.61	5.63
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	6.99	7.16	7.08	4.63	4.60	4.65	7.95	6.34	7.15	5.99	5.72	5.86
T_8 -75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	7.67	7.23	7.45	4.72	4.70	4.72	7.97	7.12	7.54	6.13	5.92	6.03
SEm±	**0.30**	**0.29**	**0.20**	**0.19**	**0.27**	**0.17**	**0.15**	**0.27**	**0.14**	**0.33**	**0.50**	**0.36**
CD (P=0.05)	**NS**	**NS**	**NS**	**0.60**	**NS**	**0.54**	**0.45**	**NS**	**0.44**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**6.12**			**4.32**			**6.24**			**5.19**	

Total Cr (mg kg^{-1}): Fly ash – 41.50 FYM- 14.85 **MPL (mg kg^{-1}):** 20

Table 4.9.2 Effect of fly ash doses applied with and without FYM on Co content of different parts of plant paddy at harvest

Treatment	Co content (mg kg^{-1})											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	5.07	4.94	5.01	1.99	2.47	2.23	3.58	4.27	3.93	2.75	1.72	2.23
T_2- GRD (100:60:40)	4.97	4.93	4.95	2.73	2.32	2.52	4.16	4.47	4.32	3.23	1.97	2.60
T_3- 75% GRD + 20 t ha^{-1} fly ash	5.27	5.31	5.29	2.36	2.88	2.62	4.40	4.56	4.48	3.30	2.23	2.76
T_4- 75% GRD + 40 t ha^{-1} fly ash	5.30	5.37	5.34	2.84	3.64	3.24	4.50	5.13	4.82	3.67	2.77	3.22
T_5- 75% GRD + 60 t ha^{-1} fly ash	5.60	6.13	5.87	3.13	3.59	3.36	5.17	5.31	5.24	3.77	3.01	3.39
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	4.90	5.21	5.06	2.39	2.78	2.58	3.95	4.49	4.22	2.83	2.14	2.49
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	5.47	5.26	5.36	2.77	2.79	2.78	4.52	4.57	4.55	2.95	2.24	2.60
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	5.57	5.27	5.42	2.85	2.97	2.91	4.58	4.82	4.70	3.73	2.77	3.25
SEm±	**0.48**	**0.43**	**0.43**	**0.37**	**0.42**	**0.33**	**0.21**	**0.30**	**0.15**	**0.31**	**0.26**	**0.19**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.63**	**NS**	**0.47**	**NS**	**0.18**	**0.58**
Non amended plant (Near by)		**5.28**			**2.19**			**4.21**			**2.34**	

Total Co (mg kg^{-1}): Fly ash – 70.0 FYM- 17.32 **MPL (mg kg^{-1}):** 50

Table 4.9.3 Effect of fly ash doses applied with and without FYM on Ni content of different plant parts of paddy at harvest

Treatment	Ni content (mg kg^{-1})											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	14.03	12.64	13.34	8.56	7.30	7.93	10.80	9.98	10.39	6.86	8.52	7.69
T_2- GRD (100:60:40)	13.90	12.72	13.31	9.44	7.61	8.53	11.77	10.78	11.27	8.24	9.12	8.68
T_3- 75% GRD + 20 t ha^{-1} fly ash	14.17	13.33	13.75	9.75	8.78	9.27	10.73	11.28	11.01	8.28	9.33	8.81
T_4- 75% GRD + 40 t ha^{-1} fly ash	14.23	13.46	13.85	9.80	8.81	9.31	12.08	11.50	11.79	9.03	9.36	9.19
T_5- 75% GRD + 60 t ha^{-1} fly ash	14.73	14.09	14.41	9.85	8.86	9.36	13.12	11.76	12.44	9.14	10.23	9.68
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	13.93	13.42	13.67	8.98	7.80	8.39	11.71	10.53	11.12	8.32	8.96	8.64
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	14.20	13.56	13.88	9.74	7.98	8.86	12.18	10.95	11.56	8.27	9.32	8.80
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	14.53	13.59	14.06	10.22	8.53	9.37	12.48	11.40	11.94	8.36	9.41	8.88
SEm±	**0.28**	**0.35**	**0.25**	**0.50**	**0.52**	**0.47**	**0.52**	**0.28**	**0.33**	**0.62**	**0.30**	**0.34**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.85**	**1.00**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**11.23**			**7.59**			**8.96**			**9.23**	

Total Ni (mg kg^{-1}): Fly ash – 31.80 FYM- 13.00 **MPL (mg kg^{-1}):** 20-30

Table 4.9.4 Effect of fly ash doses applied with and without FYM on Pb content of different plant parts of paddy at harvest

Treatment	Pb content (mg kg^{-1})											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	3.15	3.35	3.25	2.00	1.92	1.96	2.73	2.67	2.70	1.97	2.75	2.36
T_2- GRD (100:60:40)	3.47	3.52	3.49	2.03	1.95	1.99	2.70	2.78	2.74	2.27	2.77	2.52
T_3- 75% GRD + 20 t ha^{-1} fly ash	3.67	3.72	3.69	2.04	2.12	2.08	2.73	2.98	2.86	2.17	2.82	2.49
T_4- 75% GRD + 40 t ha^{-1} fly ash	3.47	3.68	3.57	3.12	2.19	2.65	2.83	3.28	3.06	2.23	2.89	2.56
T_5- 75% GRD + 60 t ha^{-1} fly ash	3.84	3.81	3.83	3.23	3.14	3.18	3.10	3.30	3.20	3.17	2.88	3.02
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	3.37	3.49	3.43	2.06	2.17	2.12	2.70	2.93	2.81	2.23	2.77	2.50
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	3.60	3.78	3.69	2.10	2.20	2.15	3.15	3.03	3.09	2.37	2.79	2.58
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	3.37	3.75	3.56	3.16	2.24	2.70	3.03	3.26	3.15	2.27	2.95	2.61
SEm±	**0.15**	**0.11**	**0.09**	**0.23**	**0.23**	**0.13**	**0.19**	**0.14**	**0.12**	**0.24**	**0.05**	**0.11**
CD (P=0.05)	**NS**	**NS**	**0.29**	**0.70**	**NS**	**0.40**	**NS**	**0.42**	**NS**	**NS**	**1.17**	**NS**
Non amended plant (Near by)		**3.1**			**2.4**			**2.61**			**1.98**	

Total Pb (mg kg^{-1}): Fly ash – 16.52 FYM- 10.21 **MPL (mg kg^{-1}):** 5.0

Table 4.9.5 Effect of fly ash doses applied with and without FYM on Cd content of different plant parts of paddy at harvest

Treatment	Cd content (mg kg^{-1})											
	Root			Grain			Leaf			Stem		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T_1-Control	2.16	2.08	2.12	1.79	1.56	1.67	2.45	2.63	2.91	1.81	2.69	2.25
T_2- GRD (100:60:40)	2.73	2.24	2.48	1.88	1.64	1.76	2.72	2.98	3.31	2.00	2.70	2.35
T_3- 75% GRD + 20 t ha^{-1} fly ash	2.78	2.25	2.51	1.92	1.87	1.89	2.78	3.02	3.36	2.01	2.72	2.37
T_4- 75% GRD + 40 t ha^{-1} fly ash	2.82	2.48	2.65	1.96	1.74	1.85	3.12	3.04	3.56	2.01	2.84	2.43
T_5- 75% GRD + 60 t ha^{-1} fly ash	1.88	2.48	2.18	2.00	2.16	2.08	3.24	3.12	3.71	2.12	2.73	2.42
T_6- 75% GRD + 20 t ha^{-1} fly ash + 5 t ha^{-1} FYM	2.76	2.33	2.55	1.87	1.86	1.86	2.74	2.78	3.23	1.99	2.61	2.30
T_7- 75% GRD + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM	2.92	2.35	2.63	1.91	1.87	1.89	2.80	2.80	3.26	2.12	2.81	2.47
T_8-75% GRD + 60 t ha^{-1} fly ash + 5 t ha^{-1}FYM	2.94	2.51	2.73	1.96	2.13	2.05	2.81	3.05	3.38	2.11	2.86	2.48
SEm±	**0.45**	**0.12**	**0.21**	**0.08**	**0.16**	**0.09**	**0.10**	**0.17**	**0.15**	**0.06**	**0.08**	**0.05**
CD (P=0.05)	**NS**	**0.02**	**NS**	**NS**	**NS**	**NS**	**0.30**	**NS**	**NS**	**NS**	**NS**	**NS**
Non amended plant (Near by)		**2.22**			**1.53**			**2.14**			**2.12**	

Total Cd (mg kg^{-1}): Fly ash – 13.50 FYM- 1.6 **MPL (mg kg^{-1}):** 5-10

Application of 60 t ha^{-1} with and without FYM and 40 t ha^{-1} fly ash without FYM showed significantly higher lead content in grain over 100% recommended dose of NPK. It was maximum in grain when fly ash applied @ 60 t ha^{-1} without FYM.

Lead concentration in leaf and stem was not influenced by the treatments of fly ash. Lead concentration showed a decreasing trend in the different plant parts of rice in the order of root > grain > leaf > stem

4.9.5 Cadmium

Cadmium concentration in different plant parts i.e. root, grain, leaf and stem of rice was not significantly influenced by application of fly ash integrated with and without FYM (Table 4.9.5 and fig 4.9.5).Maximum concentration of cadmium when was observed fly ash was applied without FYM than with FYM. Cadmium distribution recorded a decreasing pattern from leaf > root > stem> grain at maturity.

Increasing doses of fly ash with and without FYM showed increased concentration of heavy metals due to high content in fly ash. Metal accumulation was highest in different rice plant parts when fly ash was applied without FYM. In general metal content increased with increase in fly ash level. The concentration of heavy metal in plants depends upon the content of the particular elements in the material used (Soil/ fly ash /FYM), the ratio of ash/ FYM application, the soil properties and the type of plant.

The distribution pattern of heavy metals in different plant parts was the ranking order of Ni > Cr > Co >Pb> Cd and the heavy metals generally accumulate higher in root followed by leaf, grain and stem. This might be due to redox reaction that occurs in the plants which causes the reduction in movement from root to the shoot part.

Bhattacharyya *et al*. (2005) reported that Chromium (III) can also react with carboxylic functional groups (-COOH) in soil and plants which prevents the translocation of the metals from root to the shoot, thus the chromium concentration in the shoot part is low.

From the average concentration of heavy metals in the paddy plant parts, as shown in table 4.9.1 to 4.9.5, it can be seen that all metals under the study were present in the plant parts and that the highest accumulation of metals occurred in the roots, with the exception of Cd, which was highly present in the leaves in higher quantity.

Mo *et al*. (2001) reported that most of the heavy metals absorbed by the paddy plant gets accumulated in the roots, where there was a high metabolic rate and that the accumulation in the stem and leaves was low. The accumulation and distribution of heavy metals in the upper parts of a plant are determined by several factors like crop species, anatomical, biochemical and physiological factors such as bioaccumulation factor, translocation factor and enrichment factor etc.

All the factors and possibility of availability and movement of metals between root and shoot are usually determined by correlating the metal concentration in different plant parts and other elements in the rhizosphere affected the bioavailability and plant uptake of heavy metals from the soils and different plant parts. They also emphasized that plant roots and soil microbes and their interaction could improve the metal bioavailability in rhizosphere through secretion of proton, organic acids, phytochelatins (PCs), amino acid and enzymes.

The heavy metal concentration decreased with application of fly ash in combination with organic manure (FYM) compared to without organic manure. FYM might have played the controlling availability of metals by chelation, adsorption and precipitation. It was possible that high accumulation of elements 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 to upper parts of the plant. The results obtained are also supported from the findings of Singh and Agrawal (2007) and Singh *et al*. (2004).

Pandey *et al*., (2009) and Jala and Goyal, (2006) reported that the availability and bioaccumulation of metal depends on soil environmental factors such as pH, solubility, soil mineralogy, texture, chemical speciation of the metal, presence of humic substances, other organic chelators, presence of other metals and amorphous Fe and Al content. Increasing doses of fly ash have been reported to increase the heavy metals contents in the plants, with highest accumulations reported in the 100 per cent fly ash use.

Singh *et al.* (2016) reported that the metal accumulation in rice root grown in without fly ash was in order of Mn>Zn>Cu>Se>As>Ni>Co>Pb>Hg>Cr>Cd, however, in fly ash treated soil the order was Zn> Mn> Cu> As> Se> Pb>Ni>Cr>Hg>Cd>Co. Interestingly, total accumulation of toxic metals, particularly Cd, Cr, Pb and As was about 5, 5, 4 and three fold higher in plants grown on FA amended soil than GS (garden soil). The total accumulation of toxic metals, particularly Cd, Cr, Pb and As were 14–15 fold higher in roots and shoots and 4–20 fold higher in grains for the plants grown on FA amended soil than GS. Increase in the level of toxic metals such as As, Cd, Hg and Pb was also reported in various plants including rice grown in FA amended soil due to their more availability in FA, depending on physicochemical properties of the soil.

The distribution of heavy metals in different plant parts was also supported by the results of Maiti and Nandhini (2006), Pandey *et al*. (2012), Tripathi *et al*. (2008) and Sinha *et al*. (2007).

The result of heavy metal content in rice root followed by leaf was also reported by Singh *et al*. (2016), Kingsawat and Roachanakana (2011), Ram *et al*. (2006) and Salt *et al*. (1995).

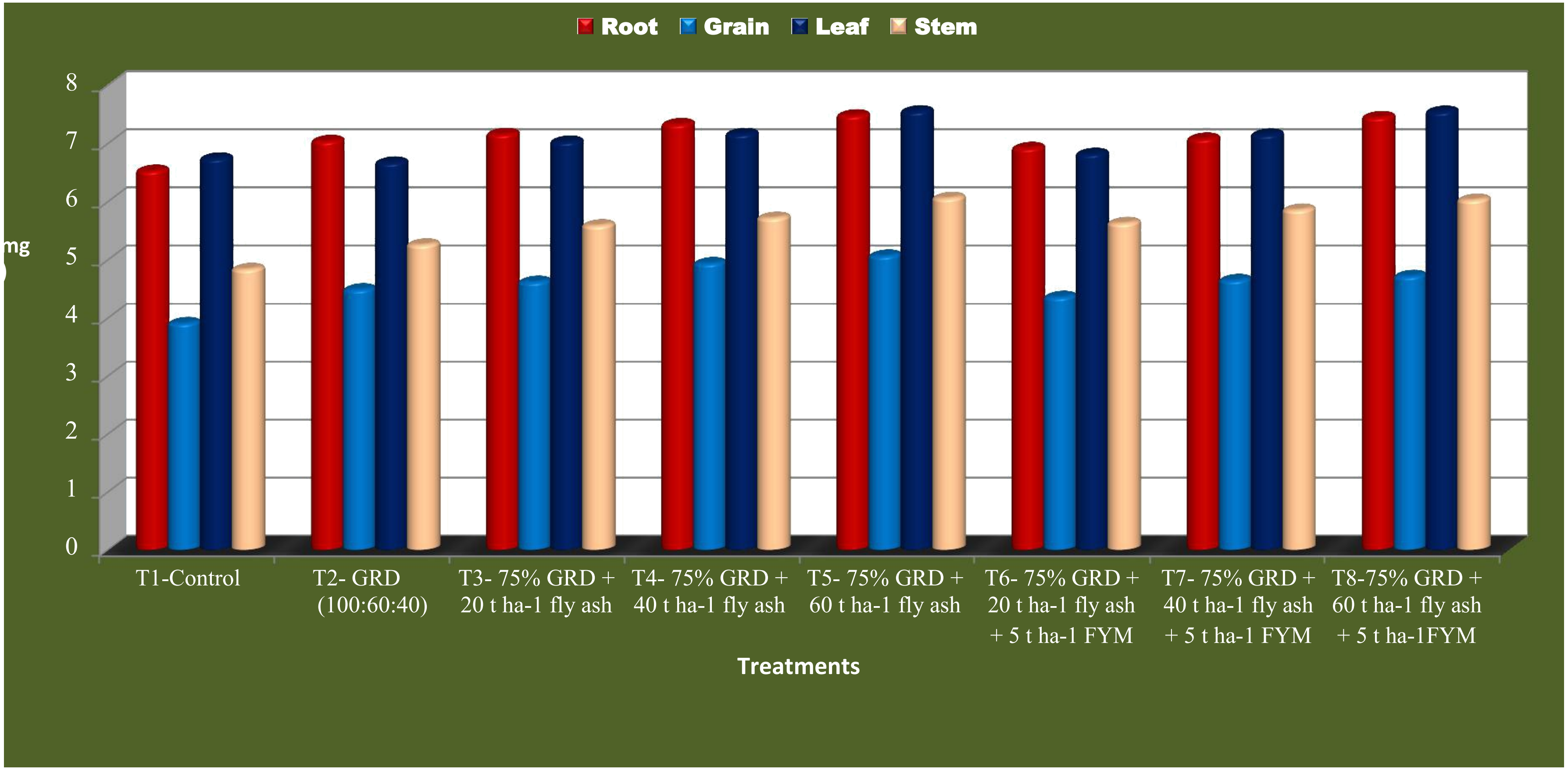


Fig.4.9.1 Effect of fly ash doses applied with and without FYM on Cr content of different plant parts of paddy at harvest

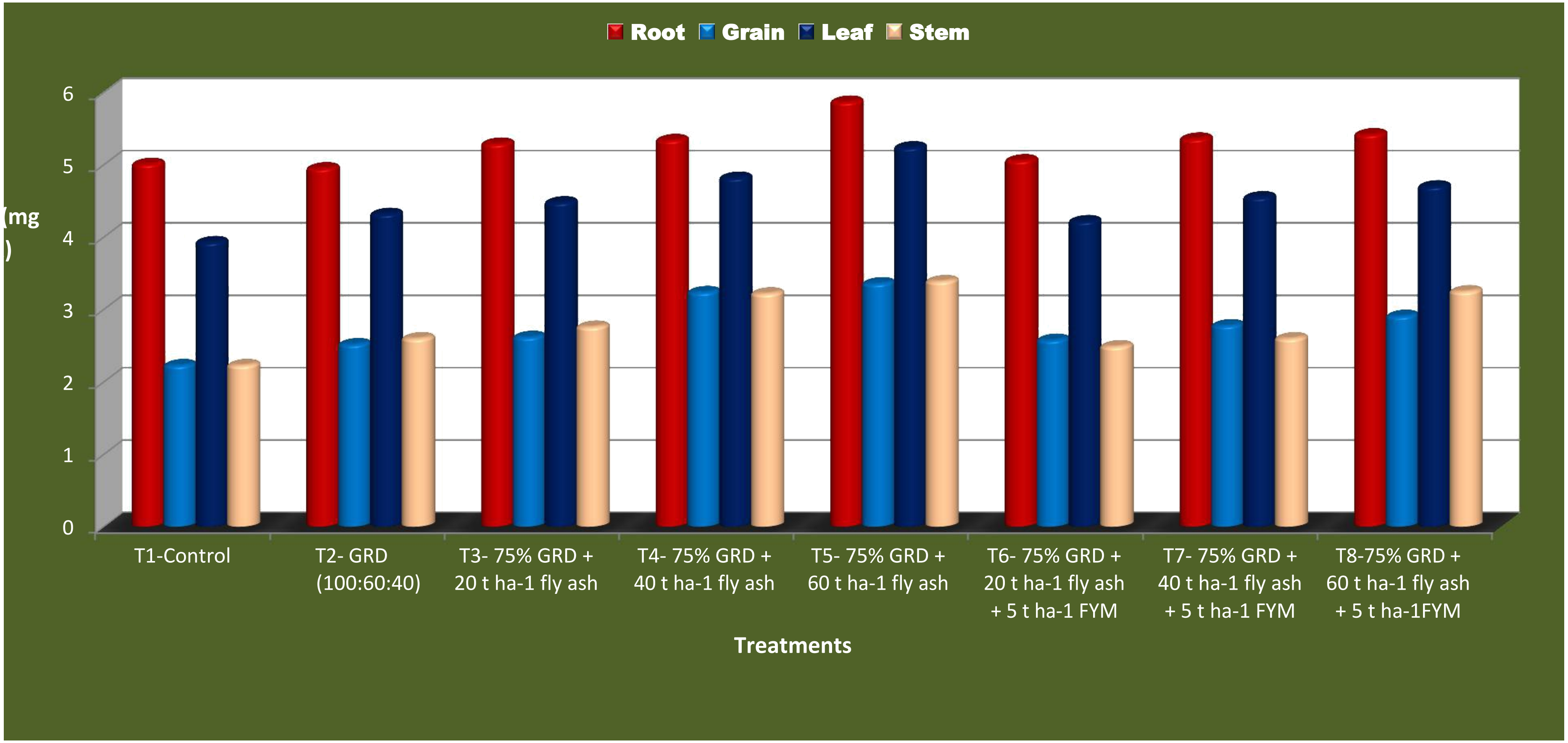


Fig.4.9.2 Effect of fly ash doses applied with and without FYM on Co content of different plant parts of paddy at harvest

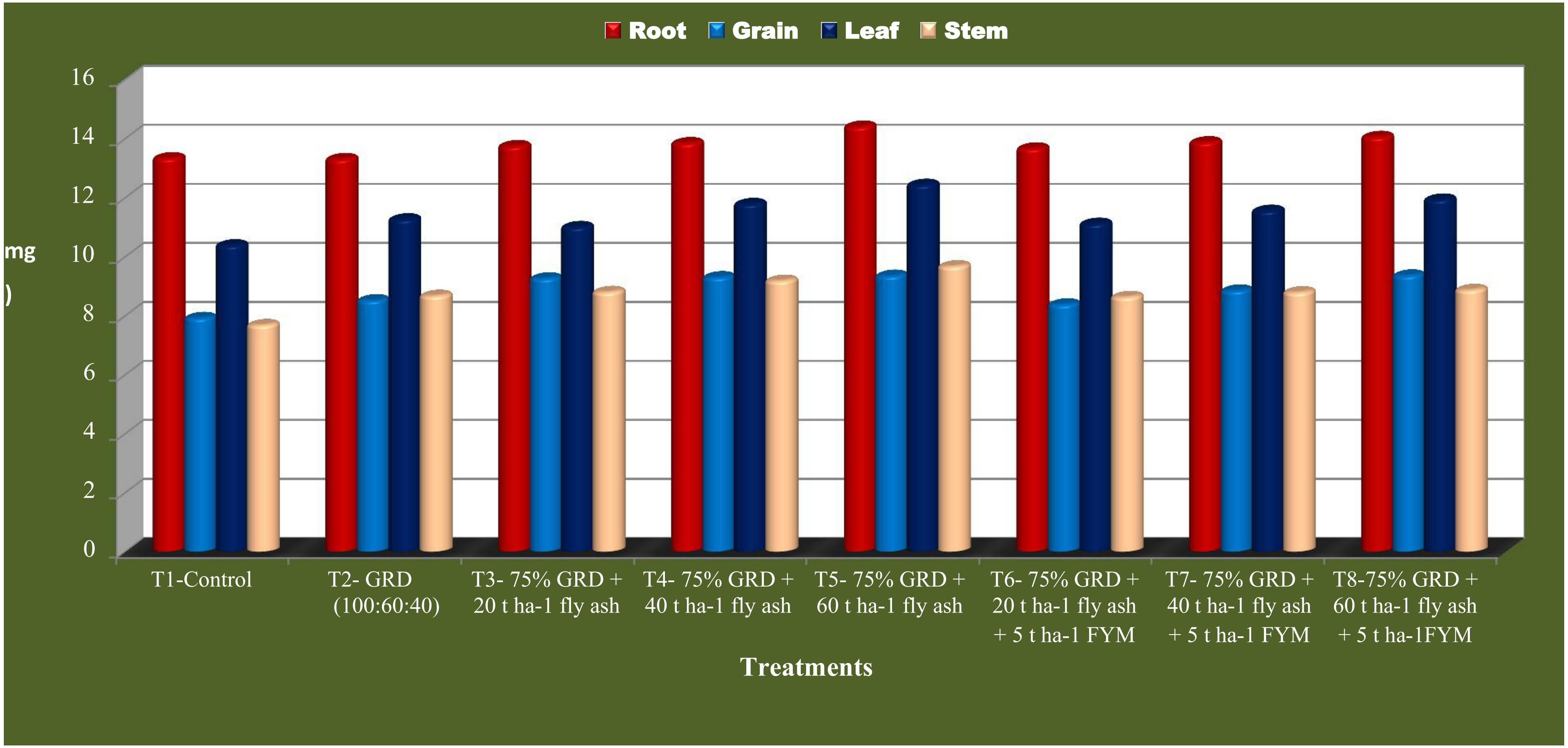


Fig.4.9.3 Effect of fly ash doses applied with and without FYM on Ni content of different plant parts of paddy at harvest

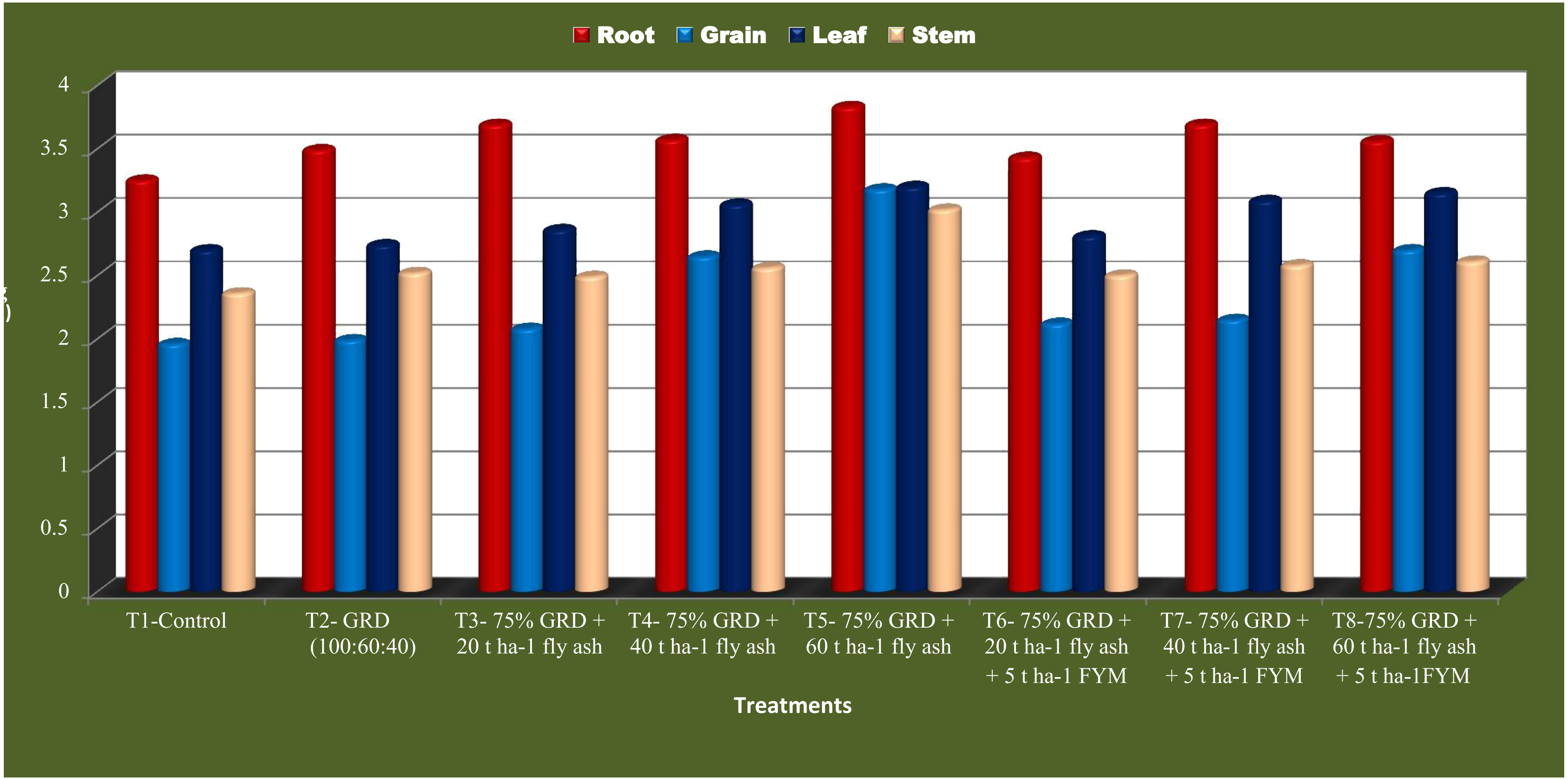


Fig.4.9.4 Effect of fly ash doses applied with and without FYM on Pb content of different plant parts of paddy at harvest

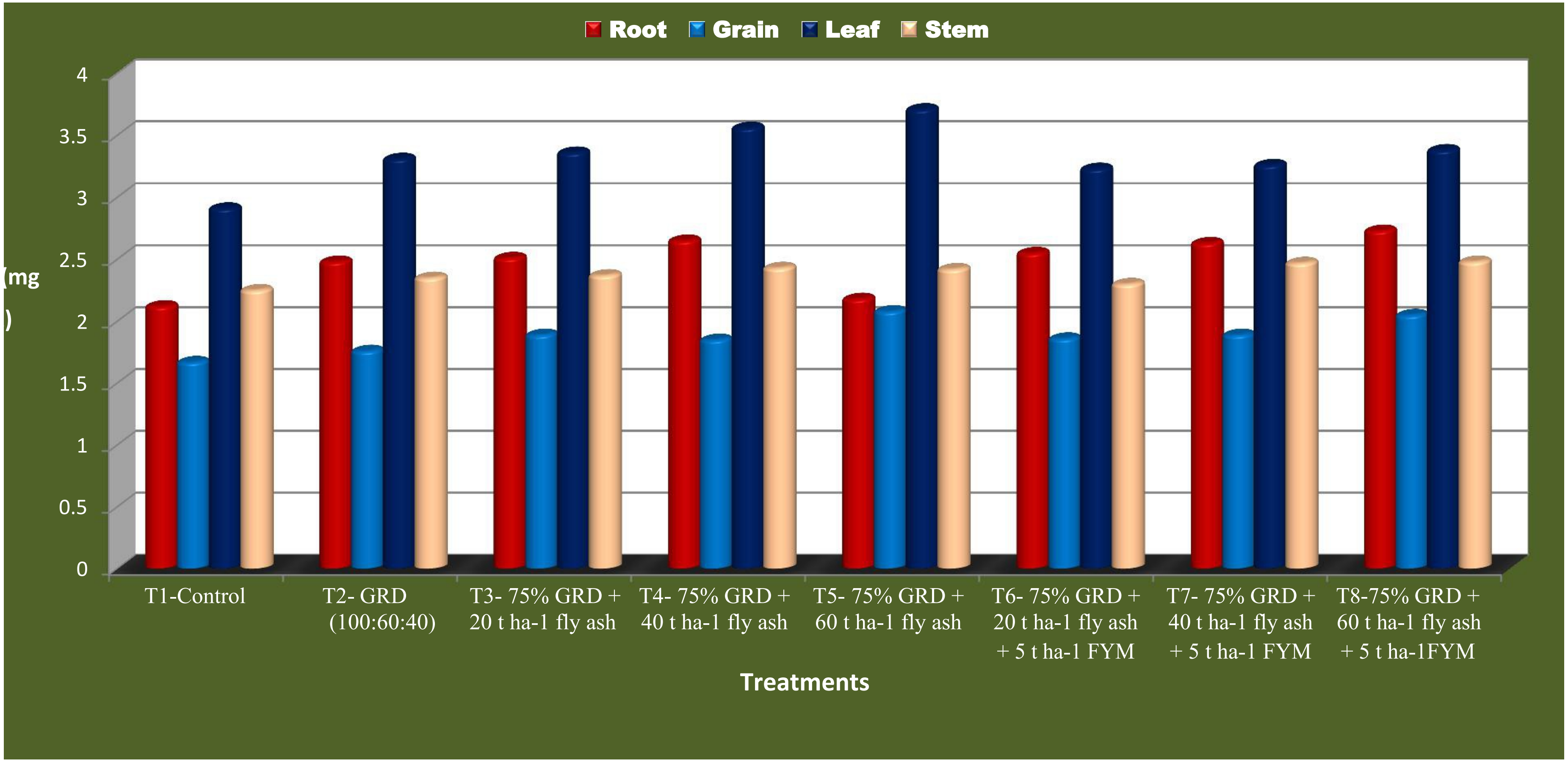


Fig.4.9.5 Effect of fly ash doses applied with and without FYM on Cd content of different plant parts of paddy at harvest

Fig. 4.10 Field view of different treatments of the kharif rice- 2016

Fig. 4.11 Field view of different treatments of the kharif rice- 2017

CHAPTER-V

SUMMARY AND CONCLUSIONS

The experiment entitled **"Study of fly ash incorporation on yield and partitioning of heavy metals in rice"** was carried out during the *kharif* seasons of 2016 and 2017 at the Research Farm of Krishi Vigyan Kendra, Janjgir – Champa, Chhattisgarh.

The experiment was laid in a Randomized Block Design with eight treatments i.e. no fly ash (control) , GRD (100:60:40), 75% GRD + 20 t ha^{-1} fly ash, 75% GRD + 40 t ha^{-1} fly ash, 75% GRD + 60 t ha^{-1} fly ash, 75 % GRD + 20 t ha^{-1} fly ash+ 5 t ha^{-1}FYM, 75 % GRD + 40 t ha^{-1} fly ash+ 5 t ha^{-1} FYM and 75 % GRD + 60 t ha^{-1} fly ash+ 5 t ha^{-1}FYM. The above treatments were randomized with three replications."Rajeshwari (IGKV R-1)" paddy cultivar was the test crop for the experiment.

In Chhattisgarh, fly ash is a serious concern as it is produced in huge quantity from the large number of power plants. Beneficial effect of its utilization in agriculture was reported by several workers due to the presence of various essential plant nutrients which makes a source of supplemental plant nutrient. The beneficial effect of fly ash on the crop mainly depends on quantity of fly ash used physical and chemical characteristics of soil and the presence of many toxic metals in fly ash which are harmful for plant, animal and human health. However continuous application of fly ash to soil needs intensive monitoring because of a possibility of heavy metal accumulation. Therefore the present study was conducted for two consecutive years to find out the efficient utilization of fly ash in agriculture.

The objectives of the study were as given below.

1. To study the effect of different doses of fly ash on rice yield and its yield attributing characters.
2. To monitor the soil nutrients and heavy metals status as influenced by fly ash application

3. To assess the effect of fly ash on heavy metals accumulation and it's portioning in rice crop

Experimental soil was clay loam in texture. The soil was neutral in reaction and low in electrical conductivity. The soil was low in available N and P and high in K. Soil available micronutrients Fe, Mn, and Cu were designated above the critical levels, while Zn concentration was below the critical value. The soil available heavy metals i.e. Cr , Pb , Ni Co and Cd were below the critical value for soil.

The findings of the experiments are summarized in brief as below:

1. The nutrient composition of fly ash indicated that it contains major nutrients in relatively small quantities but considerable amount of micronutrients based on the requirement of rice crop. It also contained sufficient amount of heavy metals (Ni, Cr, Co, Pb and Cd) (Table 3.3).
2. Application of fly ash with and without FYM and recommended dose of NPK significantly increased the yield components like effective tillers, panicles length in cm and grains per panicle. Integration of FA with 75% recommended dose of NPK and FYM (5 t ha^{-1}) further increased yield attributes of rice as compare to fly ash without FYM. Effect of different treatments was non significant on total tillers and test weight.
3. Integration of FA @ 40 t ha^{-1} + 75% recommended dose of NPK +5 t ha^{-1} FYM showed significantly higher grain and straw yield. Application of fly ash up to 40 t ha^{-1} with and without organic and chemical fertilizer increased grain yield. The highest dose (60 t ha^{-1}) of fly ash with and without FYM reduced the yields. Fly ash integrated with recommended fertilizers and FYM showed significant positive effect on grain and straw yield than without FYM.
4. The soil organic carbon content increased due to application of different fly ash treatments in the 0-15 and 15-30 cm soil depths. The fly ash doses when applied with FYM showed higher soil organic carbon compared to control and 100% GRD. The effect of the treatments on soil pH and electrical conductivity was non significant.

5. Application of fly ash doses with and without FYM had increased available N, P, and K content of soil after harvest of rice crop in both surface and subsurface soil layers. The soil availability major nutrient was higher when fly ash treatments were applied with FYM. Addition of fly ash along with FYM has resulted in buildup of available nutrients in post harvest soil compared to initial status.
6. Soil available micronutrients i.e. Fe, Mn, Zn and Cu content of soil increased significantly with an increase in fly ash levels with and without combination of FYM in 0-15 cm and 15-30 cm soil depths. Maximum content of micronutrients was noticed when fly ash was applied with FYM (Table 4.5.1 to 4.5.4).
7. Different fly ash treatments increased the available heavy metals in soil such as nickel, cobalt, chromium, lead and cadmium. Further increase was observed with increasing dose of fly ash applied with and without FYM in 0-15 cm and 15-30 cm soil depths. Maximum concentration in respect of these metals was recorded with the treatment of FA without FYM. However, highest the contents of these metals were recorded in 75% GRD + 60 t ha^{-1} fly treatment and control showed lowest.
8. Total nitrogen concentration in different plant parts of rice were increased by the different fly ash doses. The concentration of nitrogen significantly increased in root, grain and leaf are but not in stem with different doses of fly ash applied. Integration of fly ash with FYM recorded higher content of N than without FYM.
9. Application of different dose of fly ash either with or without FYM increased phosphorus and potassium concentration in different plant parts of rice over the control and 75% recommended dose of NPK. Integration of fly ash with FYM and 100% recommended fertilizer dose at recorded higher content of phosphorus and potassium than without FYM (Table 4.7.2 and 4.7.3).
10. Concentration of nitrogen in different plant parts of rice was in order of root (1.98 to 2.29%)>grain (1.18 to 1.42%)> leaf (0.30 to 40 %)> stem (0.24 to 0.34 %). Phosphorus in different plant parts of rice was in order of

root (0.32 to 0.50%)>grain (0.27 to 0.42 %)> leaf (0.11 to 18%)>stem (0.11 to 0.17%) and potassium in order of leaf (1.29 to 1.42%)> stem (1.15 to 1.24%)> root (0.43 to 0.57%> grain (0.31 to 0.40%).

11. The concentration of Fe varied from 312.17 to 339.83 mg kg^{-1} in root, 110.65 to 124.67 mg kg^{-1} in grain, 222.67 to 237.83 mg kg^{-1} in leaf and 213.00 to 228.50 mg kg^{-1} in stem of rice and influenced by different fly ash treatments, maximum content being recorded in application of highest dose (60 t ha^{-1}) of fly ash with 75% recommended dose of NPK and FYM. Increasing doses of fly ash with and without FYM increased iron content in different plant parts of rice.
12. Manganese concentration in root (87.20 to 101.98 mg kg^{-1}), grain (68.00 to 83.33 mg kg^{-1}) and stem (132.41 to 145.24 mg kg^{-1}) did not change by fly ash application treatments. Leaf (142.95 to 157.68 mg kg^{-1}) concentration of manganese was significantly higher over control and 100% recommended dose of NPK. Maximum accumulation was recorded in highest (60 t ha^{-1}) dose of fly ash with FYM.
13. Zinc concentration in root (38.18 to 47.72 mg kg^{-1}) and stem (22.92 to 28.27 mg k^{g-1}) did not change by fly ash application treatments. Grain (14.20 to 20.56 mg kg^{-1}) and leaf (26.00 to 33.15 mg kg^{-1}) concentration of zinc in FA treatment was significantly higher over control and 100% recommendedd dose of NPK. Increasing dose of fly ash with and without FYM increased zinc content in different plant parts of rice.
14. Significantly higher concentration of Cu was observed in rice grain (9.67 to 16.67 mg kg^{-1}) by application of different doses of fly ash as compared to control and 100% GRD. Maximum concentration of Cu was recorded in treatments of fly ash with 75% recommended dose of NPK+5 t ha^{-1}FYM followed by without integration of FYM while, it was non-significant in root (27.50 to 34.50 mg kg^{-1}), leaf (16.00 to 20.57 mg kg^{-1}) and stem (11.58 to 21.33 mg kg^{-1}).
15. Results of these study showed accumulation of micronutrients such as Fe, Zn, Cu in order of root > leaf > grain>stem except Mn, which was recorded more in leaf of the rice.

16. Chromium concentration in grain (3.91 to 5.07 mg kg^{-1}) and leaf (6.67 to 7.55 mg kg^{-1}) were significantly increased in different fly ash treatments but not in root (6.53 to7.48 mg kg^{-1}) and stem (4.84 to 6.06 mg kg^{-1}) parts. Maximum concentration of Cr was recorded when fly ash was applied highest (60 t ha^{-1}) dose with chemical fertilizer without FYM.
17. Higher concentration of cobalt was recorded when fly ash was applied at highest dose (60 t ha^{-1}) with 75% recommended dose of NPK. Cobalt concentration significantly increased in upper portion (3.39 to 5.24 mg kg^{-1} in leaf and 2.23 to 3.39 mg kg^{-1} in stem) of the plant but marginally increased in root (4.95 to 5.87 mg kg^{-1}) and grain (2.23 to 3.36 mg kg^{-1}).
18. Significantly higher concentration of nickel was recorded in rice grain by application of different doses of fly ash with and without integration of FYM than the control and 100% GRD (Table 4.9.3). The maximum concentration of nickel was observed in treatments of fly ash without FYM followed by with integration of FYM while, non significant in root (13.31 to 14.41 mg kg^{-1}), leaf (10.39 to 12.44 mg kg^{-1}) and stem (7.69 to 9.68 mg kg^{-1}).
19. Application of different dose of fly ash with and without FYM significantly increased lead (Pb) content in grain and root whereas marginal increase in leaf and stem over the control and 100% recommended dose of NPK. Maximum concentration of lead is also accumulated in the treatments when fly ash was applied without integration of FYM (Table 4.9.4).
20. Cadmium concentration in all the plant parts did not vary significantly with different fly ash doses applied with and without FYM (Table 4.9.5).
21. Total heavy metals i.e. Cr, Co, Ni, Pb and Cd concentration in the different rice plant parts was higher when fly ash was applied at highest dose (60 t ha^{-1}) without FYM.
22. Increasing doses of fly ash with and without FYM recorded increasing concentration of heavy metals in all the plant parts.
23. The distribution pattern of heavy metals i.e. Cr, Co, Ni and Pb was in decreasing order of root > leaf > grain>stem while, the order was leaf > root > grain>stem in case of Cd.

24. Among all the five heavy metals (Pb, Cd, Cr, Ni and Co) assessed, Ni showed highest accumulation in different plant parts (13.31 to 14.41 mg kg^{-1} in root, 7.93 to 9.37 mg kg^{-1} in grain, 10.39 to 12.44 mg kg^{-1} in leaf and 7.69 to 9.68 mg kg^{-1} in stem).
25. The foregoing observations clearly indicate that although FA cannot substitute the chemical fertilizers completely for sustainable yield, its application @ 40 t ha^{-1} can save 25% of the fertilizers recommended for rice without sacrificing the crop yield of rice. Besides, the application of FA @ 40 t ha^{-1} with or without FYM can promote soil properties.
26. Results of the continuous application of fly ash to soil showed that the concentration of toxic metals viz., Ni, Co, Cr, Pb and Cd in different plant parts were below maximum permissible limit for soil and plant given by the WHO (Table 3.1). Based on these values, it was observed that the consumption of rice grown on FA amended soils may not pose a risk to human health. However, regular monitoring is recommended in case of fly ash used in long term basis.

CONCLUSIONS

From the study it could be concluded that

1. Fly ash is a source of supplemental plant nutrients which has positive effect on grain and straw yield and its attributes such as effective tillers, panicle length and number of grains per panicle and integration of 75% recommended dose of NPK + 40 t ha^{-1} fly ash + 5 t ha^{-1} FYM application found the best.
2. Application of different fly ash doses with and without FYM increased soil available major (N, P, K), micronutrients (Fe, Mn, Zn, Cu) and heavy metals (Ni, Cr, Co and Pb) content at crop harvest in different soil depths. The available metals content are within safe limit.
3. The increasing doses of fly ash with and without FYM increased micronutrient and heavy metals content in different plant parts and their

accumulation was more in roots of rice plant in comparison with the aboveground parts including grain, leaf and stem.

4. Fly ash used in the study contained higher amounts of heavy metals but the concentration of heavy metals in fly ash amended soil and the rice plant parts was within the maximum permissible limit as reported by WHO even with the application of highest dose of fly ash (60 t ha^{-1}).
5. The most of the heavy metals accumulated was higher in the roots of the paddy plants except for Mn and Cd which was retained more in the leaves. The lowest concentration of the metals was observed in stem.
6. The occurrence of metal elements in paddy field soils was in the order of Fe>Mn>Cr> Cu>Pb>Co>Ni>Zn>Cd and in rice plant parts it was in order of Fe>Mn>Zn>Cu >Ni>Cr>Co>Pb>Cd.
7. The continuous application of fly ash @ 20 and 40 t ha^{-1} with and without FYM for two years can be recommended without any harmful effect of different heavy metals content in different plant parts. However, regular and intermittent monitoring of soil and crops is necessary. The above doses of fly ash with and without FYM saved 25% of NPK fertilizers.

SUGGESTIONS FOR FUTURE WORK

Based on the findings of the present study, the following suggestions are being made for future work.

- In India and abroad, a lot of research has been done on the use of fly ash in improving physical and chemical properties of different soils in various crops. However, there is enough scope to explore the possibilities to quantify optimum dose of fly ash of a particular source depending upon type of soil, degree of soil problem like acidity/alkalinity etc.
- The study provides information on available major, micronutrients and heavy metals from on short term experiment. There is a need for long term intensive research through field experiment in different crops and different soils.
- Use of fly ash can be explored for horticultural as well as plantation crops under diverse agro-climatic conditions.

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APPENDIX – A

Table: Meteorological data during the crop growth period (weekly) 2016

Week No.	Date		Temperature (°C)		Rain-Fall (mm)	Relative Humidity (%)		Vapour Pressure (mm)		Wind Velocity (Km ph)	Evapo-ration (mm)	Sun Shine (hours)
			Ma.	Min.		I	II	I	II			
27	Jul	02-08	30.4	23.1	119.4	95	84	22.9	25.0	-	12.0	-
28		09-15	30.6	24.1	59.6	94	82	23.9	24.8	-	18.0	-
29		16-22	68.7	23.1	96.2	96	77	23.1	24.8	4.2	14.8	-
30		23-29	32.0	53.9	80.6	93	77	23.2	24.6	4.2	17.9	-
31		30-05	31.6	23.3	116.2	96	80	23.5	24.9	2.8	16.8	-
32	Aug	06-12	29.5	23.3	55.8	94	81	22.9	23.7	4.2	16.6	-
33		13-19	29.3	23.5	17.2	90	76	22.3	22.5	5.1	15.8	-
34		20-26	32.0	23.3	1.0	92	71	22.8	23.3	3.6	19.4	-
35		27-02	32.9	23.4	76.6	92	72	23.6	25.4	3.8	17.2	-
36	Sep	03-09	30.8	23.7	28.0	93	78	23.0	24.3	2.7	11.8	-
37		10-16	32.5	23.8	19.0	94	70	23.5	24.5	4.1	13.8	-
38		17-23	33.0	23.7	7.2	92	69	24.0	23.9	3.7	18.2	-
39		24-30	31.1	22.8	123.0	94	75	22.6	23.8	4.9	17.7	-
40	Oct	01-07	32.7	23.4	0.8	95	74	23.7	23.0	3.6	17.1	5.9
41		08-14	32.3	20.3	25.1	94	56	20.0	19.1	2.8	17.7	6.1
42		15-21	32.1	16.5	0.0	90	38	14.9	12.7	1.9	21.3	9.4
43		22-28	32.3	16.6	0.0	85	39	13.6	13.7	2.2	19.2	9.2
44		29-04	30.9	18.3	0.0	84	46	14.9	14.3	2.8	18.4	7.9
45	Nov	05-11	30.6	14.7	0.0	83	30	11.8	9.4	2.6	18.3	8.2
46		12-18	29.1	14.0	0.0	86	35	11.3	10.1	2.5	16.3	8.3
47		19-25	29.9	11.2	0.0	84	25	9.4	7.3	2.2	16.6	9.3
48		26-02	30.0	11.9	0.0	89	30	10.3	8.9	2.2	14.4	8.5

APPENDIX – B

Table: Meteorological data during the crop growth period (weekly) 2017

Week No.	Date		Temperature (°C)		Rain-Fall (mm)	Relative Humidity (%)		Vapour Pressure (mm)		Wind Velocity (Km ph)	Evapo-ration (mm)	Sun Shine (hours)
			Max.	Min.		I	II	I	II			
23	Jun	04-10	41.3	25.7	10.4	65	39	21.9	20.8	4.7	53.8	5.8
24		11-17	38.7	23.8	3.4	82	47	22.8	24.2	4.3	42.8	6.6
25		18-24	38.5	22.7	26.6	81	50	23.4	23.6	4.6	37.2	6.2
26		25-01	33.4	21.9	51.2	94	71	23.8	24.3	3.8	18.2	2.4
27	Jul	02-08	31.9	21.9	87.8	90	69	23.4	23.5	4.3	15.1	3.5
28		09-15	31.8	23.7	67.2	93	77	23.2	23.7	3.7	16.7	2.8
29		16-22	32.3	25.0	74.4	95	73	24.5	24.8	4.9	18.1	3.7
30		23-29	29.5	24.8	18.0	94	80	22.7	23.5	4.7	13.7	1.3
31		30-05	33.2	25.6	50.2	92	68	23.9	23.1	2.3	23.4	3.0
32	Aug	06-12	30.2	24.8	64.6	94	80	23.5	24.0	2.2	15.0	0.8
33		13-19	32.6	25.0	64.4	93	76	24.2	23.6	2.5	19.7	3.9
34		20-26	32.4	25.0	97.8	93	71	24.3	24.3	2.9	18.9	4.7
35		27-02	31.9	25.6	33.2	93	74	24.2	23.5	2.3	16.6	3.7
36	Sep	03-09	34.1	24.9	13.8	92	63	24.0	23.9	1.3	22.4	7.0
37		10-16	33.2	25.1	2.5	93	66	24.1	22.6	1.3	19.2	3.3
38		17-23	31.2	24.0	70.0	95	76	23.0	22.5	1.4	16.6	2.6
39		24-30	33.5	24.2	0.0	90	63	22.3	22.0	1.4	20.0	6.6
40	Oct	01-07	32.8	23.9	40.2	93	66	22.7	22.9	1.4	16.7	6.2
41		08-14	32.3	23.8	1.0	91	62	22.1	22.1	0.8	16.4	7.8
42		15-21	33.3	21.2	3.2	85	54	18.8	19.2	0.8	20.2	7.8
43		22-28	33.1	20.3	0.0	88	57	17.9	20.2	0.8	20.1	7.9

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