ASSESSMENT OF HEAVY METAL CONTENT IN HINDON RIVER WATER AND AN INTEGRATED APPROACH FOR SOIL AND CROP MANAGEMENT

THESIS

SUBMITTED TO THE

SARDAR VALLABHBHAI PATEL UNIVERSITY OF AGRICULTURE AND TECHNOLOGY MEERUT- 250 110 (U.P.) INDIA

BY

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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IN

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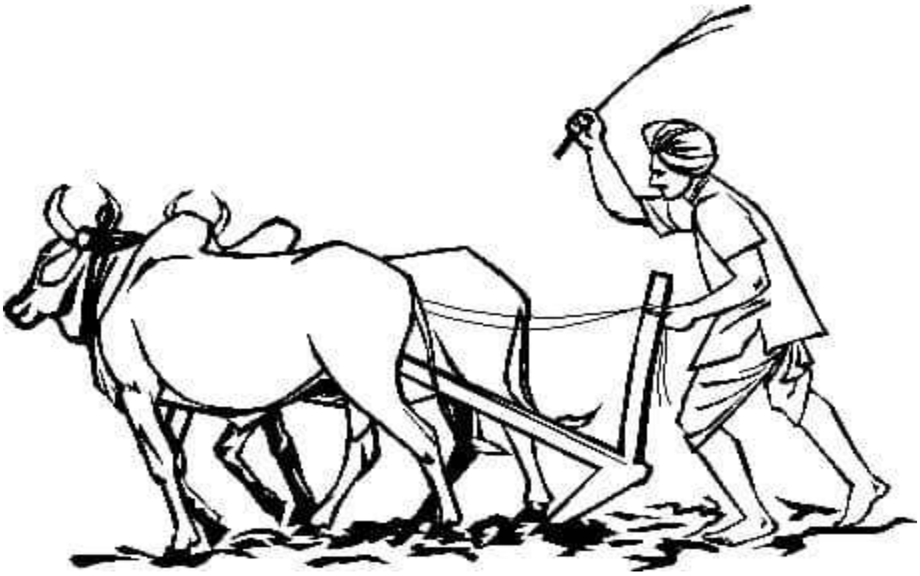

Dedicated To

My

Beloved

Parents and Farmers Community

Dimple ...✍

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CERTIFICATE

This is to certify that the thesis entitled **“Assessment of Heavy Metal Content in Hindon river water and an Integrated Approach for Soil and Crop Management”** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** in **Agronomy** and minor in **Soil Science and Agricultural Chemistry** of the College of Post-Graduate Studies, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, is a record of *bona-fide* research carried out by **Ms. Dimple Kaparwan, Id. No. 3653**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

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We, the undersigned, members of the advisory committee of **Ms. Dimple Kaparwan, Id. No. 3653,** a candidate for the degree of **Doctor of Philosophy** with major in **Agronomy** and minor in **Soil Science and Agricultural Chemistry** agree that the thesis entitled **"Assessment of Heavy Metal Content in Hindon river water and an Integrated Approach for Soil and Crop Management"** may be submitted by **Ms. Dimple Kaparwan,** in partial fulfillment of the requirements for the degree.

(N.S. Rana)
Chairman
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(Vivek)
Member

(R.K. Naresh)
Member

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Member

LIST OF TABLES

LIST OF FIGURE

Abbreviations used

%	:	Per cent	m^2	:	Squire meter
a.i.	:	Active ingredient	MBC	:	Microbial biomass carbon
B:C ratio	:	Benefit Cost ratio	MBN	:	Microbial biomass nitrogen
^0C	:	Degree Celsius	m ha	:	Million hectare
CD	:	Critical difference	mm	:	Millimeter
CGR	:	Crop growth rate	Max.	:	Maximum
Chl	:	Chlorophyll	Min.	:	Minimum
cm	:	Centimeter	N	:	Nitrogen

cm^2	:	Squire centimeter	NAR	:	Net assimilation Rate
Day^{-1}	:	Per day	NS	:	Non significant
DAS	:	Days after sowing	pH	:	Per cent of hydrogen ions
df	:	Degree of freedom	P	:	Phosphorus
DH	:	Dehydrogenase activity	P=0.05	:	Significant at 5 % probability
$dS\ m^{-1}$	:	Desi simen per meter	P_n	:	Net photosynthesis rate
et al.	:	et allii; (co-authors)	POC	:	Particulate organic carbon
etc.	:	et cetera (and others)	RGR	:	Relative growth rate
Fig.	:	Figure	RH	:	Relative humidity
g	:	Gram	S^{-1}	:	Per second
G_s	:	Stomatal conductance	SEm ±	:	Standard error of mean
ha	:	Hectare	Sig	:	Significant
ha^{-1}	:	Per hectare	S. No.	:	Serial number
i.e.	:	Id east (that is)	SPAD-502	:	Soil plant analysis development
K	:	Potash	SSNM	:	Site specific nutrient management
kg	:	Kilo gram	STCR	:	Soil test crop response
LAI	:	Leaf area index	t	:	Tonnes
LFC	:	Labile fraction carbon	*Viz.*	:	Videlicot (Sl/ 1g) namely
µ	:	Micro	WSOC	:	Water soluble organic carbon
m	:	Meter	Wt	:	Weight

CONTENTS

1. INTRODUCTION

Deterioration of water quality has been an age-old problem in India making it rank at a position of 120th out of 122 countries in terms of water quality. The water resources here are contaminated to an extent up to 90% with industrial & domestic waste coupled with excess use of agriculture chemicals such as pesticides and fertilizer residues. In India, approximately forty-two rivers are polluted with at least two heavy metals (Central Water Commission) and heavy metal pollution is now a global problem to be dealt with.

Mostly in developing countries, the waste discharged from industries is disseminated into rivers and streams with minimal or no wastewater treatment making the water resources unsuitable for drinking purpose. The water from such rivers when used for irrigation purpose might cause heavy metal contamination of agricultural soils and crops with probable effects on food production and human health. Solid waste disposal, wastewater irrigation, sludge applications and industrial actions are the major sources of heavy metal pollution in soil and an increased metal uptake by food crops grown on these contaminated soils is not uncommon. In general, wastewater usage provides substantial amount of potentially toxic heavy metals, which are creating problems for agricultural production. Heavy metal contamination is caused by continuous growth in mining, fertilizer, tannery, paper, batteries and electroplating industries which subsequently has shown noxious effects on human health worldwide. Heavy metals like arsenic, cadmium, chromium, lead and mercury ranks among the priority metals that are of public health significance based on their high degree of toxicity. Unlike organic contaminants, heavy metals are non-biodegradable and also carcinogenic. Heavy metals such as Zinc, Copper, Nickel, Mercury, Cadmium, Lead, Chromium and Arsenic tend to accumulate in organisms which may lead to reduction in species diversity.

Indefinite use of agro chemicals and dumping of minimally/ untreated industrial waste water in rivers has led to severe toxicity of heavy metals in soils along with their potential translocation to the crops that has opened pathways to bioaccumulation of these toxic elements. Heavy metal ions, when present at an elevated level in the environment, are excessively absorbed by roots and accumulated in shoot, leading to impaired metabolism and reduced growth (Bingham *et al*., 1986; Foy *et al*., 1978).

Plant growth is influenced by various factors *viz.,* soil physio-chemical properties; weed management, irrigation and fertilizer management etc., of which irrigation management plays a major role for healthy crop development (Razzaque *et* *al.,* 1992). The use of wastewater for agricultural irrigation in urban and peri-urban areas has increased in recent times mainly due to the economic interests of farmers.

Heavy metals are naturally occurring elements that have high atomic weight and a density at least 5 times greater than that of water. These are also considered as trace elements because of their presence in trace concentrations (ppb range to less than 10 ppm) in various environmental matrices. The concentration of toxic heavy metal in annual crops due to long-term sewage irrigation did not increase (Cambell *et al.,* 1983; Tripathi *et al.,* 1987; Truby and Raba 1990). In contrast, Baraman (1994) observed adverse effect of sewage irrigation on growth and yield of pulses and oil seeds. Sewage irrigation increased heavy metal accumulation in wheat plant parts (Karatas *et al..* 2006).The conjunctive use of sewage and good water has been recommended to improve the yield of many crops without pollution effect of toxic heavy metals (Nagaraja and Krishnamurthy (1988); Monte and Sousa (1992). Increased concentration of heavy metals like Hg and As has affected soil microbial activity and other heavy metals like Cr, Zn have not affected microbial activity in soil due to sewage irrigation (Zhang *et al.,* 2008; Oliveira and Pampulha 2006).

Heavy metal contamination in water and soil poses a major environmental and human health problem. Globally, about 20 million ha of land is irrigated with municipal wastewater (raw, diluted, or treated) which is more likely to increase over the next few decades in response to growing levels of water stress in inhabited catchments. Excess of metal concentration in contaminated soils results in decreased soil microbial activity and fertility which results in high yield losses (McGrath *et al*., 1995). The demand for food supply continues to grow with an increasing population growth, which in turn has led to increased use of pesticides, fertilizers, herbicides as well as the use of poor quality or untreated wastewater for irrigation. Food crops grown in metal-contaminated soils might uptake and accumulate metals in quantities high enough to affect the food quality and safety (Muchuweti *et al.,* 2006). This in-turn has caused nutritional deficiency of micro and macro nutrients in plants and poses serious risk of health hazards due to dietary intake of the contaminated food.

One such scenario of using waste water for irrigating field crops is Hindon river water application for vegetable and cereal crop production in western Uttar Pradesh that has started gaining attention due to high amount of toxic heavy metals present in Hindon river water. In the polluted stretch of river Hindon and its tributaries, total discharge of 674.033 MLD is estimated in the form of sewage and industrial effluent through 31 drains and direct discharge in the river. As per desk inventory, about 595.643 MLD of sewage and 78.39 MLD of industrial effluent are currently being discharged into the river. Industrial effluents of 78.39 MLD from 453 industries situated in 06 Districts directly discharge effluents into Hindon river and its tributaries (Kali & Krishni) after treatment. The treatment of sewage is a major area of concern as out of total estimated sewage discharge of 595.643 MLD, only 224 MLD of sewage is treated.

River Hindon originates from lower Shivalik ranges in District Saharanpur of Uttar Pradesh and is primarily rainfed. The basin area falls in the districts of Saharanpur, Muzaffarnagar, Shamil, Meerut, Bagpat, Ghaziabad and Gautambudh Nagar in western Uttar Pradesh and covers a distance of about 300 km before joining the river Yamuna downstream of Delhi. Hindon river is one of the important rivers in Western Uttar Pradesh (India) having a basin area of about 7000 km^2. The catchment area of the river lies between latitude 28^o 30’ 27” to 30^o15’ 22” N and longitude 77° 20’18” to 77° 50’ 16”E. The Hindon River has been a major source of water to the highly populated and predominantly rural population of Western Uttar Pradesh.

As highly populated rural catchment, this river is heavily utilized as a water resource for irrigating field crops. Studies have been already conducted on Hindon river water quality revealing presence of wide range of acutely toxic organochlorine and organophosphorus pesticides and heavy metals within rivers and groundwater throughout the catchment, which is used for irrigation purposes (Rakesh *et al*., 2017). However, farmers still continue to grow crops using the Hindon river water which has led to the heavy metal accumulation in soil of villages adjoining Hindon area without ever realizing that the contaminants have started entering the food chain that could possibly be hazardous to both human and animal health.

The aim of the present study was the assessment of heavy metals in irrigation water, soil, and distribution of heavy metals within the crop plants (wheat & sorghum) grown under the influence of contaminated wastewater. Extreme accumulation of heavy metals in agricultural soils through wastewater irrigation may not only result in soil contamination but also lead to elevated heavy metal up-take by crops, threatening food quality and safety. Keeping above view in mind, the present study **"Assessment of Heavy Metal Content in Hindon River Belt and An Integrated Approach for Soil and Crop Management"** was planned in sorghum- wheat cropping system with the following objectives:

1. Assessment of physio-chemical properties and heavy metal content in Hindon river water.
2. Assessment of physio-chemical properties and heavy metal content in soil adjoining Hindon river belt.
3. To study the effect of soil and crop management practices on growth, yield, quality and nutrient accumulation and partitioning in sorghum – wheat system.
4. To monitor the changes in physiochemical properties of soil under different soil management practices, and
5. Evaluation of risk hazard to human health.

2. REVIEW OF LITERATURE

Heavy metal pollution

Heavy metal pollution has become a global problem to be dealt with, owing to rapid industrial growth, intensive agriculture and high population rate. Soil pollution by heavy metals is a significant environmental problem worldwide. Concentration of these heavy metals in soil has increased drastically over the last three decades, posing high risk to the environment and human health. Not only does a metal contaminated soil have a negative effect on plant growth and yield but it also poses severe threat to bioaccumulation of toxic metals in food chain and soil biological activity. Remediation methods used for heavy metal soil cleanup include physical, chemical and biological or a combination of these techniques to remove/ reduce/stabilize heavy metals in soil. Use of organic amendments like farmyard manure, biochar, vermicompost and inorganic materials like lime, zeolites, iron oxides etc., reduce the metal mobility and bioavailability in soils. A combination of two or more of these soil amendments can be used to increase the efficiency of remediation process. This review paper presents possible sources of heavy metal pollution, their effect on soil health with appropriate remedial measures described in length.

2.1 Effect of Heavy metal pollution on

2.1.1 Irrigation Water Quality:

In a heavy metal analysis of waste water conducted by **Khan *et al*., (2005)** used for irrigation purpose in agricultural fields of Sanganer town Jaipur, revealed that water samples contained 2.52 mg/l of Zn, 1.95 mg/l of Cu, 1.12 mg/l of Ni, 0.72mg/l of Cd, 1.52mg/l of Cr, 2.11 mg/l of Pb and 0.99 mg/l of Co, which was not considered safe for irrigation purpose. In a similar study conducted by **Perveen *et al*., (2006)**, to study the impact of using irrigation water from Warsak gravity canal on soil and plants and revealed that the pH of water ranged from 7.9 to 8.0, electrical conductivity was 0.24 to 0.27 $dSm^{-1}$and heavy metal concentrations of Zn, Cu, Fe, Cd, Ni, Pb and Cr varied in a range from 0.11– 0.15, 0.58– 1.81, 0.32 – 3.15, 0.003 0.287, 0.01– 2.27, 0.05 – 1.114 and 0.0080– 0.27 mg L^{-1} respectively. They concluded that use of waste water over a period of time for irrigation purpose might result in building up of heavy metals in soil. In similar trials conducted by **Gupta *et al*., (2008)** on using of wastewater for irrigation of vegetables in Titagarh, West Bengal revealed that the mean concentration of Pb, Ni and Cu in the treated and untreated irrigation water were 4.26mg/L & 3.54 mg/L, 0.68 mg/L & 0.39mg/L and 1.56mg/L & 0.98 mg/L which were found to be beyond the permissible limits and should not be used for irrigation purpose without treatment. Similarly, in a research conducted by **Joshi and Shrivastava (2012),** they studied the physico-chemical parameters of dyeing and printing wastewater used for irrigation purpose at Sanganer (Rajasthan) and determined the quality of water by measuring the concentration of cations (Na, K Ca, Mg and Li) anions (Cl, NO_3, SO_4, PO_4, F) and the heavy metals (Cu, Fe, Cr, Ni, Zn, Pb Hg, As, Cd, Mn) in effluent discharge from the dyeing and printing textiles and concluded that there was negative effect of effluent discharge on the water quality used for irrigation purpose. In similar lines, **Al Farraj *et al*., (2013)** conducted an assessment of heavy metals in industrial waste water of Riyadh city, Saudi Arabia and revealed that most heavy metals in waste water effluent were above permissible limits, however after the filtration of wastewater, heavy metal concentrations decreased to permissible levels and could be used for irrigation. They further informed that the highest average metal concentration in digested effluents of different locations and sampling periods for Fe was 17.1 mg L^{-1} followed by Mo (11.6 mg L^{-1}) and Co (0.03 mg L^{-1}). In conjugation with these findings**, Yadav *et al*., (2013)** investigated the heavy metal status in irrigation water from different sources of industrial area at Naini Allahabad and revealed that the order of heavy metal concentration in water and soil samples was as Fe > Zn > Cd > Pb > Ni > Cu and Fe > Ni > Zn > Cu > Cd > Pb. They concluded that concentrations of heavy metals (mg/L) in irrigated water ranged from 0.249 to 0.257 for Fe, 0.049 to 0.056 for Zn, 0.028 to 0.036 for Cd, 0.015 to 0.0 19 for Cu, 0.035 to 0.042 for Pb and 0.031 to 0.038 for Ni which was lower than recommended maximum tolerable levels proposed by WHO, with the exception of Cd and Fe which exhibited elevated content and the waste water could be safely used for irrigation purpose. In further studies on heavy metal analysis of Turag river water of Bangladesh by **Afrin *et al*., (2014)** revealed that the level of heavy metals *viz.*, Pb, Cd, Cr, Cu, Hg and Fe ranged from 0.002-0.005 ppm, BDL-0.03 ppm, 0.007-0.024 ppm, 0.03-0.15 ppm, BDL - 0.00024 and 0.78-6.33 ppm, and concluded that the concentration of heavy metals in water did not exceed the permissible limit except that for Fe. They further raised a concern that river water is always flowing and metals cannot be accumulated in flowing water, however, heavy metals have toxic properties, leading to adverse effects on human and ecosystem health even in small doses, so, Turag river water was not considered safe in using for different purposes and suggested recommended steps to be undertaken for improving the water quality of the river.

2.12 Soil Health

In similar lines, **Singh *et al*., (2007)** studied the effect of heavy metal pollution using treated and untreated sewage water for irrigation purpose and revealed that heavy metals concentrations were significantly higher at sites where untreated sewage water was used compared to treated sewage water. They further studied the usefulness of sewage sludge as an amendment for palak (Beta vulgaris var. All green H-1) and conducted a pot experiment by mixing sewage sludge in 20 and 40% (w/w) amendment ratios to the agricultural soil which resulted in reduction of soil pH and increase in electrical conductance, organic carbon, total N, available P and exchangeable Na, K and Ca in soils amended with sewage sludge in comparison to unamended soil. They concluded that though sewage sludge at 20% and 40% (w/w) could be used as a soil amendment but it also leads to significant increase of heavy metals *viz*., Pb, Cr, Cd, Cu, Zn and Ni in soil. In conjugation with similar findings, **Khan *et al*., (2008)** studied the associated risk of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing China. Their results indicated that all the metal concentrations in soils except for Cd were below the Environmental Quality Standards set by the State Environmental Protection Administration (SEPA, 1995) of China, however, there was substantial build up of heavy metals with PLI indices for Cd, Cr, Cu, Ni, Pb and Zn as 84.0, 3.0, 3.9, 10.9, 18.4 and 2.1 in the waste water irrigated soils compared to the reference soils. Further, **Gupta *et al*., (2008)** carried out an assessment of heavy metal contamination in soils and vegetables irrigated with wastewater at Titagarh, West Bengal and found that the concentration of heavy metals (mg/kg of dry soil) in soil for Pb, Zn, Cd, Cr, Cu and Ni ranged from 99.3 - 168.3, 182 - 285, 22.2 - 51, 118.05 - 190.4, 22 - 166.5 and 44.72 - 133.80 with highest mean concentration recorded for Zn followed by Cr, Pb, Ni, Cu and minimum concentration was observed for Cd. They concluded that soils were highly contaminated with heavy metals and there could be possible translocation of these metals from soil to the vegetables irrigated with waste water. Similarly, **Pathak *et al*., (2011)** studied the effect of sewage water irrigation on physico-chemical parameters of soil with special reference to heavy metals contamination in Haridwar city and concluded that use of sewage water for irrigation purpose improved the water holding capacity (+27.98%), electrical conductivity (+196.15%), sulphate (+2.34%), organic carbon (+30.48%), available nitrogen

(+87.5%), available potassium (+25.77%), available phosphorous (+59.97%) and overall fertility status of the soil in comparison to soil irrigated with natural water, however, sewage irrigation also resulted in significant build-up of heavy metals such as Pb (+98.95%), Ni (+128.29%), Cu (+253.17%), Fe (+39.74%), Cd (+30.92%), Zn (+696.03%) and Cr (+13.15%) in comparison to natural water irrigated soil with maximum enrichment factor (Ef) for Cu (9.62) and minimum for Cr (1.13). In similar studies by **Zhang *et al*., (2011)**, they conducted a survey to determine the status of Copper and Cadmium accumulation in green house vegetable soils in Tongzhou, Beijing and revealed that there was a distinct increase of Cu and Cd concentration in greenhouse vegetable soil. Also concentration of Copper and Cadmium in part of soil samples exceeded the environmental quality evaluation standard for farmland of green house vegetables production of China. Similarly, in a research trial conducted on heavy metal pollution in vegetable crops irrigated with wastewater at Accra, Ghana by **Lente *et al*., (2014)**, they collected 144 soil and waste water samples and results revealed the heavy metal concentration in soil and wastewater for Fe (164.38; 162.92), Mn (39.39; 20.09), Cu (7.21; 6.13), Zn(6.03; 7.45), Pb (9.31; 7.63), Ni (5.00; 2.97), Cr (0.51;0.85), Cd (0.07;0.09) and Co (0.73;0.87) exceeded permissible limits. They concluded that heavy metal concentrations were higher in wastewater irrigated soils than groundwater irrigated soils respectively. In conjugation with above findings, a research trial was carried out to study the impact of heavy metals on physicochemical parameters of soils in the vicinity of paper manufacturing industry located in Nahan area, Himachal Pradesh and revealed that the average concentrations of heavy metals metals *viz*., Pb, Zn, Cd, Cr in soil samples were three to ten times higher than the permissible limits as given by **Sharma *et al*., (2014)**.

2.13 Field crops

2.13 Wheat

2.1.3.1 Growth

In a field trial conducted by **Khan and Jain (1995)** to study the impact of textile wastewater on growth parameters of *Triticum aestivum* revealed that there was an overall decrease in relative length of root, shoot and dry weight of seedlings, when the seeds were given different dilutions of textile industry wastewater along with distilled water. The inhibitory effect was more pronounced on the root length compared to shoot length. They concluded that application of distilled and textile wastewater in 1:1 and 0:1 ratios resulted in 40.3 & 59.3 % reduction in root length and 29.2 & 98.2 % reduction in shoot length respectively. Similarly, in an experiment conducted by **Kaushik *et al*., (2005)** to study the effect of treated and untreated textile effluents on the seed germination (%), delay index (DI), plant shoot length, root length, plant biomass, chlorophyll and carotenoid content in three different cultivars of wheat revealed that textile effluent did not show any inhibitory effect on seed germination at low concentration of 6.25%, however, wheat seeds germinated in undiluted effluents did not survive for longer period. Based on the tolerance limit to textile effluent, wheat cultivars were arranged in ascending order of: PBW-343 < PBW 373 < WH-147. They further told that effect of the textile effluent was cultivar specific and due care should be taken before using the textile effluent for irrigation purpose. Further, in a research trial laid out by **Singh *et al.*, (2007)** revealed that there was a reduction in germination percentage and early growth of wheat treated with copper at various concentrations of 5, 25, 50, and 100 ppm. Various research experiments carried out with higher concentrations of heavy metals have shown significant affect on root & shoot length as well as dry mass of wheat as given by **Shao et al., 2011** in sunflower, **Azhar *et al.*, 2006** in cow pea and **Mami *et al.*, (2011)** in tomato. In conjugation to above findings,

Deepak *et al.*, (2016) conducted an experiment to analyse the Hindon river water physico-chemical properties *viz.,* pH, Electrical conductivity (EC), Total alkalinity, Total dissolved solids (TDS), Total suspended solids (TSS), Dissolved Oxygen(DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Chloride, Sulphate and Heavy Metals (Cr, As, Cu, Pb, Cd, Hg , Zn and Ni) at Atali Village, Muzaffarnagar, (U.P). They evaluated the water quality index (WQI) and revealed that water quality status of Hindon river deteriorated from very poor to unsuitable for drinking and agricultural practices. Further, they also studied the effect of Hindon water on germination of Vigna radiata, Vigna mungo & Triticum aestivum by irrigating crops with different concentrations of Hindon water *viz.*, 0% 25%, 50%, 75%, and 100% and found that concentration of 25 and 50% had stimulatory effect on germination rate, seedling length, seedling vigour index while any further increase in concentration of Hindon water beyond 50% showed inhibitory effects even at initial growth stage of all three crops.

2.1.3.2 Heavy metal uptake

In an experiment conducted by **Singh *et al*., (2010)** to assess the risk to human health by heavy metals (Cd, Cu, Pb, Zn, Ni and Cr) through intake of locally grown vegetables & cereal crops irrigated with waste water found that Cd, Pb and Ni concentration were above the permissible limits of Indian and WHO/FAO standards in all the vegetables and cereal crops. They further told that rice and wheat grains were less contaminated with heavy metals in comparison to vegetables, however, health risk was greater due to cereals for their higher contribution in diet. They suggested that waste water irrigation leads to accumulation of heavy metals in food stuff causing potential health risks to consumer. In conjugation to above findings, an experiment conducted by **Anjula Asdeo** to analyse the effect of sewage water irrigation in cereal crops in peri-urban area of Jodhpur city, Rajasthan, they took twelve samples of wheat and millet crops randomly from fields of Vinayakiya and Shikarbera sites located within the vicinity of city sewage drains. She revealed that highest heavy metal uptake in both crops was in roots followed by stem/leaves and then grains. The average concentrations of heavy metals in agricultural soils for Pb, Cd, Cr, Cu and Zn ranged between 14.37 to 26.53 mg/kg, 3.247-9.438 mg/kg, 13.278-22.520 mg/kg, 14-289-32.273 mg/kg and 10.32516.981 mg/kg while average values of Pb, Cd, Cr, Cu, Zn in the wheat & millet grains were 1.0, 0.04 & 0.18, 0.2 & 1.15, 6.11& 5.89, 2.325 mg/kg. They concluded that concentration of lead, cadmium, chromium and copper in edible grains of wheat & millet plants were well below the Chinese National Food Guideline limit as well as Indian Standards and contents of five toxic elements were higher in roots than in the aerial parts for both crops (wheat and millet) cultivated in agricultural soil indicating that the roots act as barriers for metal translocation and protect the edible parts from toxic heavy metal contamination.

2.1.3.3 Quality

In a pot experiment conducted by **Rana and Masood (2002)** to study the toxic effect of few heavy metals *viz.,* Cd, Cu, Ni, Zn, Pb and Cr on growth, uptake and protein content of wheat revealed that heavy metals brought about significant reduction in the number of free living Azotobacter chroococcum cells as well as protein content which decreased from 19.0–71.4% in metal exposed plants at metal concentrations equivalent to those found in polluted soil over the control. They further revealed that metal uptake by grains was directly related to the applied heavy metal with greater concentrations of metals found in cases where metals were added separately rather than in combinations.

2.1.3.4 Yield

A field experiment was conducted by **S.R. Salakinkop *et al.***, to study the effect of waste water irrigation on growth and yield of wheat crop in a split plot design, with two types of main plots, first the field plot irrigated with sewage water and second plot with bore well water since 1992, with subplots irrigated with three water sources *viz.*, sewage water alone, bore well water alone (good water) and mixture of both sewage and bore well water. They revealed that crop growth in terms of photosynthesis, net assimilation rate and dry matter production significantly increased in sewage-irrigated land in comparison to bore well irrigated land with significantly higher wheat grain yield of 4370 kg ha^{-1}, protein and dry gluten content of 12.88 and 9.22 % obtained in field irrigated with sewage water compared to bore well-irrigated field, however, wheat roots accumulated significantly higher amount of Cr, Ni, Pb and Cd in sewage-irrigated plots in comparison to bore well-irrigated plots which was higher in root followed by stem and lower in grains. They further concluded that long-term irrigation of farm lands with wastewater leads to contamination of soil and plant system with significant accumulation of heavy metals compared to the freshwater-irrigated soil indicating concern of their increased absorption by wheat plant.

2.1.4 On Sorghum

2.1.4.1 Growth

In an experiment conducted to study the effect of heavy metals on growth of sorghum by Swapan Kumar Roy observed morphological changes in the leaf of sorghum plants treated with different concentrations of $CdCl_2$ (0, 50, 100, and 150 mM) and revealed that plants treated with cadmium suffered significant reduction in growth and morphological characters. They further told that growth of sorghum seedlings treated with 150 uM Cd were more inhibited than that of sorghum seedlings treated with 100 mM Cd, 50mM and control and the fresh weight of root and shoot were reduced in Cd treated sorghum compared to control. Similarly, in a pot experiment carried out by **Nafees *et al* (2014)** to evaluate the phyto-extraction capacity of heavy metals by cultivating sorghum in an artificially contaminated soil with different concentrations of lead (300, 350 and 400 mg/kg), chromium (50, 100 and 150 mg/kg) and cadmium (100, 150 and 200 mg/kg) along with 5 mM EDTA applied as chelating agent to the plants after 4 weeks of sowing. Plants were grown for a total of two months and fresh weight and dry weight of shoot and heavy metal accumulation were analyzed at six and eight weeks after sowing. The results revealed that application of cadmium, chromium, lead and EDTA adversely affected shoot length, fresh weight and dry weight of S. bicolor at both time intervals. In conjugation with above studies, a research trial was carried out to assess the effect of mercury on seed germination, growth and expression of antioxidant enzyme defense system in Sorghum vulgare by **Deepti *et al* (2016)** revealed that seed germination and seedling growth of Sorghum vulgare was reduced by exposure to mercury chloride at different concentrations, however, no effect was observed at 5 mgL-1 mercury treatment. Root length, shoot length, fresh weight and dry weight of seedlings were reduced. The water retention capacity of seedlings was reduced. Protein content of seedlings was reduced by mercury exposure.

2.1.4.2 Heavy metal uptake

An experiment was conducted at Po River Delta where soils were highly contaminated with heavy metals, situated in Padania Plain area at the confluence of Adriatic Sea. The already reclaimed soils were chosen for sorghum cultivation as test field. They measured heavy metal concentrations in soil, rhizosphere, seeds and aerial parts of sorghum plants and results revealed that higher concentrations of Cr and Ni were contained in soil and rhizosphere samples with micronutrients such as Zn and Cu found in higher concentrations in seed portion compared to Cr and Ni, however, all the metals (except Cd) were below the national admitted limits. Similarly, a pot experiment was conducted to evaluate the phyto-extraction capacity of heavy metals by **Nafees *et al*.,(2014)** in sorghum crop. Sorghum bicolor was grown in soil artificially contaminated with different concentrations of lead (300, 350 and 400 mg/kg), chromium (50, 100 and 150 mg/kg) and cadmium (100, 150 and 200 mg/kg). Five mM EDTA was applied, as chelating agent to the plants after 4 weeks of sowing. Plants were grown for a total of two months and the results revealed that application of cadmium, chromium and lead adversely affected shoot length, fresh weight and dry weight of S. bicolor at all time intervals. Heavy metals uptake increased with the increment of heavy metal by S. bicolor species. Application of 5mM EDTA enhanced the uptake of heavy metal. Similarly, a pot experiment was conducted by **Zhang *et al* (2016)** to investigate the physiological and biochemical indexes as well as the characteristics of uranium accumulation in Sorghum bicolor×S.Sudanense, under different concentrations of uranium (0,1, 5, 20mg/kg). The results revealed that with the increase in application of uranium concentration in Sorghum bicolor×S.Sudanense, increased uranium uptake, and the enrichment in the shoots was higher than that in the roots. Further, in an experiment conducted by **Poor *et al.* (2015),** they revealed that application of 0.1 muM $CuCl_2$ in sorghum negatively affected the transport and uptake of Fe and Mn in sorgum plants while enhanced the CO_2 assimilation rate and soluble sugar content in all plant tissues;

2.1.4.3 Quality

In a research trial conducted to study the effect of zinc on activity of nitrate reductase by **Kumar and Arciaswamy (1994)** reported that zinc at concentration of 50 ppm and above reduces the activity of nitrate reductase in Sorghum bicolor and relationship between reduction in nitrate reductase activity and zinc concentration was found to be simple linear and negative. Similarly, a pot experiment was conducted by **Zhang *et al* (2016)** to investigate the physiological and biochemical indexes as well as the characteristics of uranium accumulation in Sorghum bicolor×S.Sudanense, under different concentrations of uranium (0,1, 5, 20mg/kg). The results revealed that photosynthetic pigment and soluble protein content increased under the low uranium concentration stress, but with the increase in uranium concentration, the synthesis of photosynthetic pigments and soluble proteins was inhibited.

2.1.4.4 Yield

Baligar *et al.* (1989) studied the aluminium tolerance of different cultivars of sorghum grown under both field and green house condition collected from eleven countries exposing to nine different concentrations of aluminium ranging from 2.5 to 750 mg kg'1. They revealed that seven cultivars were proved to be aluminium susceptible while few were found to be highly tolerant to aluminium. They further concluded that higher concentration of aluminium had negative effect with respect to growth, development, yield and nutrient efficiency ratio (NER) in sorghum.

2.2 Effect of consumption of heavy metal contaminated food on Human health

Rapid industrialization, intensive agriculture and other anthropogenic activities have led to soil degradation, environmental pollution and decline in crop productivity and sustainability. These have been of great concern to human and animal health. One of the prominent sources contributing to increased load of soil contamination is disposal of municipal and industrial wastes. Though, sewage is a potential source of nutrients and is used for irrigation purpose as well, however, it is also a source of toxic heavy metals. Various studies have revealed that heavy metal contamination of the food basket has serious consequences on human health and have even established the fact that macro quantities of metals pose serious health hazards.

In a study conducted on the chronic toxicity of REE (rare earth elements) in human beings by **Zhang *et al*., (2000)** they found that the influence of REE on males is a one-way irreversible process, whereas females show a strong ability of restoration. In a research conducted by **Schumann *et al*.**, (2002) to study the mechanism of copper in human body and its damage caused by copper overload. They stated that a family in Vermont experienced recurrent gastro intestinal irritation as a result of Cu contaminated water consumption (2.8-7.8 mg Cu/ L). In further studies by **Jarup (2003)** on threats to human health from exposure to Pb, Cd, Hg and As revealed that children are particularly susceptible to lead exposure due to high gastrointestinal uptake and the permeable blood brain barrier. In similar studies conducted by **Chandra and Kulshreshtha (2004)**, they revealed that leather tanners suffered from ulcers, allergic dermatitis, lung cancer and liver necrosis due to prolonged contact with Cr salt. Similarly, **Fan *et al.*, (2004)** studied the effects of exposure of rare earth elements and health responses in children aged 7-10 years and found that IQ levels in children were severely affected. In conjugation with above studies, **Gupta *et al.*, (2013)** investigated the concentration of copper, chromium, zinc, and lead in the most frequently consumed vegetables *viz.*, *Pimpinella anisum, Spinacia oleracea, Amaranthus viridis, Cori andrum sativum,* and *Trigonellafoenum graecum* at various sites in Raipur city, India. They revealed that mean concentration for each heavy metal in the vegetables samples were in the decreasing order of Cr > Zn > Cu > Pb and vegetables consumption in that region could prove to be a health hazard for humans.

2.3 Effect of various soil amendments *viz.*, Biochar, Activated Charcoal and Vermicompost on immobilization of heavy metals in soil

2.3.1 Biochar

In a study conducted by **Sizmur *et al*. (2011)** to ammend the polluted soil collected in the vicinity of Copper mine using biochar in combination with compost and earthworms and revealed that all treatments *viz.*, biochar alone, biochar + compost and biochar + compost + earthworms) reduced the amount of heavy metals compared to the control soils. However, they told that using earthworm with remediation purposes could lead to the mobilization of heavy metals in soil and increase heavy metal uptake by plants. Similarly, **Park *et al*. (2011)** studied the effect of two types of biochar in a heavy metal spiked soil and a naturally strongly polluted soil. They performed a sequential extraction of some heavy metals and found chicken manure biochar was effective to reduce extractable concentrations of Cd and Pb, but not Cu concentration, while green waste biochar was more effective to diminish all of the heavy metals studied. In conjugation with these findings, **Beesley and Marmiroli (2011)** detected retention surface of As, Cd and Zn on biochar and revealed that leachate concentrations of Cd and Zn were reduced 300 and 45 folds, respectively. Similarly, **Namgay *et al.* (2010)** reported that the concentrations of Cd, As and Pb in maize shoots decreased after biochar application. In further studies by **Karami *et al.* (2011)** where they added biochar to a mine soil polluted with Pb and Cu and found that biochar addition reduced pore water Pb concentrations to half their values in the mine soil. Also, when biochar was combined with greenwaste compost the levels of Pb concentrations in the pore water was 20 times lower than in the control. In similar lines, **Jiang *et al*. (2012)** found that the acid soluble fractions of Pb(II) and Cu(II) diminished by 18.8–77.0% and 19.7–100.0%, depending on application of biochar concentration.

2.3.2 Activated Carbon

In a study conducted by **Abdul Zameel and Zahir Hussain (2009)** revealed that using activated carbon of rice husk removed copper, lead, chromium and nickel as 50%, 50%, 61% and 60%. Similarly, in a research trial to study the removal of heavy metals using rice husk charcoal and fly ash as adsorbants by **Ahmed Hegazi (2013)** revealed that these low cost adsorbents could be effectively used in removing heavy metals like Fe, Pb, Ni, Cd and copper within a concentration range of 20-60ppm. Rice husk was effective in the simultaneous removal of Fe, Pb and Ni wheras fly ash was effective in removing Cd and Cu. In further studies by **Kadirvelu *et al.*, (2003)** they prepared activated carbon from agricultural solid wastes, silk cotton hull, coconut tree saw dust, sago waste, maize cob and banana pith and used them to eliminate heavy metals and dyes from aqueous solution. They revealed that adsorption of heavy metal ions and dyes required very short time and showed quantitative removal. Similarly, **Oszin *et al.* (2019)** produced activated carbon from chickpea husk by chemical activation using KOH and K_2CO_3 and examined their efficiency in removing heavy metals from aqueous solution. They concluded that maximum adsorption capacities for Pb(II), Cr(VI), and Cu(II) were found to be 135.8, 59.6, and 56.2 mg/g respectively. In similar lines, **Sharififarid *et al*. (2016)** investigated the removal of lead ions from aqueous solution using iron-activated carbon nano composite and found that under optimum conditions, 96% lead was removed using the nano composite.

2.3.3 Vermicompost

Vermicomposting is considered a simple and low-cost technique of removing toxic metals and breaking down complex chemicals into non-toxic forms **(Hand *et al.*, 1988; Jain & Singh, 2004)**. Earthworm casting is the final product used for farming as fertilizer **(Gunadi *et al.*, 2002)**. The secretions in the intestinal tracts of earthworms, along with some soil passing through the earthworms, make nutrients more concentrated and immediately available for plant uptake. The nutrients from earthworms include micronutrients because the worms in vermicompost break down food wastes and other organic residues into nutrient-rich compost (**Ndegwa& Thompson, 2001**). Earthworms, especially E. fetida, have the capability to accumulate heavy metals in sewage sludge vermicompost **(Saxena & Chauhan, 1998)**. The viability of using earthworms as a treatment or management technique for numerous organic waste streams has been investigated by a number of researchers **(Hand *et al.*, 1988; Madan *et al.*, 1988; Logsdon, 1994; Singh & Sharma, 2002)**. Similarly, a number of industrial wastes have been vermicomposted and turned into nutrient-rich manure (**Sundaravadivel& Ismail, 1995**). Further, Earthworms are known to inhabit and survive in sites heavily contaminated with metals **(Lukkari *et al.*, 2004)** and have the ability to accumulate heavy metals in the cells of yellow tissue **(Fischer and Molnar, 1992)**.

3. MATERIALS AND METHODS

The detailed description of various techniques adopted, and different procedures followed along with the materials used in finalizing the investigation entitled **"Assessment of Heavy Metal Content in Hindon River Belt and an Integrated Approach for Soil and Crop Management"** is being presented in this chapter. The research experiment was conducted in agriculture field adjoining Hindon river at Atour village, Ghaziabad, to cultivate fodder sorghum in *kharif* and wheat in *rabi* season for the two consecutive years, June 2019- April 2021, respectively.

3.1 Experimental site and Location

The research experiment was laid out in the field adjoining Hindon river at Atour village, Ghaziabad for the duration of two years from June2019 to April, 2021 by taking up fodder sorghum in *kharif* and wheat in *rabi* season. The research field has geographical location of 28^0 41′ 54″ N latitude, 77^0 24′ 13″ E longitude with an elevation of 214 metres above the mean sea level.

3.2 Climate and weather

Ghaziabad enjoys semi-arid and sub-tropical climate of extremely hot summer and cold winter with higher temperature of 41.3 ^{0}C recorded in second week of June 2019. Minimum and maximum temperature both exhibited a gradual increase starting from first week of June and declined towards the stating of September & reached their minimum in December and January in 2019-20. There was increase in the temperature from first week of February and peak value was noticed in fourth week of May 2020. The mean weekly maximum temperature reached as high as 40.4^0C in fourth Week of June 2019 while mean weekly minimum temperature reached as low as 4.3^0C in second week of January 2020. The area received mean annual rainfall of 800 mm of which more than 80 % was during July- September through south-west monsoon during 2019.

A few winter showers were also received. April and May were the driest months with mean relative humidity as low as 50 to 55 % whereas high humidity (92%) was recorded in the month of August. Mean weekly minimum temperature varied from 4.8^0C in third week of January to 19.6^0C in fourth week of April during 2020-21. The crop experienced lowest (4.8^0C) of mean weekly minimum temperature in 2^{nd} week of January and highest (38.2^0C) in fourth week of April during 2019-2020. The mean weekly maximum temperature was recorded to be highest (38.1) in fourth week of June 2020and lowest (15.6^0C) in 1^{st} week of January during 2021. Fourth week of September& third week January were most humid (93.3 and 96.7 %) during 2020-21, respectively. However, the driest (30.3 & 34.1 %) crop season was in third and fourth week of April during both the years. Accordingly, the evaporation demand of the atmosphere during 2019-20 was maximum (86.50 mm) during last week of April 2019 and minimum (1.3 mm) during first week of January 2020 while during 2020-21 the respective value was 81 mm & 6.9 mm.

3.3 Soil of the experiment field

Prior to conduct of research experiment, random soil samples were collected to a depth of 0-15 cm from agricultural fields adjoining Hindon river *i.e.* Morti, Atour and Nagla villages in Ghaziabad & Barnawa, Sarfabad and Baleni villages in Baghpat Districts. The collected samples were mixed homogenously, and a composite soil sample was drawn, air dried, powdered and allowed to pass through 2 mm sieve for analyses of soil physical and chemical properties separately for both locations. The values obtained are given in table 3.3. The soil of experimental site was sandy loam in texture, medium in available nitrogen& organic carbon, high in available phosphorus and potassium with alkaline pH. The contents of arsenic (5.7), lead (11.8), iron (2159), and manganese

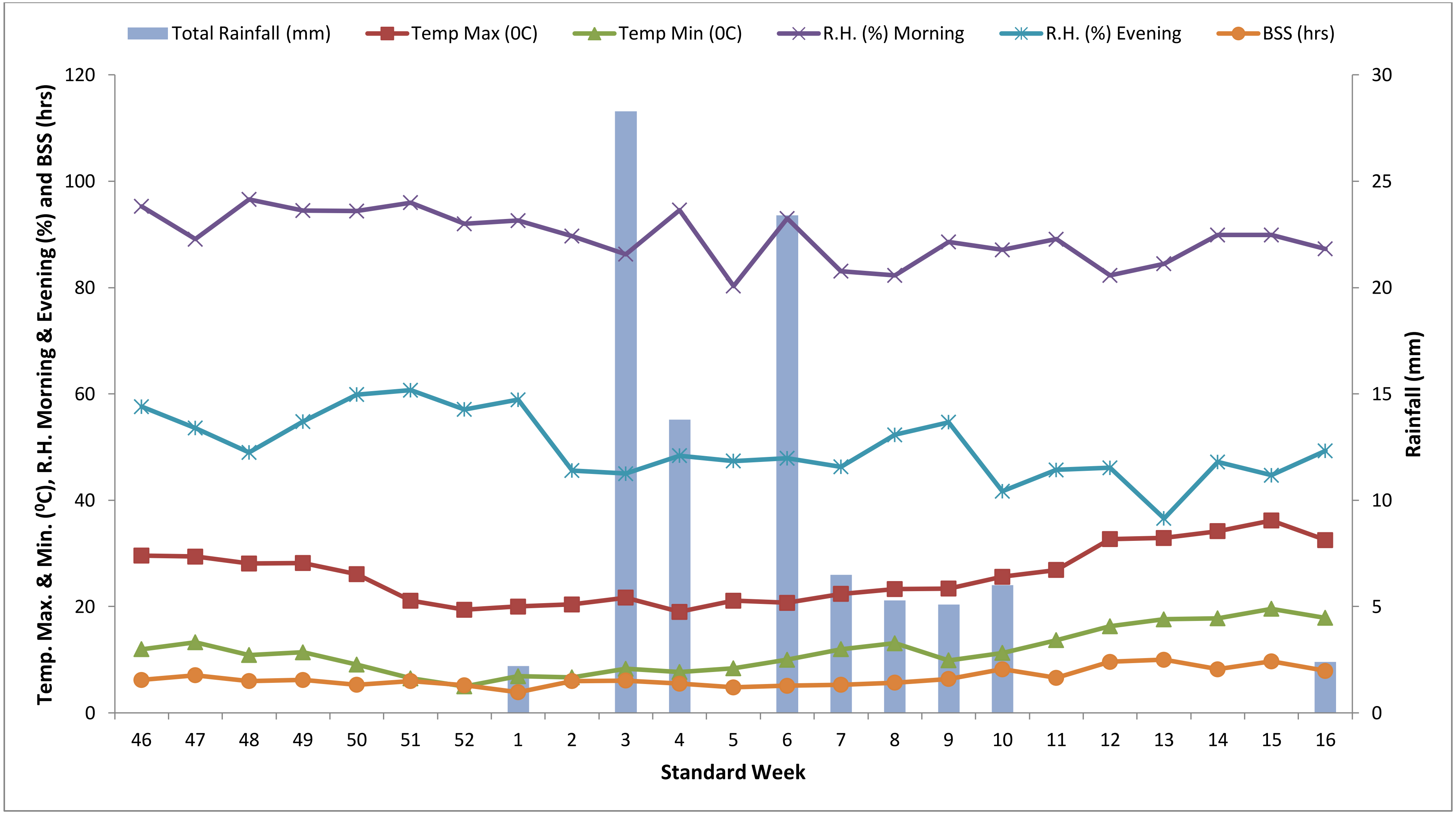


Fig. 3.1 (a) Mean weekly Agro-meteorological data during the crop growing *rabi* season (2019-20)

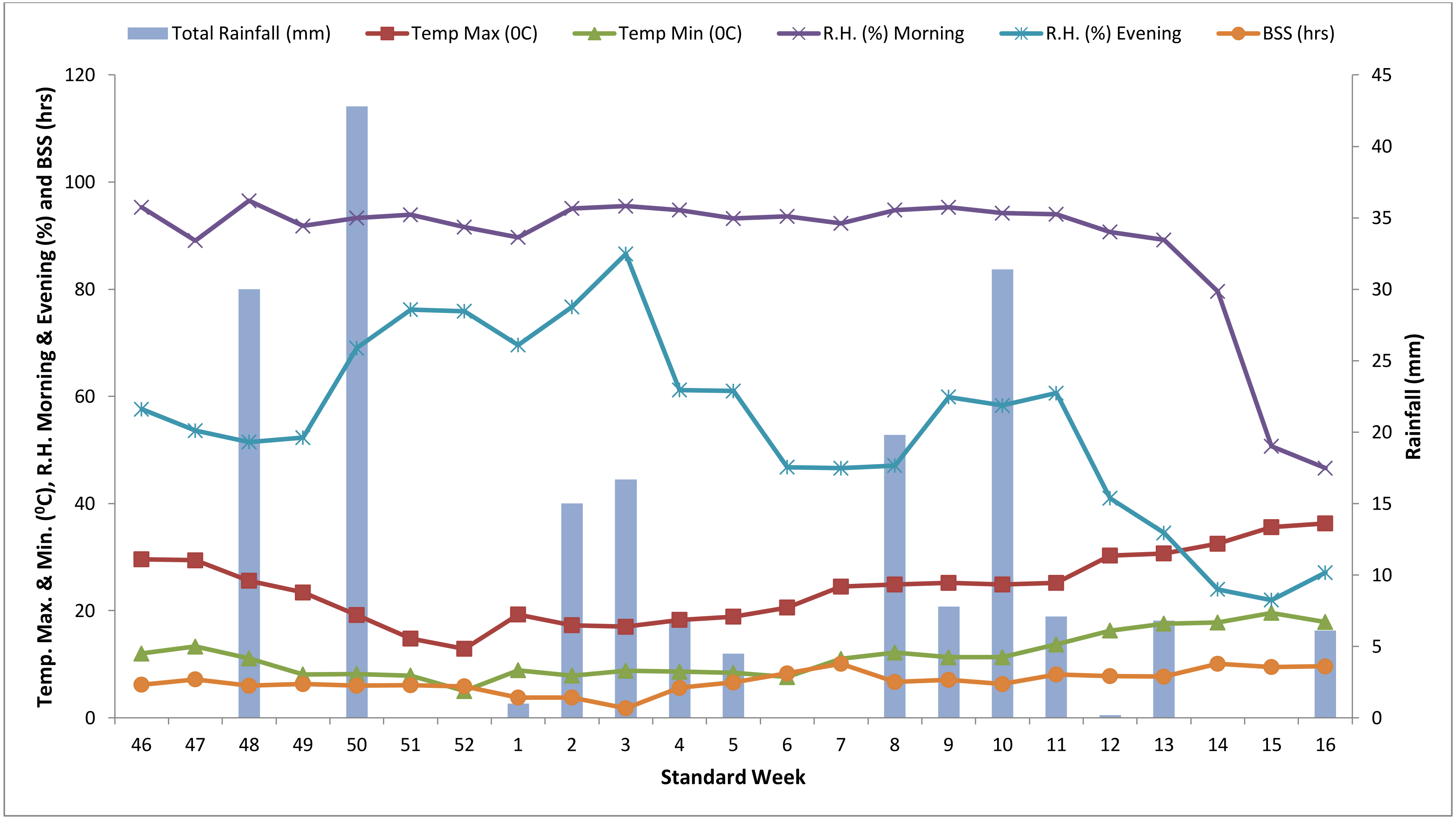


Fig. 3.1 (b) Mean weekly Agro-meteorological data during the crop growing *rabi* season (2020-21)

Table 3.3 Physico-chemical properties of soil samples at Ghaziabad and Baghpat

S. No.	Characteristics	Ghaziabad			Baghpat		
		Site 1	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**
(A)	**Particle size** (%)						
1	Sand	71.9	71.9	71.8	72.1	72.0	72.1
2	Silt	19.1	19.6	18.7	19.6	20.6	19.8
3	Clay	9.0	8.5	9.5	8.2	7.4	8.1
4	Textural class	Sandy	Sandy	Sandy	Sandy	Sandy	Sandy
(B)	**Physical Characteristics**						
1	Bulk density (g cc^{-1})	1.65	1.68	1.55	1.61	1.62	1.58
(C)	**Chemical characteristics**						
1	pH (1:2.5 Soil : water)	8.1	7.8	7.7	7.4	7.6	7.5
2	EC_e (dSm^{-1} at $25C^o$) 1:2.5	2.0	1.9	1.9	1.9	1.8	1.7
3	Organic Carbon (%)	0.65	0.62	0.58	0.52	0.55	0.57
4	Available N (kg ha^{-1})	294	287	301	278.6	263	269
5	Available P (kg ha^{-1})	40.5	37	35.2	37.1	36.2	32.0
6	Available K (kg ha^{-1})	195	200	190	178	181	189
7	Arsenic(mg/kg)	5.78	5.2	4.6	4.7	4.1	3.7
8	Cadmium(mg/kg)	0.87	0.64	0.67	0.78	0.73	0.82
9	Lead (mg/kg)	11.8	10.1	12.0	9.5	10.9	11.2
10	Nickel(mg/kg)	21.5	20.7	22.4	17.6	18.3	17.1
11	Iron(mg/kg)	2159	2271	2088	1914	2061	2754
12	Manganese (mg/kg)	512	480	495	473.3	480	507
13	Zinc(mg/kg)	57.5	51.1	53.8	49.0	45.9	42.8

(512) were above the permissible limits in the soil while that of cadmium (0.8), nickel (21.5), and zinc (57.5) were within their limits.

Table 3.4 Standard procedure for Soil analysis

S. No.	Characteristics	Permissible limit	Method followed	Reference
(A)	**Particle size** (%)		Hydrometer method	Bouyoucos (1936)
1	Sand	-		
2	Silt			
3	Clay			
4	Textural class		USDA triangular diagram	Brady and Well (1996)
(B)	**Physical Characteristics**			
1	Bulk density (g cc^{-1})	-	Core method	Blake, (1965)
(C)	**Chemical characteristics**			
1	pH (1:2.5 Soil : water)	4-8.5	Glass electrode pH meter	Jackson (1962)
2	EC_e (dSm^{-1} at $25C^o$) 1:2.5	4.0	Solubridge	Jackson (1962)
3	Organic Carbon (%)	-	Rapid titration method	Walkey and Black's method (1965)
4	Available N (kg ha^{-1})	-	Alkaline potassium permanganate	Subbbiah and Asija (1956)
5	Available P (kg ha^{-1})	-	0.5 M $NaHCO_3$	Olsen *et al.* (1954)
6	Available K (kg ha^{-1})	-	1N neutral ammonium acetate	Muhr*et al* (1973)
7	Arsenic(mg/kg)	3.0	AAS	Lindsay and Norvell (1978)
8	Cadmium(mg/kg)	50	AAS	Lindsay and Norvell (1978)
9	Lead (mg/kg)	10	AAS	Lindsay and Norvell (1978)
10	Nickel(mg/kg)	100	AAS	Lindsay and Norvell (1978)
11	Iron(mg/kg)	2000	AAS	Lindsay and Norvell (1978)
12	Manganese (mg/kg)	50	AAS	Lindsay and Norvell (1978)
13	Zinc(mg/kg)	300	AAS	Lindsay and Norvell (1978)

3.4 Cropping history of the experimental field

Cropping history of the experimental field for the last five years was carefully examined before initiating the present investigation and has been summarized in Table **3.4.**The farmer practised maize- wheat system during previous years. Maize was taken up in *kharif* and wheat in *rabi* season prior to conduct of experiment. This study was done to know the nature of crop grown on particular piece of land where the experiment was conducted and may be helpful in the interpretation and discussion of results.

Table 3.4 Cropping history of the experimental field

Year	**Crop**	
	Kharif	***Rabi***
2015-16	Maize	Wheat
2016-17	Maize	Wheat
2017-18	Maize	Wheat
2018-19	Maize	Wheat
2019-20	Sorghum	Wheat
2020-21	Sorghum	Wheat

3.5 Experiment details

Treatments were formulated as to ensure the possible use of Hindon water (pure or water mixtures) for irrigation purpose and to study the effect of appropriate soil amendments in addressing the issue of heavy metal uptake by grain and fodder crops in metal contaminated soils. The experiment was laid out in Split plot design with three replications, keeping irrigation water (pure/ mixtures) in the main plot and soil amendments in sub plot. The nature of irrigation necessitates larger plot size and thus assigned to main plot. Since, soil amendments effect, needed higher accuracy and therefore allocated to sub plots. Experiment design, plot size and layout etc., were done as per the standard procedure to allow measurement of variation within data and to have error measurement as follows:

3.5.1 Treatments-

Considering the problem of irrigating field crops by metal polluted Hindon water, used as an inexpensive source of water by farmers, four types of irrigation water (pure or/and mixtures) were tested with three soil amendments and a control. Thus, treatments (16) comprised of all possible combinations of irrigation water (04) and soil amendments (04). Further details are given hereunder:

Treatments

Factor A: Irrigation water (pure/ mixture) – 04		**Symbol**
i.	Ground water (100%)	I_1
ii.	Ground water (75%) + Hindon water (25%)	I_2
iii.	Ground water (50%) + Hindon water (50%)	I_3
iv.	Hindon water (100%)	I_4

Factor B: Soil amendments – 04		**Symbol**
i.	Biochar @ 5t/ha	S_0
ii.	Activated Carbon @ 5t/ha	S_1
iii.	Vermicompost @ 5t/ha	S_2
iv.	No Amendment	S_3

3.5.2 Treatment combinations

The treatments (16), as above, were laid out in Split plot design with three replications. Four irrigation treatments were planned in main factor *viz.*,100% Ground water (GW), 100% Hindon water (HW), 75% Ground water (GW)+ 25% Hindon water (HW) and 50% Ground water (GW) + 50% Hindon water (HW) and three soil amendments *viz.*, Biochar, Vermicompost, activated carbon & a control were taken in sub plots. All the possible combinations of the factors under consideration are given in table 3.5.

Table 3.5: Treatment combinations

Combinations	**Symbol**
1. Ground water (100%) + Biochar	(I_1 S_0)
2. Ground water (100%) + Vermicompost	(I_1 S_1)
3. Ground water (100%) + Activated carbon	(I_1 S_2)
4. Ground water (100%) + No Amendment	(I_1 S_3)
5. Ground water (75%) + Hindon water (25%)+ Biochar	(I_2 S_0)
6. Ground water (75%) + Hindon water (25%) + Vermicompost	(I_2 S_1)
7. Ground water (75%) + Hindon water (25%) + Activated carbon	(I_2 S_2)
8. Ground water (75%) + Hindon water (25%)+ No Amendment	(I_2S_3)
9. Ground water (50%) + Hindon water (50%) + Biochar	(I_3 S_0)
10. Ground water (50%) + Hindon water (50%) + Vermicompost	(I_3 S_1)
11. Ground water (50%) + Hindon water (50%) + Activated carbon	(I_3 S_2)
12. Ground water (50%) + Hindon water (50%) + No Amendment	(I_3 S_3)
13. Hindon water (100%)+ Biochar	(I_4 S_0)
14. Hindon water (100%) + Vermicompost	(I_4 S_1)
15. Hindon water (100%) + Activated carbon	(I_4 S_2)
16. Hindon water (100%) + Control/No Amendment	(I_4 S_3)

The layout plan is given in Fig. 2a. In sorghum and wheat, row-row distance was kept as 30 and 20 cm, respectively.

3.5.3 Irrigation water mixing & storage

Four tanks of 1000 litre capacity were kept at the trial site. Before start of experiment, all the four tanks were marked with marker at 100 litre level on the inner side of tank. The Hindon water was collected in tank by pumping through the tractor which was already in use by farmer. Ground water was collected in tank through pipe connected to nearby tube-well. As per the treatment, Hindon and ground water was mixed & stored in tank for irrigation purpose.

Table 3.6: Quantity of water as per treatment

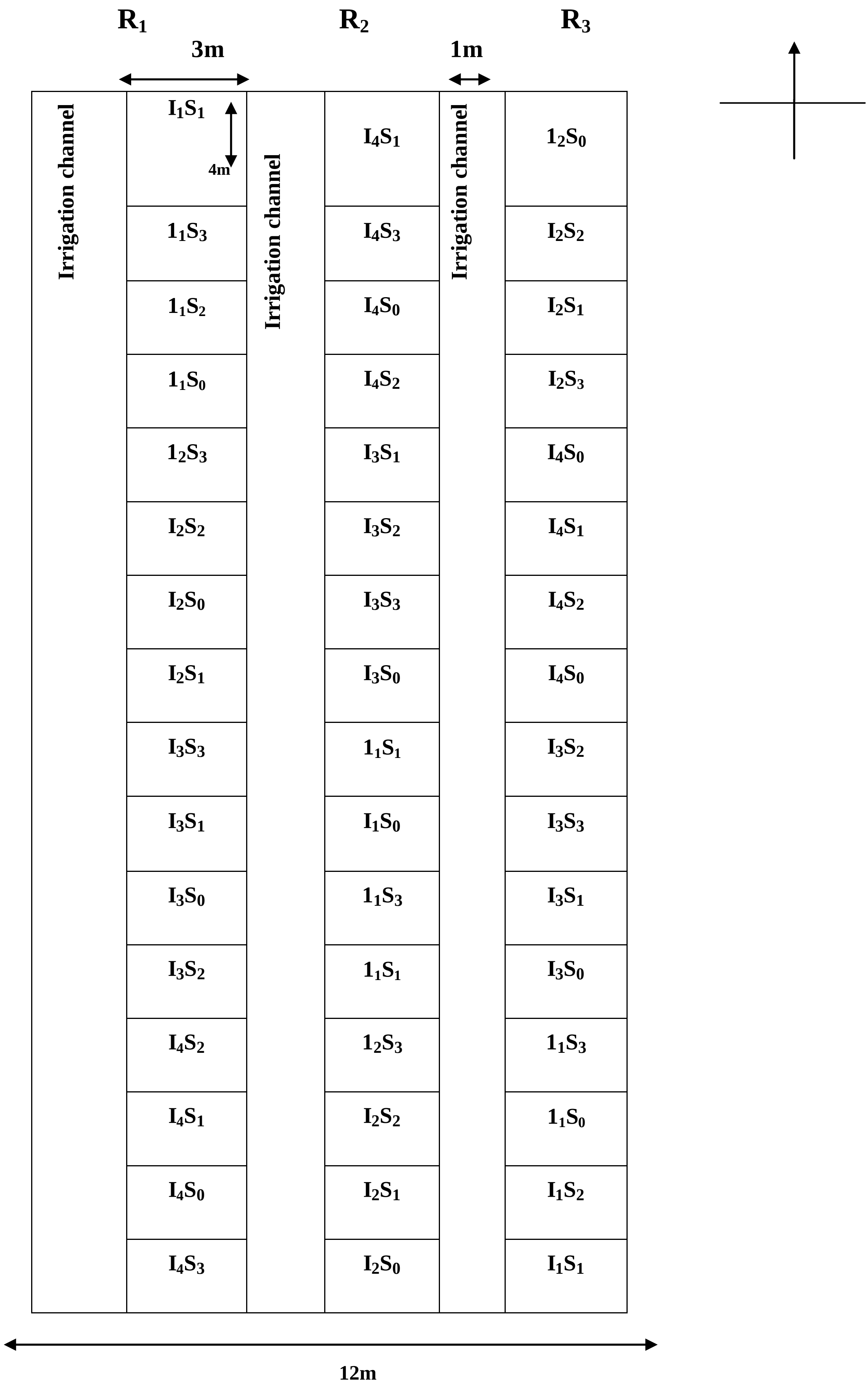
Quantity of irrigation water as per treatment for wheat				
Area (m^2)	**Irrigation water treatments (litre)**			
	100% GW	75% GW+ 25% HW	50% GW + 50% HW	100% HW
10000	7,50,000	5,00,000+2,50,000	3,75,000+ 3,75,000	7,50,000
$12m^2$ (plot size)	900	600+300	450+450	900
Quantity of irrigation water as per treatment for sorghum				
Area (m^2)	**Irrigation water treatments (litre)**			
	100% GW	75% GW+ 25% HW	50% GW + 50% HW	100% HW
10000	4,50,000	1,50,000+ 3,00,000	2,25,000+ 2,25,000	4,50,000
$12m^2$ (plot size)	540	360 + 180	270+270	540

*wheat requires 7.5 cm water per irrigation
*sorghum requires 4.5 cm water per irrigation

3.5.4 Design and Layout

Further information on design and layout is as under:

Experimental design	:	Split-plot design
Main plot	:	Irrigation water (pure/ mixture)
Sub plot	:	Soil Amendments
No. of treatment combinations		4 X 4=16
No. of replications	:	03
Total number of plots		16 X 3 = 48
Plot size		
(i) Gross plot	:	4.0 m X 3.0 m = 12.0 m^2
(ii) Net plot	:	3.0 X 1.8 = 5.4 m^2
Variety- Sorghum	:	Pant Chari-5
Wheat	:	PBW 343
Seed rate (Kg ha^{-1})	:	
Sorghum		35 $kgha^{-1}$
Wheat		100 $kgha^{-1}$
Spacing- (row-row)		
Sorghum		30 cm
Wheat		20 cm
Depth-		
Sorghum		2-3 cm
Wheat		4-5 cm
Fertilizer dose – (N:P_2O_5: K_2O - kg/ha)		
Sorghum		85:40:40
Wheat		150:60:30



R_1
R_2
R_3
3m
1m
Irrigation channel
Irrigation channel
Irrigation channel
4m
I_1S_1
1_1S_3
1_1S_2
1_1S_0
1_2S_3
I_2S_2
I_2S_0
I_2S_1
I_3S_3
I_3S_1
I_3S_0
I_3S_2
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I_4S_0
I_3S_2
I_3S_3
I_3S_1
I_3S_0
1_1S_3
1_1S_0
I_1S_2
I_1S_1
12m

Fig. 3.2 Layout plan of the field experiment

The experimental field was divided into three equal blocks, each block was sub-divided into 04 main plots and further each main plot into 4 sub-plots of similar dimensions as given in fig. 2a. Each of the sub-plot measured 4m in length and 3 m in width. Rows or furrows were opened parallel to length and perpendicular to width. The crops were sown with row-to-row distance of 30cm for sorghum in *kharif* and of 20 cm for wheat in *rabi* season. Thus, there were 10 rows of sorghum and 15 rows of wheat in each sub-plot.

3.5.5 Crop Varieties

Sorghum

Pant Chari-5: This variety was developed by GBPUA&T, Pantnagar and released in 1999 for cultivation in all the *kharif* sorghum growing areas of Andhra Pradesh, Gujarat, Haryana, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, and Uttar Pradesh for fodder under irrigated conditions. The plants are semi-erect with an approximate height of 245 cm tall and are highly juicy with fully enclosed internodes. The leaves are 74 cm long and 6.2 cm broad with light green mid rib. This variety is highly resistant to anthracnose, zonate leaf spot and other foliar diseases. It has a protein content of 6.58%, digestibility of 47.7% and low HCN content of 100.4 ppm. The average green fodder and dry fodder yield is 48.2 and 13.4 t/ha.

Wheat

Wheat variety PBW 343 is well suited for cultivation in the northern plains of Punjab, Western U.P, Uttarakhand, and irrigated plains of Haryana. The crop is ready for harvest in 130-135 days in timely sown conditions with estimated yield of 55-60 quintals per hectare.

3.5.6 Soil Amendment Description:

a) Biochar:

Biochar is one of the richest sources of carbon and is obtained from agriculture and forest wastes. It is a charcoal-like substance which contains 70% carbon. It improves soil fertility, prevent soil degradation, and sequester carbon in the soil. The main quality of biochar is its carbon-rich fine-grained, highly porous structure and larger surface area that makes it an ideal soil amendment for carbon sequestration **(Lehmann, 2007)**. It improves soil fertility by retaining water and nutrients in soil, encouraging beneficial soil organisms, and thereby reducing the need for additional use of fertilizers. Biochar can store carbon in the soil for as many as hundreds to thousands of years **(IBI, 2008)**. Biochar has proved to be very effective for the treatment of heavy metal contaminated soils because it effectively adsorbs heavy metals and decreases bioavailability and toxin-induced stress to plants and microorganisms.

b) Activated carbon

Activation is a process to selectively remove the hydrogen or hydrogen-rich fractions from a carbonaceous raw material as to produce an open, porous residue giving it a very large functional surface area for its volume. Activated charcoal is one that has been treated with either a combination of heat and pressure, or with strong acid or base followed by carbonization, to make it highly porous. It is used as the remediation material in heavy metal contaminated soils because of its ability to adsorb heavy metals.

c) Vermicompost

Vermicompost is good for soils which have heavy metal problems **(Belliturk *et al*., 2015)**. It is an important organic material source for prevention of heavy metal pollution and improvement of crop quality and yield.

Table 3.7: Physio-chemical properties of soil amendments

S.No	Soil amendments		
	Biochar	Vermicompost	Activated carbon
• Particle size	3-5 mm	2-3 mm	2-3 mm
• pH	7.6-8.1	7.4-8.1	7.9-8.3
• C	65	12.2	72
• N	1.6	0.99	0.01
• P	2.2	0.5	0.02
• K	5.8	2.8	0.9

3.6 Cultural Operations in Sorghum

Crop was grown following the recommended package and practices. Certified seed of sorghum variety Pant chari 5 was taken from the university & was used for sowing. Sorghum was sown on 20-06-2019 & 17-06-2020 and harvested on 05-09-2019 & and 02-09-2020 respectively. Weed infestation was checked through pre-emergence application of Atrazine @ 0.5 kg *a.i.* ha^{-1}, after first irrigation on 21-06-2019 & 18-06-2020during the respective years of experiment. Crop took 75 days to mature for fodder purpose. Further, information on pre and post sowing operations is given in **Table 3.8**.

3.6.1 Pre-sowing irrigation

A pre-sowing irrigation was applied to the field to ensure the adequate moisture in the soil profile at the time of sorghum planting. The irrigation was given as per the respective irrigation treatment (pure/ mixture).

3.6.2 Seed bed preparation

After harvesting of farmer's preceding wheat crop, field was deeply ploughed with the tractor drawn plough followed by cross harrowing to bring the soil to a fine tilth by crushing the clods. Thereafter, the land was smoothened with the help of wooden planker to conserve the soil moisture and achieve uniform seed bed preparation.

3.6.3 Layout

The experiment was laid out in plots as per the layout plan and area was divided into three equal blocks and each block was subdivided into 04 main plots of same dimensions, which were further divided into 04 subplots each. The detailed layout plan has been given in fig. 2a.

3.6.4Fertilizer application

The recommended dose of fertilizer for fodder sorghumis85:40:40 kg of N, P_2O_5 and K per hectare, respectively. The fertilizer sources used for nitrogen, phosphorus and potassium were Urea (46% N), Di ammonium phosphate (18% N & 46% P_2O_5) and Muriate of potash (60% K_2O**),** respectively. Full doses of phosphorus and potassium along with half dose of nitrogen were applied in separate furrows opened for the purpose at the time of sowing. Remaining dose of nitrogen was top dressed as urea four days after first irrigation on 24-06-2019 & 21-06-2020 in the respective years.

3.6.5Seed treatment and sowing

Prior to twelve hours of sowing, sorghum seeds were treated with Bavistin @ 2g/kg seed. The sowing of sorghum was done in furrows at2-3 cm depth, opened by furrow opener maintaining row-row distance of 30 cm with a seed rate of 35 kg ha^{-1}on 20-06-2019 and 17-06-2020 for both the years of experiment.

3.6.6 Irrigation

The crop was irrigated as per recommendations based on critical growth stage approach. Accordingly, four irrigations were given to sorghum each to a depth of 6 cm. Irrigation water was used as per the treatment. The crop received irrigations on 20 June, 05 July, 20 July & 05 August during 2019 and on 17 June, 02 July, 17 July and 01August during 2020. The irrigation was given as per the respective irrigation treatment (pure/ mixture).

3.6.7Weed management

Weed plants pose a serious problem for the crops especially under irrigated conditions by competing for space, nutrients, water and solar radiation etc. Therefore, pre-emergence application of atrazine @0.5 kg ha^{-1} was done on June 21and 18 during 2019 and 2020, respectively, to manage weeds and prevent unwanted competition to the crop.

3.6.8 Plant protection

Application of Phorate 10G @ 20 kg ha^{-1} was done in furrows at sowing time to control the infestation of shoot fly, stem borer and other insects, irrespective the year of experimentation.

3.6.9 Harvesting and threshing

The crop was manually harvested with sickle at 50% flowering stage on September 05 and 02 respectively during 2019 and 2020. First, the plants from border rows were harvested and removed from the field. Thereafter, the net plot area was harvested, and produce was left in the field for 3-4 days to get it dried. The bundle weight was recorded from each plot and expressed in kg ha^{-1} as green fodder yield.

3.6.2 Cultural operations

During both the years, cultural operations carried out for raising the sorghum crop are summarized below in Table 3.6.

Table 3.9: Schedule of cultural operations carried out in the experiment field

Particulars of operation	Date of operation		Method used
	2019	2020	
Pre sowing irrigation	07-06-2019	05-06-2020	Ground water
Ploughing	17-06-2019?	14-06-2020	Tractor drawn disc
Harrowing &Levelling	18-06-2019	15-06-2020	Tractor drawn disc harrow &leveller
Layout	19-06-2020	16-06-2020	Manually
Seed treatment with Bavistin	19-06-2020	16-06-2020	Manually
Sowing of sorghum	20-06-2019	17-06-2020	Line sowing
Fertilizer application	20-06-2019	17-06-2020	Basal application
Pre emergence application of Atrazine	21-06-2019	18-06-2020	Manually
Pre emergence application of Phorate 10G	21-06-2019	18-06-2020	Manually
Irrigation			Pure/ water mixtures
1st	20-06-2019	17-06-2020	
2nd	05-07-2019	02-07-2020	
3rd	20-07-2019	17-07-2020	
4th	05-08-2019	01-08-2020	
Harvesting	05-09-2019	02-09-2020	Manually by sickle

3.7 Cultural Operations in wheat

The wheat crop was grown with the recommended package of practices. Certified seed of wheat variety PBW-343 was taken from the University and used for sowing. Weed infestation was checked by performing two hand weeding at 35 and 55 days after sowing during both the years. Crop protection measures were not required as there was no disease or pest infestation which crossed the ETL.

3.7 .1 Pre-sowing irrigation

A pre-sowing irrigation was applied to the field to ensure the adequate moisture in the soil profile at the time of wheat sowing. The irrigation was given as per the respective irrigation treatment (pure/ mixture).

3.7.2 Seed bed preparation

The experimental field was ploughed with soil turning plough followed by one planking operation. Dry weeds and stubbles were removed, and the field was ploughed again by cultivator and leveled with wooden plank for obtaining a good tilth. All the operations of seed bed preparation were done.

3.7.3 Seed treatment

Wheat seeds were treated with bavistin @ 2g/kg seed and dried in shade twelve hours prior to sowing.

3.7.4 Seed rate and sowing

Wheat variety PBW 343 was sown on Nov ----during 2019 and on Nov – during 2020 in furrows opened 20 cm apart by furrow opener using the uniform seed rate of 100 kg ha^{-1} ·

3.7.5 Fertilizer application

In experiment, 150:60:30 (kg ha^{-1}) nitrogen, phosphorus and potassium, respectively was applied under recommended NPK. The fertilizer sources used for nitrogen, phosphorus and potassium were Urea (46% N), Di ammonium phosphate (18% N & 46% P_2O_5) and Muriate of potash (60% K_2O).Half of the nitrogen and full doses of phosphorus and potassium were applied at the time of sowing and remaining half dose of nitrogen was top dressed four days after first irrigation on 16-12-2019 &

18-12-2020 for both the years of experiment.

3.7.6 Weed management

Weed plants pose a serious issue to crop growth and development under irrigated conditions by competing with field crops for available resources. To control the weeds, two hand weeding were done at 35 and55days after sowing on 27-12-2019 & 17-01-2020 and 30-12-2019 & 15-01-2021 for both the years of experiment.

3.7.7 Irrigation

Irrigation channels measuring 1 m wide were placed between the replications to ensure easy and uninterrupted flow of irrigation water. Wheat crop was given five irrigations comprising of pure / water mixtures as per the treatment as on 11-12-2019, 05-01-2020, 25-01-2020, 23-02-2020, 22-03-2020 and 14-12-2020, 07-01-2021, 27-01-2021, 25-02-2021, 24-03-2021 for both the years of experiment. The irrigation was given as per the respective treatment (pure/ mixture).

3.7.8 Harvesting and Threshing

The wheat crop was harvested manually with the help of sickle at ripening stage. The plants from border rows were harvested first and thereafter wheat plants in net plot area were harvested and produce was left in the field for 3-4 days to get it dried. The bundle from individual net plot was weighed. Thereafter, threshing operation was done manually and the grains were cleaned, weighed and yield per plot was expressed in terms of kg ha^{-1}. The weight of wheat straw was obtained by subtracting the grain weight from total biomass yield and was expressed in terms of kg ha^{-1}.

3.7.10 Cultural operations

During both the years, cultural operations carried out for raising the wheat crop are summarized below in Table 3.7.

Table 3.10: Schedule of cultural operations carried out in the experiment field.

Particulars of operation	Date of operation		Method used
	2019-20	**2020-21**	
Pre-sowing irrigation	10-11-2019	12-11-2020	Ground water
Harrowing & Ploughing	18-11-2019	20-11-2020	Tractor drawn disc plough& cultivator
Levelling&Layout	19-11-2019	21-11-2020	Wooden plank Manually
Fertilizer application	20-11-2019	22-11-2020	Manually
Sowing of wheat	20-11-2019	22-11-2020	Manually
Irrigation			Pure/ water mixture
1st	11-12-2019	14-12-2020	
2nd	05-01-2020	07-01-2021	
3rd	25-01-2020	27-01-2021	
4th	23-02-2020	25-02-2021	
5th	22-03-2020	24-03-2021	
Hand weeding	27-12-2019 17-01-2020	30-12-2020 15-01-2021	Manually
Harvesting	07-04-2020	09-04-2021	Manually by sickle
Threshing	16 -04-2020	19-04-2021	Manually

3.8 Observations

The observations on water, soil, crop and weather parameters etc., were recorded during the experiment. Initial soil test values have been given in Table **3.3** while weather conditions have been cited in appendix I and II, depicted in Fig. 3.1a and b. Further, observations on soil and crop were taken as under:

3.9 Water Study

To study the physio- chemical properties of Hindon river, water samples were collected from two districts- Baghpat and Ghaziabad. Water samples were collected at one - two metres away from the Hindon river shore at a depth of 15-30 cm using plastic bottles. Also, ground water samples were taken from the villages where Hindon water samples were collected.

3.9.1 Procedure of Hindon and Ground water sampling

Water analysis was carried out to identify the physio- chemical properties of Hindon and ground water. Two days before the sampling date, polyvinyl chloride (PVC) bottles were decontaminated and washed with detergent followed by thorough rinsing with water to remove any detergent and thereby rinsed with distilled water. Further, bottles underwent two successive 1 hour shaking treatment with nitric acid followed by rinsing with distilled water and cleaning with acetone (to dry off water). Water samples were collected at one - two metres away from the Hindon river shore at a depth of 15-30 cm using plastic bottles. Ground water samples were also collected from villages adjoining Hindon river sampling sites. The samples were then transferred to the laboratory for further analysis.

3.9.2 Physio- chemical properties of Hindon and Ground water:

Water analysis was based on the below mentioned parameters to estimate the pollution load of selected sites in Hindonand ground water at Baghpat and Ghaziabad. After analysing the physio- chemical properties of water samples, maximum concentration of heavy metals in Hindon river was found in district Ghaziabad.

Table 3.11 Physio- chemical properties of Hindon and Ground water at Ghaziabad

		Ghaziabad							
		Hindon water				Ground water			
S. No.	Attribute	Site 1	Site 2	Site 3	Av.	Site 1	Site 2	Site 3	Av.
1.	P^H	7.8	7.9	7.7	7.8	7.0	7.2	7.1	7.1
2.	EC (dsm^{-1})	1.08	1.04	1.12	1.08	0.7	1.04	0.36	0.7
3.	Total dissolved solids	629	610	650	629.6	110	100	120	110
4.	Bicarbonate	402	370	437	403	162	175	190	175.6
5.	Carbonate	100	80	110	96.6	60	66	72	43
6.	Sodium (mg/l)	33	25	43	33	10.7	9.8	11.7	10.7
7.	Calcium (mg/l)	88	75	79	80.6	40	35	28	42.8
8.	Magnesium (mg/l)	46	52	55	51	19	29	25	25.6
9.	Nitrate	3.7	3.1	2.9	3.2	1.8	2.6	1.2	1.8
10.	Phosphate	4.5	2.8	4.1	3.8	0.9	3.8	0.7	1.8
11.	Potassium	45	32	38	38.3	12	7.5	8.6	9.3
12.	Biological oxygen demand	160	150	185	165	35	38.3	39	37.4
13.	Chemical oxygen demand	390	416	455	420.3	98	100	105	101
14.	Residual sodium carbonate	1.6	0.61	2.3	1.5	0.7	0.9	1.1	0.9
15.	Sodium adsorption ratio	3.2	3.1	5.3	3.8	1.9	1.7	1.8	1.8
16.	Heavy metals (mg/l)								
	Arsenic	0.003	0.002	0.005	0.003	0.002	0.01	0.00	0.001
	Cadmium	0.006	0.008	0.004	0.006	0.002	0.003	0.01	0.005

	Nickel	0.56	0.4	0.8	0.586	0.07	0.33	0.18	0.193
	Lead	0.08	0.06	0.1	0.08	0.04	0.02	0.01	0.023
	Zinc	0.4	0.2	0.7	0.433	0.04	0.51	0.31	0.286
	Iron	10.5	7.8	12.6	10.3	4.9	5.6	4.81	5.10
	Manganese	4.06	3.8	4.4	4.08	2.05	2.0	2.2	2.08

Table 3.12 Physio- chemical properties of Hindon and Ground water at Baghpat

		Baghpat							
		Hindon water				**Ground water**			
S.No	**Attribute**	**Site 1**	**Site 2**	**Site 3**	**Av.**	**Site 1**	**Site 2**	**Site 3**	**Av.**
1.	P^H	7.6	7.9	7.5	7.6	7.3	7.1	7.4	7.2
2.	EC (dsm^{-1})	1.04	1.09	1.01	1.04	0.66	0.81	0.55	0.67
3.	Total dissolved solids	494	527	530	517	78	72	89	80
4.	Bicarbonate	390	419	380	396	160	145	137	147
5.	Carbonate	85	95	101	93	67	69	56	64
6.	Sodium (mg/l)	45	31	23	33	12.8	10	11.5	11.4
7.	Calcium (mg/l)	90	81	72	81	44	38	36	39
8.	Magnesium (mg/l)	40	42	50	44	25	19	23	22
9.	Nitrate	2.6	3.1	3.3	3	1.2	1.7	1.5	1.4
10.	Phosphate	3.8	4.3	2.9	3.6	0.7	0.8	1.1	0.86
11.	Potassium	37.5	29	30	32.1	8.4	10.5	8.9	9.2
12.	Biological oxygen demand	74.3	80	95	83.1	30	37	29	32
13.	Chemical oxygen	215	280	310	268	89	95	98	94

	demand								
14.	Residual sodium carbonate	1.3	2.4	1.8	1.8	0.6	1.2	0.3	0.7
15.	Sodium adsorption ratio	5.5	3.9	2.8	4.0	2.2	1.7	1.9	1.9
16.	Heavy metals (mg/l)								
17.	Arsenic	0.002	0.001	0.004	0.002	0.01	0.04	0.005	0.018
18.	Cadmium	0.003	0.004	0.001	0.002	0.15	0.11	0.06	0.106
19.	Nickel	0.03	0.12	0.27	0.14	0.03	0.05	0.09	0.056
20.	Lead	0.002	0.005	0.008	0.005	0.001	0.003	0.005	0.003
21.	Zinc	0.53	0.1	0.3	0.31	0.2	0.6	0.4	0.4
22.	Iron	8.16	7.1	10.5	8.5	4.81	4.2	3	4
23.	Manganese	3.76	3.3	4.2	3.7	1.92	1.88	2.3	2

Table 3.13 Physio-chemical properties of Irrigation water treatments

S. No.	**Attribute**	**Hindon+GroundWater 50%+50%**	**Hindon+GroundWater 25%+75%**	**Ground Water100 %**	**Hindon Water 100%**	**Permissible limit in irrigation water(mg/l)**
1.	P^H	7.5	7.3	7.1	7.8	6.5 to 8.4
2.	EC (dsm^{-1})	1.02	0.8	0.36	1.12	3.0
3.	Total dissolved solids (TDS)	305	220	120	650	2100
4.	Bicarbonate	260	204	190	437	600
5.	Carbonate	52	30	**72**	110	
6.	Sodium (mg/l)	15	12	11.7	43	90
7.	Calcium	45.5	32	28	79	60

	(mg/l)					
8.	Magnesium (mg/l)	32	21	19	55	
9.	Nitrate	2.2	1.9	1.2	2.9	-
10	Phosphate	3.0	2.4	0.7	4.1	-
11	Potassium	32	20	11.6	38	-
12	Biological oxygen demand	37	74.3	39	185	30
13	Chemical oxygen demand	99	215	105	455	250
14	Residual sodium carbonate	1.1	1.0	0.8	2.3	<1.25
15	Sodium adsorption ratio	2.4	2.3	1.8	5.3	26
16.	**Heavy metals** (mg/l)					
	Arsenic	0.002	0.001	0.00	0.1	5.0
	Cadmium	0.005	0.003	0.002	0.005	0.01
	Nickel	0.45	0.19	0.01	0.004	0.01
	Lead	0.06	0.04	0.01	0.8	0.2
	Iron	8.7	6.4	4.81	12.6	3.0
	Manganese	3.02	2.19	2.1	4.4	0.2
	Zinc	0.3	0.2	0.31	0.7	2.0

Table 3.14 Standard procedure for Water analysis

S. No.	Attribute	Study interval/timings	Method	Reference
1.	P^H	Initial	pHmeter	Jackson(1973)
2.	EC	Initial	Conductivity Meter	Jackson(1973)
3.	Total dissolved solids	Initial	Filtration method	APHA (2012)

	(TDS)			
4.	Bicarbonate	Initial	Versenate method	Richards(1954)
5.	Carbonate		Versenate method	Richards(1954)
6.	Sodium	Initial	Flame photometer	Jackson(1973)
7.	Calcium & Magnesium	Initial	Versenate method	Black (1965)
8.	Biological oxygen demand	Initial	BOD incubator	APHA (2012)
9.	Chemical oxygen demand	Initial	Reflux assembly	APHA (2012)
10.	Residual sodium carbonate	Initial		
11.	Sodium adsorption ratio	Initial		
12.	Nitrate	Initial		
13.	Phosphate	Initial		
14.	Potassium	Initial		
15.	**Heavy metals (mg/kg)**			
	Cd (Cadmium)	Initial	AAS	APHA (2012)
	Ni (nickel)	Initial	AAS	APHA (2012)
	Pb (lead)	Initial	AAS	APHA (2012)
	As(Arsenic)	Initial	AAS	APHA (2012)
	Zn (zinc)	Initial	AAS	APHA (2012)
	Fe (Iron)	Initial	AAS	APHA (2012)
	Mn(Mangnese)	Initial	AAS	APHA (2012)

3.9.2 Physio- chemical properties of Hindon and ground water adjoining experimental site- At our village (Ghaziabad):

3.9.2.1 pH

The pH balance of water describes how acidic or alkaline it is. The normal pH range for irrigation water is considered between 6.5 to 8.4. The pH of Hindon river and adjoining ground water samples was determined using pH meter. pH of Hindon water varied in range of 7.7-8.1 with a mean value of 7.8 whereas it varied from 7.2-7.4 in ground water samples with average value of 7.4.The standard values of pH for irrigation water given by WHO is in range of 6.5 to 8.4. The pH value of Hindon water sample was in range of 7.7-8.1 which is acceptable for irrigation purpose.

3.9.2.2 Electrical Conductivity

Salt concentration of irrigation water is measured as electrical conductivity (EC). It was estimated with the help of Conductivity meter and expressed in *Decisiemens per metre*. The conductivity of Hindon water was in the range of 1.04-1.12 dS/m with a mean value of 1.08 and that in ground water samples varied from 0.36-1.04 with average value of 0.77. The electrical conductivity of Hindon water was in range of 1.04-1.12 which is below the permissible limit for irrigation purpose as given by WHO.

3.9.2.3 Total dissolved solids (TDS)

Total Dissolved Solids refer to any materials, salts, metals, cations or anions dissolved in water. It is measured in parts per million (ppm) or milligrams per litre (mg/L). Total Dissolved Solids varied from 610-650 in Hindon water and 100-120 in ground water samples and was below the permissible limit as given by WHO.

3.9.2.4 Carbonate and bicarbonate

Alkalinity of water is determined by titrating the sample with a standard solution of acid. Alkalinity due to carbonate was determined to the first end point (pH 8.3) using phenolphthalein indicator and bicarbonate alkalinity was determined to the second end point (pH 4.5) using methyl orange. The carbonate and bicarbonate value ranged from 80-110 & 370-437 with mean value of 103 & 405 in Hindon water and from 40-45 and 175-190 with average values of 62.5 and 183 in ground water respectively.

3.9.2.5 Biological oxygen demand

Biochemical Oxygen demand is a measure of quantity of oxygen required by microorganisms in the oxidation of organic matter. The biological oxygen demand of Hindon and ground water samples was measured by estimating the dissolved oxygen content of the sample before and after five days of incubation at 20° C. BOD values of Hindon water were in the range from 150-185 mg/l with mean value of 166.6while for ground water varied from 35-39 with average value of 37 which is higher than the permissible limit of 30 mg/l according to WHO.

3.9.2.6 Chemical oxygen demand

The chemical oxygen demand of Hindon and ground water samples was determined by oxidizing the organic matter by reflection with known excess of $K_2Cr_2O_7$ with standard ferrous ammonium sulphate solution. Chemical oxygen demand of Hindon water was in the range from 390-416 mg/l with mean value of 402 which was higher than the permissible limit of 250 mg/l given by WHO while it varied from 98-105 with average value of 99.0 in ground water samples.

3.9.2.7 Sodium

Sodium in hindon and ground water samples was estimated using flame Photometry as described by **Richards (1968)**. Sodium in Hindon water was in range of 25-43 mg/l with mean value of 33 mg/l which was lower than the permissible limit of 90 mg/l (as given by WHO) while it varied from 9.8-10.7 with average value of 10.2 in ground water.

3.9.2.8 Residual sodium carbonate

The hazardous effect of carbonate and bicarbonates on water quality was determined by Richard and classified the water for irrigation purposes in terms of residual sodium carbonate (RSC) as given below. The value of residual sodium carbonate in Hindon water was calculated as 1.7, which was above the permissible limit for irrigation purpose while in it was 1.03 for ground water.

$$\mathbf{RSC = [HCO_3^- + CO_3^{2-}] - [Ca^{2+} + Mg^{2+}]}$$

3.9.2.9 Sodium adsorption ratio

Sodium adsorption ratio is an important parameter for determination of soil alkalinity or alkali hazards in the use of ground water for agricultural applications. The SAR measures the relative proportion of sodium ions in a water sample to those of calcium and magnesium. The SAR of Hindon and ground water was 4.03 and 1.92 which was below the permissible limit as described by WHO.

3.9.2.10 Heavy metals (Arsenic, Cadmium, Nickel, Lead, Iron, Manganese and Zinc)

The heavy metals in Hindon and ground water samples were measured with AAS (AOAC 2012). The values of arsenic, cadmium, lead and nickel, iron, manganese and zinc varied from 0.002-0.005, 0.006-0.008, 0.06-0.1, 0.4-0.8,7.8-12.6, 3.8-4.4 & 0.2-0.7 with average value of 0.003, 0.007, 0.08, 0.56 10.5, 4.06 & 0.4 in Hindon water and 0.001, 0.001-0.003, 0.01-0.02, 0.07-0.18,4.9-5.6, 2.0-2.2 & 0.04-0.31 with mean value of 0.001, 0.002, 0.01, 0.12 4.25, 2.05 & 0.17 in ground water respectively. Of these, nickel, iron and manganese were present above the permissible limit in Hindon water as described by WHO.

3.10 Meteorological observations

Observations on various weather parameters were recorded and presented on weekly basis during the crop period at KVK Ghaziabad as given below:

1. Air temperature (maximum and minimum)
2. Rainfall
3. Sunshine hours
4. Relative humidity

3.11 Soil study

3.11.1 Collection of soil samples

The present study area was located in western part of Uttar Pradesh, India, where Hindon water is being frequently used for irrigating adjoining agricultural fields, over more than three decades. River Hindon originates from lower Shivalik ranges in District Saharanpur of Uttar Pradesh and is primarily rainfed. The basin area falls in the districts of Saharanpur, Muzaffarnagar, Shamli, Meerut, Bagpat, Ghaziabad and Gautambudh Nagar in western Uttar Pradesh and covers a distance of about 300 km before joining the river Yamuna downstream of Delhi. The Hindon river has been a major source of water to the highly populated and predominantly rural population of Western Uttar Pradesh. Soil samples were collected from two villages adjoining Hindon river at Baghpat and three villages at Ghaziabad.

3.11.2 Soil Analysis

Soil samples were collected from agriculture fields adjoining Hindon river in Morti, Atour and Nagla villages at Ghaziabad & Barnawa and safirabad villages in Baghpat. The collected soil samples were mixed homogenously and a composite soil sample was drawn, air dried, powdered and allowed to pass through 2 mm sieve for analyses of soil physical and chemical properties. Physical and chemical properties of soil samples were analyzed in laboratory and accordingly experimental site was chosen based on the severity of heavy metal contamination in the soil. Also, soil samples were collected from individual treatment plots post harvest of wheat for further analysis. Initial composite soil samples of the whole experimental field and the subsequent soil samples were collected with the help of a spade and auger from 0-15 cm depth of each individual plot after completion of the experimentation year wise to study soil physical and chemical properties. The initial soil test values using the analytical procedures were given in table. 3.6.

3.11.3 Soil of the experiment field

The soil of experimental site was sandy loam in texture, medium in available nitrogen & organic carbon, high in available phosphorus and potassium with alkaline pH.The maximum heavy metal content in soil samples was recorded at Atour village, Ghaziabad and so this place was chosen to carry out the field experiment.

3.11.4 Soil Texture

The soil texture was determined by hydrometer method given by Bouyoucos (1962). In this method, 100gm of soil sample was taken in 500ml beaker and soil was givenH_2O_2treatmentfor the organic matter destruction in the sample. Thereby, 200ml of distilled water was added to 100ml of the sodium hexa met phosphate and a solution was prepared by stirring well with the glass rod & kept for 4 to 5 hours followed by mechanical stirring. The mechanical stirring was done for ten minutes and the contents were transferred to the suspension cylinder of 1000ml capacity, giving five washings of distilled water. A rubber stopper was then placed tightly and the cylinder was inverted carefully to shake several times in order to disperse soil particles completely. Then, the cylinder was placed on the table and the stopper was removed. The hydrometer was placed in the suspension to check the upward and downward movement and reading was recorded exactly 40 seconds after the placement of hydrometer. Thereby the rubber stopper was replaced and inverted several times again to observe the complete dispersion of particles, kept on the table. Two hours later, hydrometer was placed again into the suspension and the reading of hydrometer was recorded. Also, blank reading was noted without soil sample &room temperature was recorded in Fahrenheit to calculate the texture of soil.

3.11.5 Bulk Density

Bulk density of soil was measured using the core-ring method as given by Blake (1965). In this method a core sampler of 5 cm height and diameter was pressed into the soil to collect soil sample. After this, the cylinder was removed, extracting a soil sample of known volume followed by recording the moist sample weight. Thereafter soil sample was dried in an oven at 105°C for 24 hrs, until changes in weight becomes constant followed by weighing of oven dried samples.

$$\text{BD} = \frac{\text{Oven dry weight of soil}}{\text{Volume of core sampler}}$$

3.11.6 Organic Carbon (%)

The organic carbon content in soil sample was determined by Walkely and Black wet oxidation method. One gm of soil sample was taken in a 500 ml erlenmeyer flask followed by addition of 10 ml of 1N potassium dichromate solution and 20 ml sulphuric acid. Further, 200 ml of deionised water, 10 ml of phosphoric acid, 0.2g ammonium fluoride and 10 drops of diphenylamine indicator were added to this sample. Thereby, sample was titrated with 0.5N ferrous ammonium sulphate solution till the colour changed from dull green to a turbid blue and then to brilliant green. The organic carbon content in the soil was calculated with below mentioned formula:

Organic matter in soil (%) = % organic C × 1.724

3.11.7 pH

Soil pH is the measure of the amount of acidity or alkalinity that is present in soil solution. The pH of soil sample was measured by using glass electrode pH meter maintaining the soil: water in the ratio of 1:2 as given by Jackson (1962). In this method, twenty grams of soil sample was weighed and transferred into 100 ml beaker to which forty mL of distilled water was added and was stirred with a glass rod. Then, the mixture was allowed to stand for half an hour with intermittent stirring. The glass electrode was immersed in the soil water suspension in a beaker and pH value was determined from pH meter display.

3.11.8Electric Conductivity (EC)

Soil electrical conductivity (EC) is the measure of amount of salts in the soil (salinity of soil) and is an important indicator of soil health. Electrical conductivity was determined in 1:2 soil-water extract using Conductivity Bridge and expressed as dSm^{-1} (Jackson, 1962). In this,air-dried soil sample of ten grams was taken in a 50 ml beaker and 20 ml of distilled water was added to it. Thereafter, the suspension was stirred at regular intervals for 20 to 30 minutes using magnetic stirrer and after one hr of keeping undisturbed soil suspension, electrical conductivity was measured using Conductivity Bridge.

3.11.9 Available Nitrogen

Available Nitrogen in the soil sample was determined by the method given by Subbiah and Asija (1956) using alkaline potassium permanganate ($KMnO_4$)**.** In this method, organic matter in soil is treated with hot alkaline $KMnO_4$ followed by release of ammonia that is distilled and trapped in boric acid mixed indicator solution. The quantity of NH_3 trapped is estimated by titrating with standard acid. Five gram of soil sample was transferred to digestion tube and was distilled with 0.32% $KMnO_4$ and

2.5% NaOH with heating of sample by passing steady steam and the liberated ammonia is collected in conical flask containing 20 ml of 2% boric acid with mixed indicator. Then, colour change was noticed from pink to green and distillate was titrated against 0.02 N sulphuric acid with colour change to original pink.

3.11.10 Available Phosphorous

Method for estimation of available phosphorous depends on the pH of soil sample which was determined using pH meter. The pH of soil sample was 7.9 which is in alkaline range so, 0.5M $NaHCO_3$ extractable method was used to determine available phosphorus as given by Olsen *et al*., (1954). In this method, two gram of soil sample was weighed to which a pinch of Darco G- 60 activated charcoal was added and mixed with extraction solution [50 ml of 0.5 M $NaHCO_3$ (pH 8.5)] followed by continuous shaking of solution for 30 minutes and thereby filtrate was collected (5 ml) in 25 ml volumetric flask. To this filtrate, two to three drops of p- nitro phenol indicator was added resulting in yellow colour development thereby, adding of 5N H_2SO_4 drop by drop, until yellow colour disappeared to acidify upto pH 5. Thereafter, 4 ml of ascorbic acid solution was added to the flask resulting in blue colour development. The intensity of blue colour which is proportional to phosphate was read on the spectrophotometer at a wave length of 660 nm. A blank was also prepared with all chemicals and no soil. The concentration of available phosphorus in soil was expressed in kg ha^{-1}.

Available phosphorus (kgha^{-1}) = ppm of P calculated from standard curve X dilution factorX2.24

3.11.11Available Potassium

Soil sample of five gram was taken in a 150 ml conical flask and was mixed with 25 ml of normal ammonium acetate (pH 7) and kept for 5 minutes and filtered. Thereafter, filtrate was aspirated into the atomizer of calibrated flame photometer and reading of potassium was taken. The concentration of available potassium in soil was expressed in kg ha^{-1} and calculated as:

Available potassium (kg ha^{-1}) = ppm of K X dilution factor X 0.83

3.11.12Heavy metals (Arsenic Cadmium, Nickel, Lead Zinc, Iron and Manganese)

Arsenic, cadmium, nickel, lead, zinc, iron and manganese were estimated using atomic absorption spectrophotometer. In this, 12.5 grams of soil sample was weighed in 100 ml iodine value flasks followed by addition of 25 ml DTPA solution. Thereafter, this mixture was shaken for 2 hrs in automated shaker at 70 to 80 oscillations per minute. The mixture was filtered through whatman filter paper (42 no.) and filtrate was collected in plastic bottles. The heavy metal content in DTPA extract was determined on Atomic absorption spectroscopy using respective cathode lamps.

3.12 Crop Studies

3.12.1 Crop Stand

3.12.2 Growth

The sorghum- wheat cropping system was adopted during the respective *kharif* and *rabi* seasons of the year 2019-20 and 2020 -21. Observations common to both crops have been given together while observations specific tothe crop are mentioned separately.

3.12.3Plant population

3.12.3.1 Initial plant population

Initial plant population for both sorghum & wheat was determined in each net plot area and converted on per hectare basis.

3.12.3.2 Plant population at Harvest

At harvest, plant population was estimated for both sorghum & wheat crop in respective net plot and computed on per hectare basis.

3.12.3.3 Plant height (cm)

For the study of plant height in wheat, longest tiller height was measured for five tagged plants starting from the base to the tip of the plant using meter scale. The height of the plant in cm was recorded at 30, 60, 90 days after sowing and at harvest. Similarly, five randomly selected sorghum plants were chosen to measure height from the ground level to the top of the main shoot at 30, 60 DAS & at harvest.

3.12.3.4 Number of tillers per meter square

Total number of wheat tillers per meter square were recorded at 30, 60 and 90 days after sowing from three sites in each net plot and expressed as average number of total tillers per meter square. Since Sorghum was cultivated for fodder purpose, so this observation was specific to wheat crop.

3.12.3.5 Dry matter accumulation

Three randomly selected sorghum and wheat plants were cut close to the ground at 30 days interval till harvest. The plant samples were left for sun drying and then dried in oven at 70° C till the constant weight was obtained. After drying, the samples will be weighed for recording dry weight.

3.13 At Harvest

3.13.1 Yield attributes and Yield

3.13.1.1 Number of effective tillers per meter square

The number of spike bearing tillers was recorded from the sampling unit at the time of maturity and data was expressed as number of effective tillers m^{-2}.

3.13.1.2Spikelets per spike

Five ears (spikes) were collected at random from each net plot and their spikelets were counted & average was worked out.

3.13.1.3 Number of grains per earhead

Randomly selected five earheads were taken from each net plot and threshed manually. The number of grains was counted and average for number of grains per ear head was calculated.

3.13.1.4 Test weight

Random grain samples of wheat were drawn from the bulk produce of each net plot and 1000 grains were counted and weighed on electrical balance.

3.13.1.5 Grain yield (q/ha)

Wheat plants from each net plot were harvested, threshed and winnowed separately. After cleaning, the grains were sun dried and thereafter the grain yield was recorded by weighing grains from each plot separately and expressed in $kgha^{-1}$.

3.13.1.6 Straw yield (kg/ha)

The wheat plants of the net plot were removed just near to the ground with the help of sickle and weight of straw obtained from the net plot area was recorded. Finally, the straw yield was computed on hectare basis using the dry matter content on oven dry weight basis and then expressed in kg/ha.

3.13.1.7 Biological yield (q/ha)

Grain and straw yield were obtained from each net plot and was added to compute biological yield in kilogram from each plot.

3.13.1.8 Green fodder yield

Sorghum was harvested at 50% flowering stage for green fodder. Two border rows from each side of individual plot at half metre distance from each side were harvested first as border rows. For observation of green fodder yield, crop was harvested from each net plot, tagged, weighed and expressed in q ha^{-1}.

3.13.1.9 Dry fodder yield

The sorghum sample bundles of green fodder from each net plot were initially weighed and left for thirty days for sun drying. After sun drying these bundles were weighed again and dry fodder yield was calculated for each net plot and expressed in q ha^{-1}.

3.13.1.10 Harvest index (%)

Harvest index (%) of wheat crop was calculated as the ratio of economic yield (grain) and biological yield multiplied by 100. Its value is expressed in percentage.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (kg/ha)}}{\text{Biological yield (kg/ha)}} * 100$$

(Excluding root mass)

3.14 Quality

3.14.1 Protein content

The protein percentage in wheat seed and sorghum dry matter was calculated by multiplying nitrogen percentage of wheat seed and sorghum dry matter with standard factor 6.25 (A.O.A.C.I960).

3.14.2 Protein yield

The protein yield in wheat and sorghum was calculated by multiplying the respective protein percentage with the yield of corresponding treatment. It was calculated by the formula given below:

$$\text{Protein yield wheat (kg/ha)} = \frac{\text{Protein \% * Seed yield (kg/ha)}}{100}$$

$$\text{Protein yield sorghum (kg/ha)} = \frac{\text{Protein \% * fodder yield (kg/ha)}}{100}$$

3.14.3 Nutrient content and Uptake

After the harvesting and threshing of wheat crop, seed and straw samples were drawn from each treatment and sun dried. Nutrient content in grain and straw samples of wheat plants were estimated separately for each treatment. All the samples were ground up to 20 mesh sieve using Wiley Mill grinder and digested in di-acid mixture of HNO_3:$HClO_4$ (3:1) followed by estimation of total nitrogen, phosphorus and potassium by micro Kjeldahl, Vanadomolybdo phosphoric acid yellow color and flame photometer, respectively. The nutrient (nitrogen, phosphorus, and potassium) uptake by grain and straw was calculated as follows:

Grain uptake (kg ha^{-1}) = Grain yield (kg ha^{-1}) *x Nutrient content (%) in grain

Straw uptake (kg ha^{-1}) = Straw yield (kg ha^{-1})* x Nutrient content (%) in straw

Total nutrient uptake (kg ha^{-1}) = Grain uptake (kg ha^{-1}) + Straw uptake (kg ha^{-1})

3.14.4 Nitrogen content

Nitrogen content in seed and straw of both the crops (expressed in percent) was analysed by Kjeldahl method. Plant sample of 1 g was weighed and transferred to digestion tube. Ten millilitre of sulphuric acid and five gram catalyst mixture were added to the sample. Digestion tubes were loaded in digestion unit and temperature of digestion unit was set to 110 °C till frothing was over. Thereafter temperature was increased to 400 °C. Samples turned colourless at the end of digestion process. After cooling, tubes were loaded in distillation unit. Forty millilitres of NaOH (40%) was automatically added to the sample in distillation unit with steady passage of stream and liberated ammonia absorbed in 4% boric acid having mixed indicator contained in a 250 ml conical flask. Colour changed from pink to green. Simultaneously, blank sample (without plant sample) was run. The green colour distillate was titrated against .02N sulphuric acid and colour changed from green to pink. Blank and sample titre readings were noted to calculate nitrogen content in plant samples as follows:

$$\text{N content in plant (\%)} = \frac{\text{R x Normality of acid x Atomic weight of nitrogen}}{\text{Sample weight x 100}} \times 100$$

R = Sample titre – Blank titre

3.14.5 Phosphorus content

Phosphorous content in seed and straw of both the crops (expressed in percent) was analysed by Vanado-molybdo-phosphonic yellow colour method. Plant sample of 1g was weighed and 10 ml of diacid mixture (3:1 Nitric acid: Per chloric acid) was added to the sample in a volumetric flask. Sample was placed on hot plate for digestion. The solution was filtered in 100 ml conical flask and was diluted with distill water. As to prepare standard curve, 0,1,2,3,4,5 ml of 50 ppm P solution was transferred to 50 ml volumetric flasks to get 0,100,150,200 and 250 µg P. Ten millilitre of vanadomolybdate reagent was added and content was mixed thoroughly. Readings of transmittance and absorbance were taken at 420 mµ and standard curve was plotted. Further, 10 ml of dilute solution was transferred in 50 ml volumetric flask and 10 ml of ammonium molybdate vandate solution was added and readings were recorded.

3.14.6 Phosphorus uptake

Phosphorous content in wheat seeds and straw of both crops were multiplied with respective seed and straw yield to determine the phosphorous uptake in kg/ha. Total Phosphorous uptake was calculated by adding the values of phosphorous uptake by seed and straw and expressed in kg/ha. In an intercropping system, combined total phosphorous uptake was worked out by addition of total phosphorous uptake by chickpea and mustard and expressed in kg/ha.

Grain uptake (kg ha^{-1}) = Grain yield (q ha^{-1}) *x P_2O_5 content (%) in grain

Straw uptake (kg ha^{-1}) = Straw yield (q ha^{-1}) *x P_2O_5 content (%) in straw

Total P_2O_5 uptake (kg ha^{-1} or g ha^{-1}) = Grain uptake (kg ha^{-1}) + Straw uptake (kg ha^{-1})

* Oven dried

3.14.7 Potassium content

Potassium content in wheat seed and straw of both the crops (expressed in percent) was analysed by wet digestion method. Oven dried and powdered plant sample weighing 1 g was transferred in 100 ml of digestion flask. Twenty ml of di acid mixture was added to the sample and heated slowly on hot plate rising the temperature gradually until the sample turned colourless. After digestion of sample, 20 ml of water was added and filtered through Whatman no. 40 filter paper into 100ml of volume flask. Aliquot was used to record flame photometer reading using red filter.

3.14.8 Potassium uptake

Potassium content in seed and straw of both the crops (expressed in percent) was multiplied with respective seed and straw yield to determine the K uptake in kg/ha. Total potassium uptake was calculated by adding the values of K uptake by seed and straw and expressed in kg/ha. In an intercropping system, combined total potassium uptake was worked out by addition of total K uptake by chickpea and mustard and expressed in kg/ha.

Grain uptake (kg ha^{-1}) = Grain yield (q ha^{-1}) *x K content (%) in grain

Straw uptake (kg ha^{-1}) = Straw yield (q ha^{-1})* x K content (%) in straw

Total K uptake (kg ha^{-1} or g ha^{-1}) = Grain uptake (kg ha^{-1}) + Straw uptake (kg ha^{-1})

* Oven dried

3.14.9Heavy metals (arsenic, cadmium, lead, nickel, iron, manganese & zinc)

An amount of 0.5 gm of the dried and ground sample was digested with di-acid (mixture of nitric acid and perchloric acid (4:1)) on hot plate till residue became colourless. The volume of mixture was made to 25 ml with addition of double distilled water, filtered and stored in washed plastic bottles. The heavy metals As, Cd, Ni, Pb, Fe, Mn and Zn were determined by AAS (Atomic absorption spectrophotometer).

3.15 Soil–plant metal transfer and health risk assessment indices

To compare the accumulation and transfer of metals in the different plant parts and soils, two indices were calculated according as described by Li *et al.* (2009). The bio-concentration factor (BCF) and the transfer factor (TF) were computed according to the following equations and metal concentrations expressed on dry weight basis, unless stated otherwise. The metal quantity in each plant part was computed by the metal concentration multiplied with dry matter yield. Therefore, metal accumulation in the plant is calculated as the sum of metal quantities in root, shoot and grains.

3.15.1Bio-concentration factor (BCF)

It is the ratio of content of heavy metals in plant part to that in soil in which they are grown. When BCF < 1, it indicates that the plant can only absorb but not accumulate heavy metals, when BCF > 1it shows that plant accumulated metals.

BCF = [M stem or M leaves or M root]/[M soil]

[M stem / M leaves/ M root] is the metal concentration in the stem, leaf and root tissues

[M soil] is the metal concentration in the soil (determined by aqua regia method).

3.15.2 Transfer factor (TF)

The metal quantity in each plant part was obtained by the metal concentration multiplied by dry matter yield. Therefore, metal accumulation in the plant was calculated as the sum of metal quantities in root, stem and leaves.

TF = [M shoot]/[M root]

Where [M shoot] is the metal concentration in the above ground portion of the plant (stem and leaf tissues)

[M root] is the metal concentration in roots.

3.16 Economics

The following economic parameters were worked out based on the prevailing prices of output and cost of various inputs during the period of investigation.

3.16.1 Cost of Cultivation

Cost of cultivation incurred under cropping system was estimated by adding all costs to be invested in cultivation with interest on working capital.

3.16.2 Gross Return (Rs/ha)

Total income by selling the produce was estimated and thus gross return was calculated in rupee per hectare.

3.16.3 Net Return

Net return was obtained by subtracting the cost of cultivation from gross return as follows:

Net return = Gross return – Cost of cultivation

3.16.4 Benefit: Cost ratio

Benefit: cost ratio or net profit per rupee of investment was calculated by the following formula:

$$\text{B: C Ratio} = \frac{\text{Gross return (Rs ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs ha}^{-1}\text{)}}$$

3.17 Statistical Analysis

In order to find out the variation among the treatments, experimental data was subjected to statistical analysis. Fisher’s (1952) method of analysis was followed to calculate the nature and magnitude of the effects revealed by ‘F’ test. Appropriate standard errors along with critical differences, wherever needed, were calculated for the statistical interpretation of data. The mean data under different character is presented in tables.

3.17.1 Standard error of mean

Standard error of mean was calculated as follows:

$$\text{Standard error of mean} = \frac{\sqrt{\text{EMSS}}}{\text{r}}$$

Where; SEm± = Standard error of mean

EMSS = Error mean sum of square

r = Number of replication on which the observation is based.

3.17.2 Critical Difference

The critical difference at 5% level of significance was estimated as under:

C. D. = SEm (±) × $\sqrt{2}$ × t (at error degree of freedom)

4. EXPERIMENTAL RESULTS

This chapter deals with the analysis of data recorded during the experiment entitled **"Assessment of Heavy Metal Content in Hindon river water and an Integrated Approach for Soil and Crop Management**". An attempt was made to study the feasibility of using Hindon water by farmers as an irrigation source under various irrigation treatments. Observations recorded *viz.*, growth attributes, yield attributes & yield, quality, macro & micro nutrient content, heavy metals content, bio-concentration and transfer factor of heavy metals in both the crops, which were subjected to statistical analysis in Split plot design to find out the significance of different treatments by using the analysis of variance technique during both the years. For ease in understanding, graphical illustrations have also been incorporated for key observations.

4.1 Sorghum

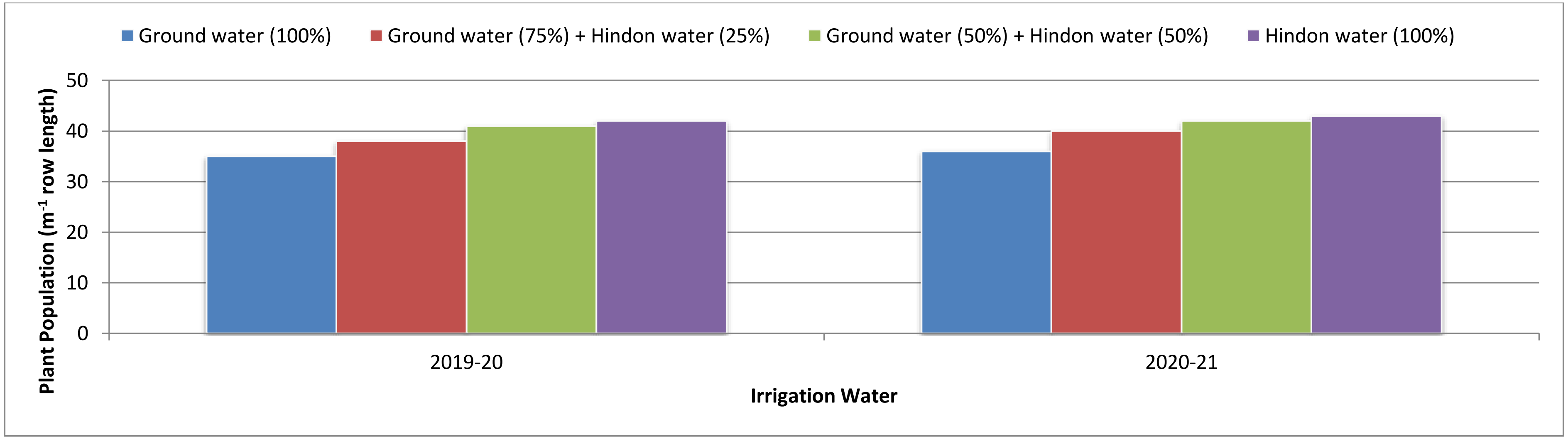
4.1 Population Studies

Plant population of fodder sorghum varied significantly under different irrigation treatments and soil amendments **(Appendix- V).** However, the interaction between irrigation water and soil amendments was found to be non-significant.

The data on plant population of fodder sorghum is given in table 4.1 and depicted in Fig. 4.1, reveals that irrigation treatments comprising of Hindon water alone or in mixture resulted in significantly higher plant population at initial and harvest stages during both the years. The highest number of plants m^{-2} was noted with 100% Hindon water (42 & 43 m^{-2}) which was statistically at par to dilution of raw Hindon water with ground water in 1:1 ratio (41 & 42 m^{-2}) and significantly superior to Hindon & ground water in 1:3 ratio (38 & 40 m^{-2}) & 100 % ground water (35 & 36 m^{-2}) respectively.

Table 4.1 Effect of irrigation treatments and soil amendments on plant population of fodder sorghum

Treatments	**Plant Population (m^{-1} row length)**	
	2019-20	**2020-21**
(A) Irrigation water		
Ground water (100%)	35	36
Ground water (75%) + Hindon water (25%)	38	40
Ground water (50%) + Hindon water (50%)	41	42
Hindon water (100%)	42	43
SE(m)±	***0.37***	***0.58***
C.D (P=0.05)	***1.07***	***1.68***
(B) Soil amendments		
Activated Carbon @ 5t/ha	38	40
Biochar @ 5t/ha	43	44
Vermicompost @ 5t/ha	41	43
Control	30	32
SE(m)±	**0.42**	**0.63**
C.D (P=0.05)	**1.21**	**1.84**



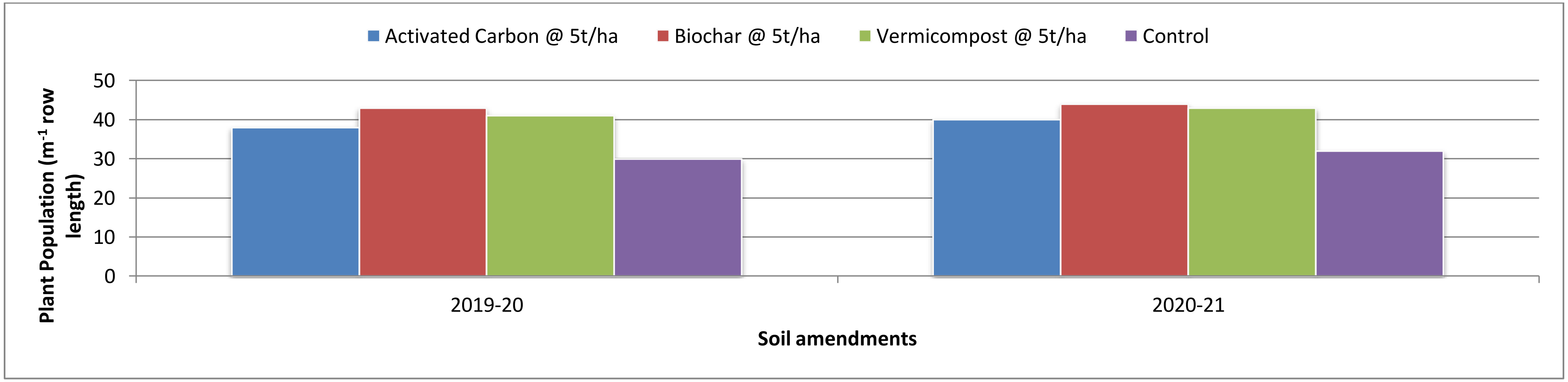


Fig. 4.1 Effect of irrigation treatments and soil amendments on plant population of fodder sorghum

Among the soil amendments, biochar @ 5t ha^{-1} produced significantly higher plant population at initial and harvest stages (43 & 44 m^{-2}) which was statistically superior to vermicompost @ 5t ha-^{1} (38 & 40 m^{-2}) and activated carbon (41 & 43 m^{-2}) @ 5t ha^{-1} while lowest plant population was recorded in control (30 & 32 m^{-2}) against all soil amendments during both the years.

4.2 Crop studies

Observations on plant height and dry matter accumulation were recorded at different stages of growth in fodder sorghum as follows:

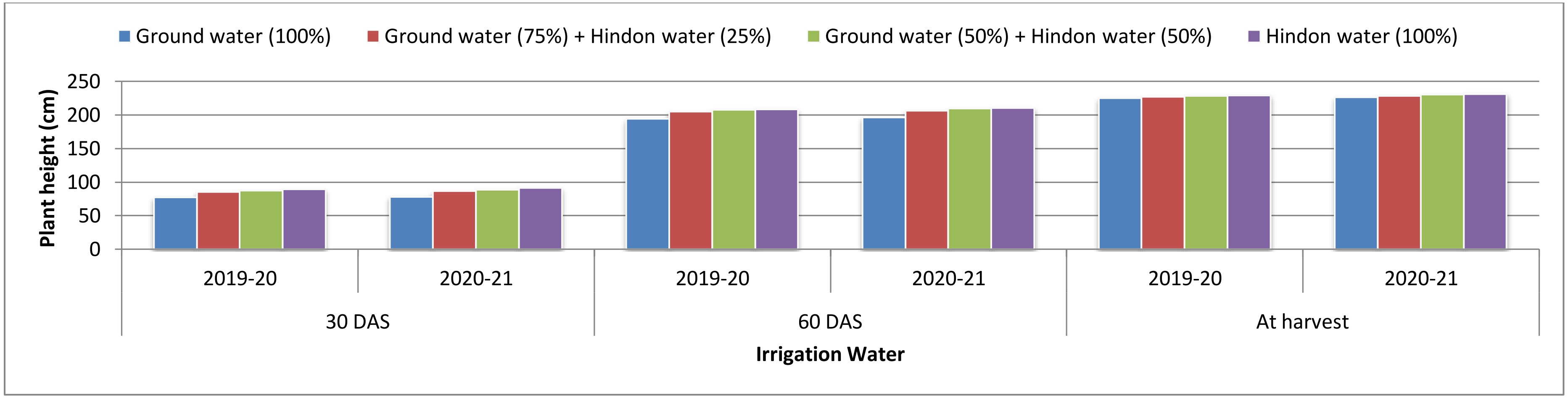
4.2.1 Plant height (cm)

Plant height in sorghum varied significantly under different irrigation treatments and soil amendments **(Appendix- VI).** However, the interaction between irrigation water and soil amendments was found to be non-significant.

The data on plant height of sorghum is given in table 4.2 and depicted in Fig. 4.2 reveals that irrigation treatments comprising of Hindon water alone or in mixture resulted in significantly taller sorghum plants. Plant height of sorghum increased as the crop advanced and reached maximum at harvest, irrespective of the treatments. The height of sorghum plants under different irrigation treatments varied from 77.4 to 89.7 & 78.3 to 91.4, 194.3 to 208.4 & 196.5 to 210.3 and 225.1 to 229.3 & 226.3 to 231.4 cm at 30, 60 days after sowing and harvest stage during both the years of experiment. The tallest height of sorghum plants of (89.7 & 91.4, 208.4 & 210.3 and 229.3 & 231.4) at 30, 60 days after sowing and at harvest was noted with 100% Hindon water which was statistically at par to dilution of raw Hindon water with ground water in 1:1 ratio (87.1 & 88.7, 207.5 & 209.5 and 228.4 & 230.5) and significantly superior to Hindon & ground water in 1:3 ratio (85.6 & 86.5, 205.4 & 206.5 and 227.1 & 228.3) respectively.

Table 4.2 Effect of irrigation treatments and soil amendments on plant height (cm) of fodder sorghum

Treatments	Plant height (cm)					
	30 DAS		60 DAS		At harvest	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	77.4	78.3	194.3	196.5	225.2	226.3
Ground water (75%) + Hindon water (25%)	85.6	86.5	205.4	206.5	227.1	228.3
Ground water (50%) + Hindon water (50%)	87.1	88.7	207.5	209.5	228.4	230.5
Hindon water (100%)	89.7	91.4	208.4	210.3	229.3	231.4
SE(m)±	**0.89**	**0.95**	**1.05**	**1.14**	**1.47**	**1.56**
C.D (P=0.05)	**2.61**	**2.78**	**3.10**	**3.34**	**4.32**	**4.60**
B. Soil amendments						
Activated Carbon @ 5t/ha	84.3	86.2	201.9	203.6	228.1	230.6
Biochar @ 5t/ha	90.6	92.3	210.5	212.4	230.1	232.4
Vermicompost @ 5t/ha	87.4	88.8	206.3	207.4	227.4	228.5
Control	75.6	77.6	190.4	192.5	224.1	226.3
SE(m)±	**1.01**	**1.10**	**1.16**	**1.21**	**1.81**	**1.90**
C.D (P=0.05)	**3.03**	**3.24**	**3.40**	**3.55**	**5.32**	**5.62**



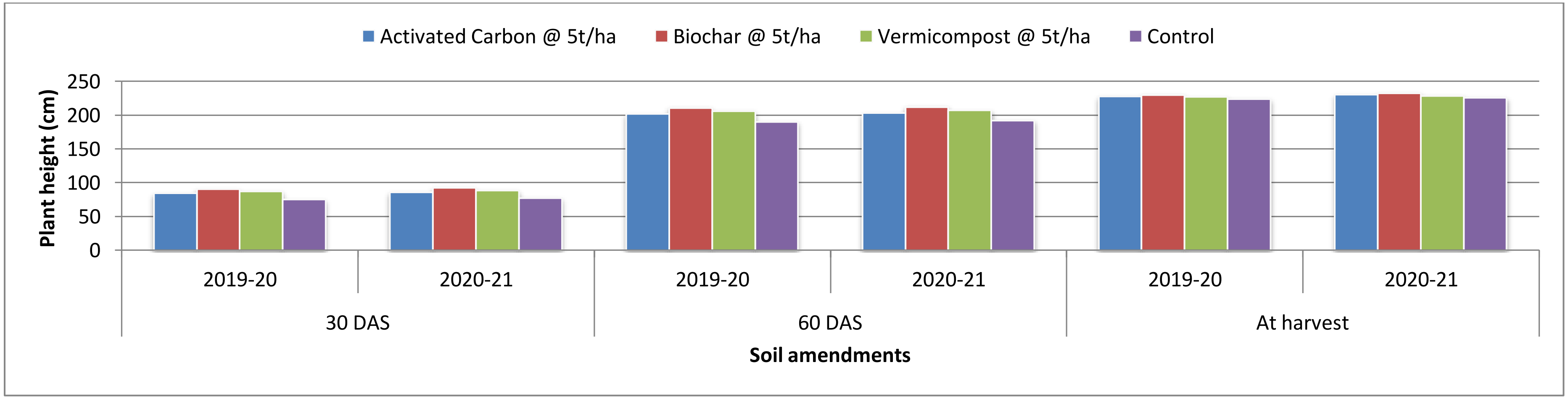


Fig. 4.2 Effect of irrigation treatments and soil amendments on plant height (cm) of fodder sorghum

Irrigation treatment of 100% Hindon water resulted in increase of 15.8 & 16.7, 7.25 & 7.01 and 1.8 & 2.2 (%) in plant height over 100% ground water at 30, 60 days after sowing and at harvest stage respectively.

Among the soil amendments, biochar @ 5t ha^{-1} produced significantly taller plants of sorghum (90.6 & 92.3, 210.5 & 212.4 and 230.1 & 232.4 cm) at 30, 60 days after sowing and at harvest which was statistically superior to vermicompost @ 5t ha-[1] (87.4 & 88.8, 206.3 & 207.4 and 227.4 & 228.5) and activated carbon @ 5t ha^{-1} at 30, 60 days after sowing and at harvest stage during both years of experiment. Lowest plant height was observed in control (75.6 & 77.6, 190.4 & 192.5 and 224.1 & 226.3 cm) against all soil amendments during both the years. There was about 19.8 & 18.9, 10.5 & 10.3 and 2.6 & 2.7 (%) increase in plant height by application of biochar @ 5t ha^{-1} over control at 30, 60 days after sowing and at harvest respectively.

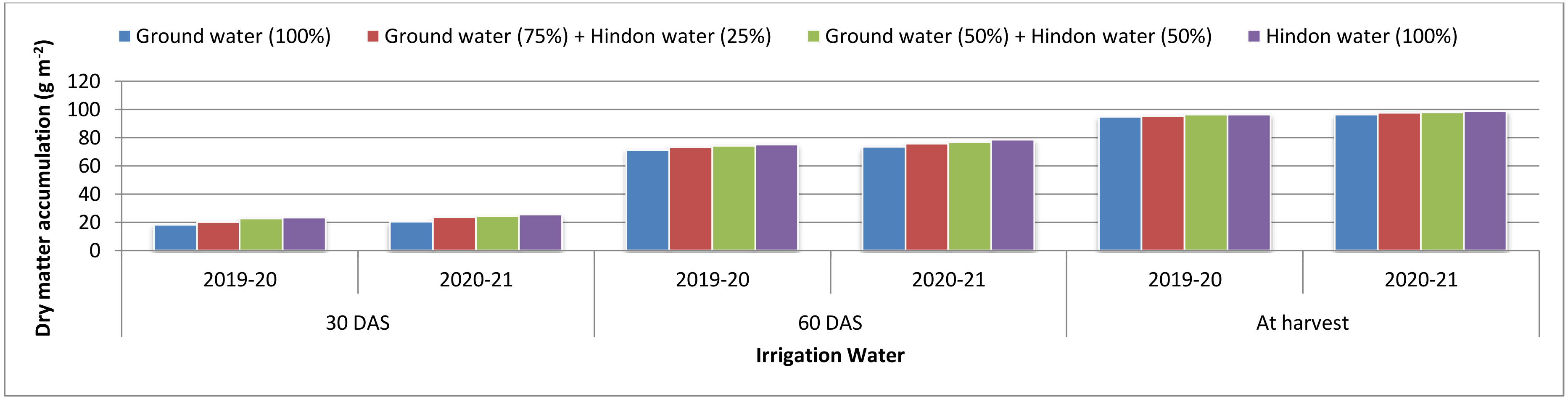
4.2.2 Dry matter (g m^{-2})

Accumulation of dry matter in sorghum was significantly influenced under different irrigation treatments and soil amendments **(Appendix- VII)**. No significant interaction was found between irrigation water and soil amendments on dry matter accumulation during both the years of experiment.

The data on dry matter accumulation is given in Table 4.3 and depicted in Fig. 4.3 reveals that maximum concentration of dry matter (23.3 & 25.6, 75.1 & 78.6, 96.6 & 98.9) at 30, 60 days after sowing and at harvest was observed in sorghum plants irrigated with 100% Hindon water, being statistically at par to Hindon & ground water in 1:1 ratio (22.8 & 24.2, 75.1 & 78.6 and 96.3 & 98.2) and significantly superior to Hindon & ground water irrigation in 1:3 ratio (20.3 & 23.6 & 73.4 & 75.8 and 95.4 & 97.8 cm)

Table 4.3 Effect of irrigation treatments and soil amendments on dry matter accumulation (g m^{-2}) of fodder sorghum

Treatments	Dry matter accumulation (g m^{-2})					
	30 DAS		60 DAS		At harvest	
	2019-20	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
A. Irrigation water						
Ground water (100%)	18.3	20.5	71.5	73.6	94.9	96.3
Ground water (75%) + Hindon water (25%)	20.3	23.6	73.4	75.8	95.4	97.8
Ground water (50%) + Hindon water (50%)	22.8	24.2	74.3	76.9	96.3	98.2
Hindon water (100%)	23.3	25.6	75.1	78.6	96.6	98.9
SE(m)±	**0.40**	**0.48**	**0.34**	**0.44**	**0.36**	**0.42**
C.D (P=0.05)	**1.20**	**1.42**	**1.02**	**1.28**	**1.07**	**1.21**
B. Soil amendments						
Activated Carbon @ 5t/ha	20.1	21.5	73.2	74.6	95.5	97.2
Biochar @ 5t/ha	24.2	26.3	76.4	78.8	97.1	99.7
Vermicompost @ 5t/ha	22.5	24.7	75.1	77.3	96.3	98.3
Control	17.4	18.6	70.8	72.5	93.3	95.7
SE(m)±	**0.53**	**0.62**	**0.48**	**0.55**	**0.40**	**0.52**
C.D (P=0.05)	**1.55**	**1.80**	**1.40**	**1.61**	**1.16**	**1.53**



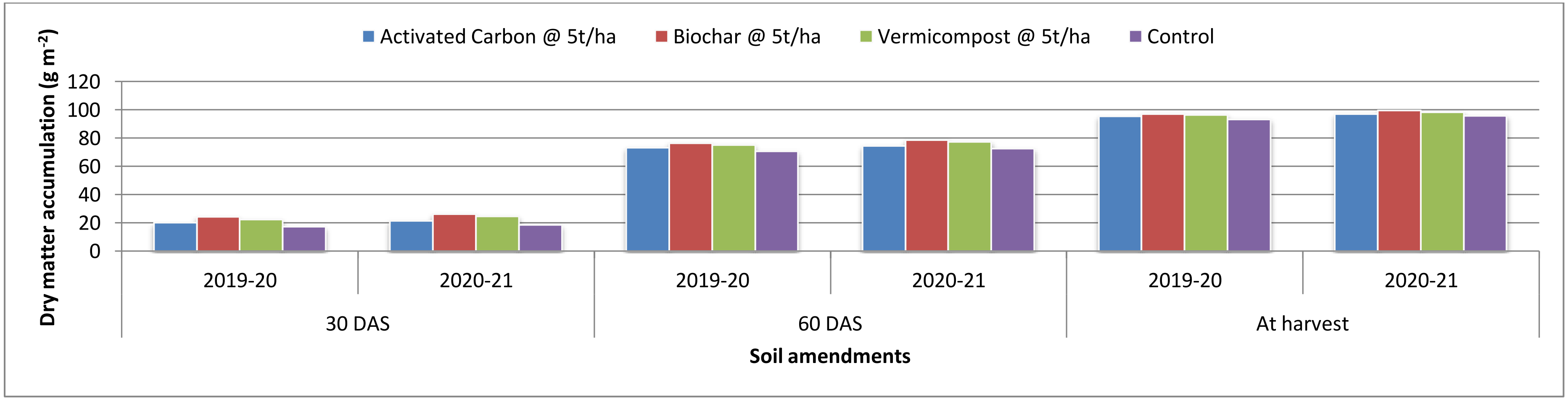


Fig. 4.3 Effect of irrigation treatments and soil amendments on dry matter accumulation (g m^{-2}) of fodder sorghum

While minimum concentration of dry matter was observed in plots irrigated with 100 % ground water (18.3 & 20.5, 71.5 & 73.6 and 94.9 & 96.3) at 30, 60 days after sowing and at harvest stages of crop during both the years of experiment. Application of irrigation with raw Hindon water resulted in percent increase of 27.6 & 24.9, 5.0 & 6.7 and 1.8 & 2.6 (%) of dry matter over 100% ground water at 30, 60 days after sowing and at harvest during both the years respectively.

Maximum dry matter accumulation (24.2 & 26.3, 76.4 & 78.8 and 97.1 & 99.7 at 30, 60 days after sowing and at harvest stage was produced in biochar treatment @ 5t ha^{-1} which was significantly superior to vermicompost @ 5t ha^{-1} (22.5 & 24.7, 75.1 & 77.3 and 96.3 & 98.3) and activated carbon @ 5t ha^{-1} (20.1 & 21.5, 73.2 & 74.6 and 95.5 & 97.2) while lowest dry matter was recorded in control (17.4 & 18.6, 70.8 & 72.5 and 93.3 & 95.7) at 30, 60 days after sowing and at harvest during both the years. There was percent increase of 39.06 & 41.14, 7.97 & 8.65 and 4.06 & 4.13 (%) in dry matter in biochar treatment over control at 30, 60 days after sowing and at harvest respectively.

4.3.1 Green fodder yield (q ha^{-1})

Green fodder yield of sorghum was significantly influenced by different irrigation treatments and soil amendments during both the years of experiment (**Appendix-VIII**). However, the interaction between irrigation water and soil amendments was non-significant.

The data on green fodder yield is given in Table 4.4 and depicted in Fig. 4.4 during both the years. Irrigation treatment of 100% Hindon water resulted in maximum green fodder yield (37.7 and 39.5 t ha^{-1}) which was significantly superior to Hindon & ground water in 1:1 ratio (36.3 and 37.5 t ha^{-1}) followed by dilution of raw Hindon & ground water in 1:3 ratio **(**34.6 and 36.5 t ha^{-1}**)** while lowest green fodder yield was recorded with 100% ground water **(**32.9 and 33.5 t ha^{-1}**)**. Application of 100% Hindon water resulted in percent increase of 14.5 & 17.8 in green fodder yield over 100% ground water, respectively.

Among different soil amendments, highest green fodder yield was produced in biochar treatment @ 5t ha^{-1} (38.1 and 40.2 t ha^{-1}) which was statistically at par to vermicompost @ 5t ha^{-1} (36.4 and 38.5 t ha^{-1}) and superior to activated carbon @ 5t ha^{-1} (35.1 & 36.8 t ha^{-1}) while lowest green fodder yield was noted in control (32.2 and 33.6 t ha^{-1}). There was about 18.2 and 19.5 (%) increase in green fodder yield by application of biochar over control.

4.3.2 Dry fodder yield (q ha^{-1})

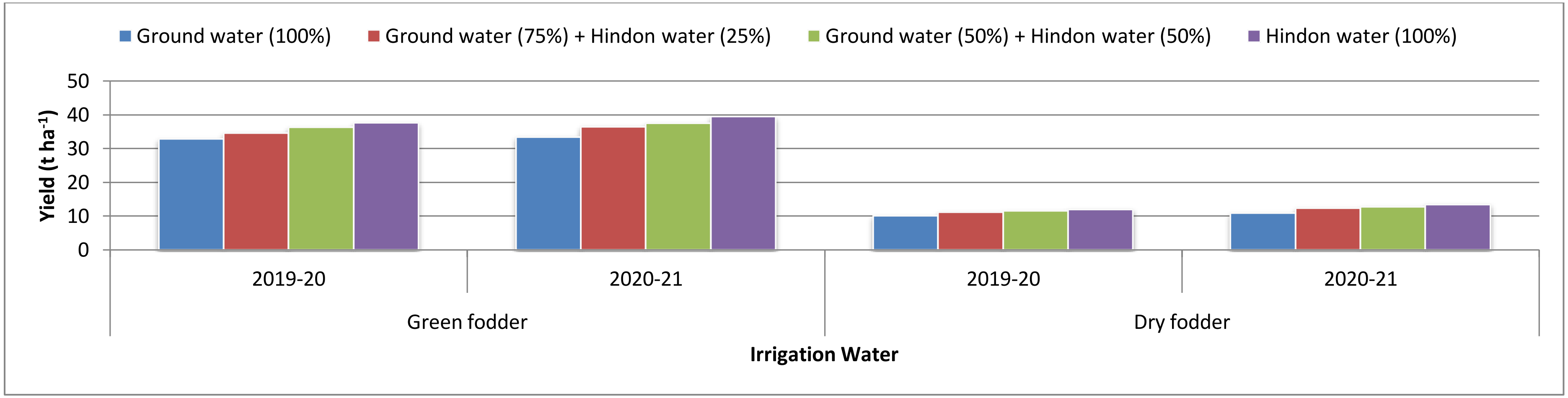
Significant variation was observed in dry fodder yield of sorghum under different irrigation water and soil amendments (**Appendix-VIII**). However, no significant variation was observed between irrigation water and soil amendments.

The data on dry fodder yield is given in table 4.4 and illustrated in Fig. 4.4 for both the years. Irrigation treatment of 100% Hindon water produced highest dry fodder yield (12.0 and 13.5 t ha^{-1}) which was statistically superior to dilution of raw Hindon water with 50% ground water (11.6 and 12.8 t ha^{-1}) followed by 75% ground and 25% Hindon water **(**11.2 and 12.4 t ha^{-1} while lowest dry fodder yield of sorghum was with 100% ground water (10.1 and 10.9 t ha^{-1}) during both the years of experiment. Application of 100% Hindon water resulted in percent increase of 19.4 & 23.3 in dry fodder yield over 100% ground water respectively.

Among different soil amendments, maximum dry fodder yield was produced with the application of biochar @ 5t ha^{-1} (12.2 & 13.8) which was significantly superior to vermicompost @ 5t ha^{-1} (11.8 and 12.8 t ha^{-1}) and activated Carbon @ 5t ha^{-1} (11.4 & 12.2)

Table 4.4 Effect of irrigation treatments and soil amendments on green and dry yield (t ha^{-1}) of fodder sorghum

Treatments	Yield (t ha^{-1})			
	Green fodder		Dry fodder	
	2019-20	2020-21	2019-20	2020-21
A. Irrigation water				
Ground water (100%)	32.9	33.5	10.1	10.9
Ground water (75%) + Hindon water (25%)	34.6	36.5	11.2	12.4
Ground water (50%) + Hindon water (50%)	36.3	37.5	11.6	12.8
Hindon water (100%)	37.7	39.5	12.0	13.5
SE(m)±	**0.95**	**1.10**	**0.38**	**0.46**
C.D (P=0.05)	**2.80**	**3.26**	**1.13**	**1.32**
B. Soil amendments				
Activated Carbon @ 5t/ha	35.1	36.8	11.4	12.2
Biochar @ 5t/ha	38.1	40.2	12.2	13.8
Vermicompost @ 5t/ha	36.4	38.5	11.8	12.8
Control	32.2	33.6	10.0	11.2
SE(m)±	**0.97**	**1.21**	**0.44**	**0.54**
C.D (P=0.05)	**2.96**	**3.58**	**1.30**	**1.57**



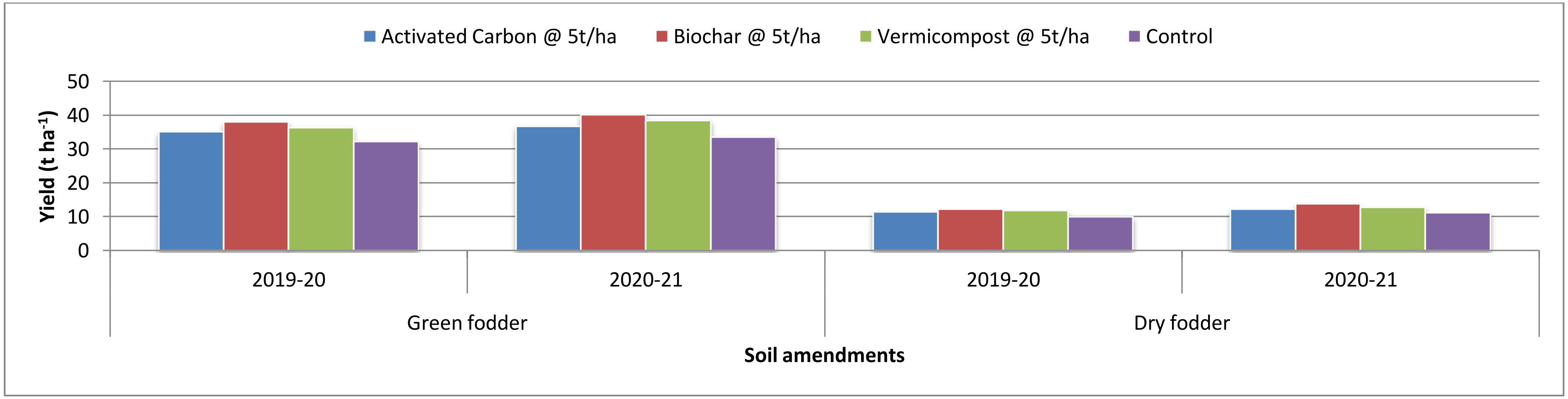


Fig. 4.4 Effect of irrigation treatments and soil amendments on green and dry yield (t ha^{-1}) of fodder sorghum

While minimum was in control (10.0 and 11.2 t ha^{-1}) during both the years of experiment. There was about 18.2 and 19.5 (%) increase in dry fodder yield in Biochar treatment over control for both the years.

4.4.1 Protein content (%)

Irrigation water and soil amendments exhibited significant effect on protein content of sorghum for both years of experiment **(Appendix-X)**. The interaction between irrigation treatments and soil amendments was non-significant.

Perusal of data given in table 4.5 and illustrated in fig. 4.5 reveals that highest protein content in sorghum was noted with 100% Hindon water (5.0 & 5.3) which was statistically at par to dilution of raw Hindon water with ground water in 1:1 ratio (4.8 & 5.1) and significantly superior to dilution of raw Hindon water with ground water in 1:3 ratio (4.6 & 4.8) while lowest protein content was recorded with 100% ground water (4.4 & 4.6) during both the years of experiment. Application of 100% Hindon water resulted in percent increase of 13.9 & 16.2 in protein content over 100% ground water for both the years.

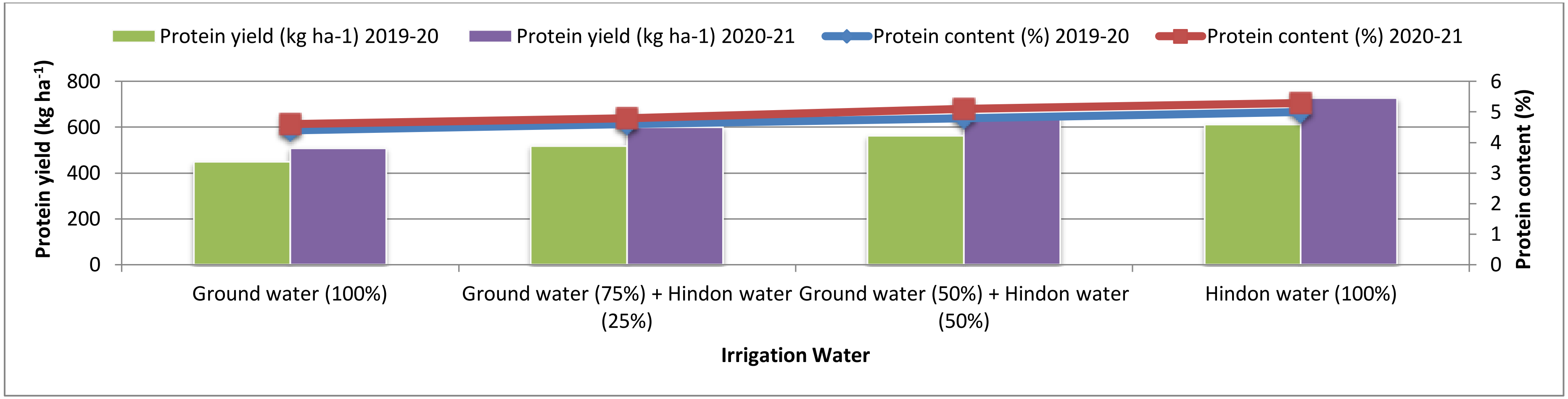
Application of biochar @ 5 tonnes ha^{-1} recorded maximum protein content (5.1 & 5.5) which was statistically at par to vermicompost @ 5 tonnes ha^{-1} (4.8 & 5.2) and significantly superior to activated carbon @ 5 tonnes ha^{-1} (4.6 & 4.8) while lowest protein content was noted in control (4.3 & 4.5) during both the years. There was about 17.1 and 20.6 (%) increase in protein content with application of biochar over control during both years.

4.4.2 Protein yield (kg ha^{-1})

Irrigation water and soil amendments exhibited significant influence on protein yield of sorghum **(Appendix-X)**. However, the interaction effect of irrigation treatments and soil amendments was non-significant.

Table 4.5 Effect of irrigation treatments and soil amendments on protein content and protein uptake (kg ha^{-1}) of fodder sorghum

Treatments	Protein content (%)		Protein yield (kg ha^{-1})	
	2019-20	**2020-21**	**2019-20**	**2020-21**
A. Irrigation water				
Ground water (100%)	4.4	4.6	444.4	501.4
Ground water (75%) + Hindon water (25%)	4.6	4.8	515.2	595.2
Ground water (50%) + Hindon water (50%)	4.8	5.1	556.8	652.8
Hindon water (100%)	5.0	5.3	600.0	715.5
SE(m)±	**0.10**	**0.20**	**32.68**	**36.59**
C.D (P=0.05)	**0.30**	**0.50**	**97.12**	**107.42**
B. Soil amendments				
Activated Carbon @ 5t/ha	4.6	4.8	524.4	585.6
Biochar @ 5t/ha	5.1	5.5	622.2	759.0
Vermicompost @ 5t/ha	4.8	5.2	566.4	665.6
Control	4.3	4.5	430.0	504.0
SE(m)±	**0.10**	**0.20**	**34.52**	**39.63**
C.D (P=0.05)	**0.30**	**0.60**	**103.32**	**117.20**



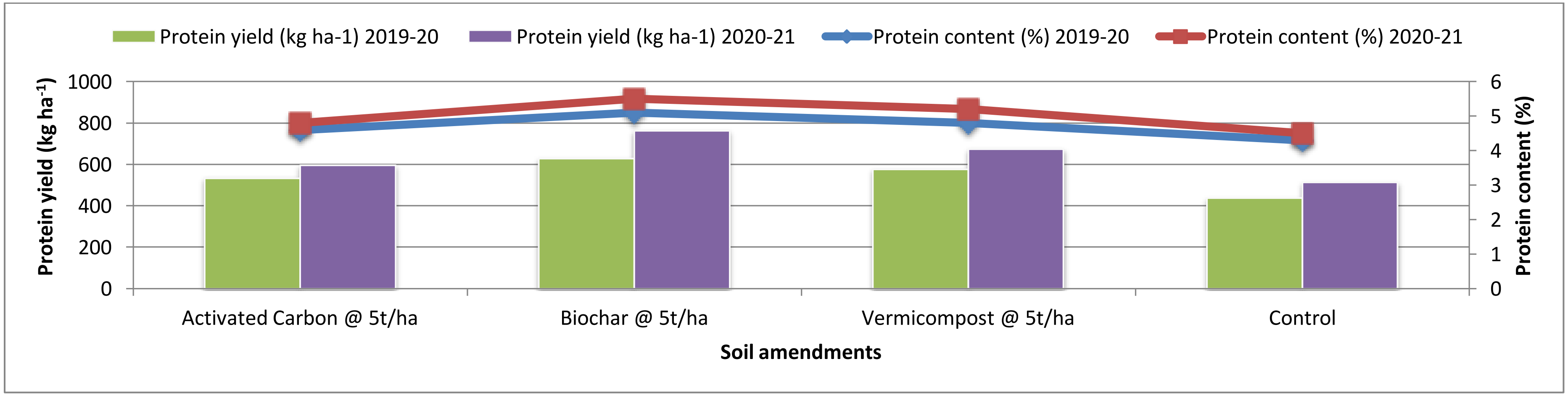


Fig. 4.5 Effect of irrigation treatments and soil amendments on protein content and protein uptake (kg ha^{-1}) in fodder sorghum

The data on protein yield is given in table 4.5 and illustrated in fig. 4.5 for both the years. Application of raw Hindon water resulted in highest protein yield (611.2 & 727.3) which was significantly superior to dilution of raw Hindon water with ground water in 1:1 ratio (561.8 & 659.2) followed by Hindon & ground water in 1:3 ratio (518.5 & 600.2) while lowest protein yield in wheat was recorded in 100% ground water treatment (448.8 & 507.4) during both the years. Application of 100% Hindon water resulted in percent increase of 36.1 & 43.3 in protein yield over 100 % ground water during both the years respectively.

. Among soil amendments, biochar @ 5 tonnes ha^{-1} recorded highest protein yield (629.9 & 763.4) which was significantly superior to vermicompost @ 5 tonnes ha^{-1} (577.3 & 674.6) followed by activated carbon @ 5 tonnes ha^{-1} (534.6 & 597.3) while lowest protein yield in sorghum was recorded in control (438.4 & 514.3) for both the years of experiment. There was about 43.6 & 48.4 (%) increase in protein yield with biochar application @ 5t ha^{-1} over control during both years respectively.

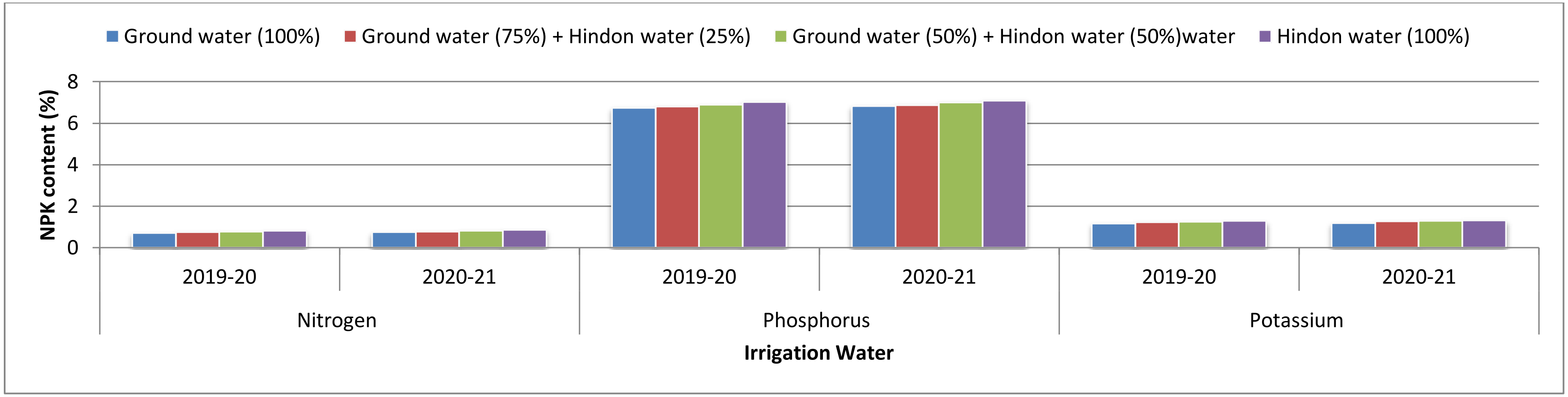
4.5.1 Nitrogen content

Nitrogen content in fodder sorghum varied significantly among different irrigation treatments and soil amendments **(Appendix IX)**. However, the interaction between irrigation water and soil amendments was non-significant.

The data on nitrogen content in sorghum is given in table 4.6 and illustrated in fig. 4.6 during years, 2019-20 and 2020-21. Irrigation treatment of 100% Hindon water (0.81 & 0.86) resulted in highest nitrogen content in fodder and was statistically superior to Hindon & ground water in 1:1 ratio (0.77 & 0.82) followed by dilution of raw Hindon water with ground water in 1:3 ratio (0.74 & 0.77)

Table 4.6 Effect of irrigation treatments and soil amendments on nitrogen, phosphorus and potassium content (%) of fodder sorghum

Treatments	NPK content (%)					
	Nitrogen		Phosphorus		Potassium	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	0.71	0.74	0.21	0.22	1.16	1.18
Ground water (75%) + Hindon water (25%)	0.74	0.77	0.27	0.30	1.23	1.26
Ground water (50%) + Hindon water (50%)water	0.77	0.82	0.33	0.35	1.25	1.29
Hindon water (100%)	0.81	0.86	0.35	0.36	1.28	1.32
SE(m)±	**0.001**	**0.001**	**0.02**	**0.02**	**0.01**	**0.02**
C.D (P=0.05)	**0.003**	**0.003**	**0.05**	**0.06**	**0.03**	**0.06**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.75	0.78	0.20	0.21	1.14	1.16
Biochar @ 5t/ha	0.82	0.88	0.34	0.36	1.30	1.34
Vermicompost @ 5t/ha	0.78	0.84	0.30	0.32	1.26	1.30
Control	0.70	0.73	0.25	0.26	1.18	1.24
SE(m)±	**0.002**	**0.002**	**0.04**	**0.04**	**0.02**	**0.03**
C.D (P=0.05)	**0.005**	**0.006**	**0.12**	**0.13**	**0.06**	**0.09**



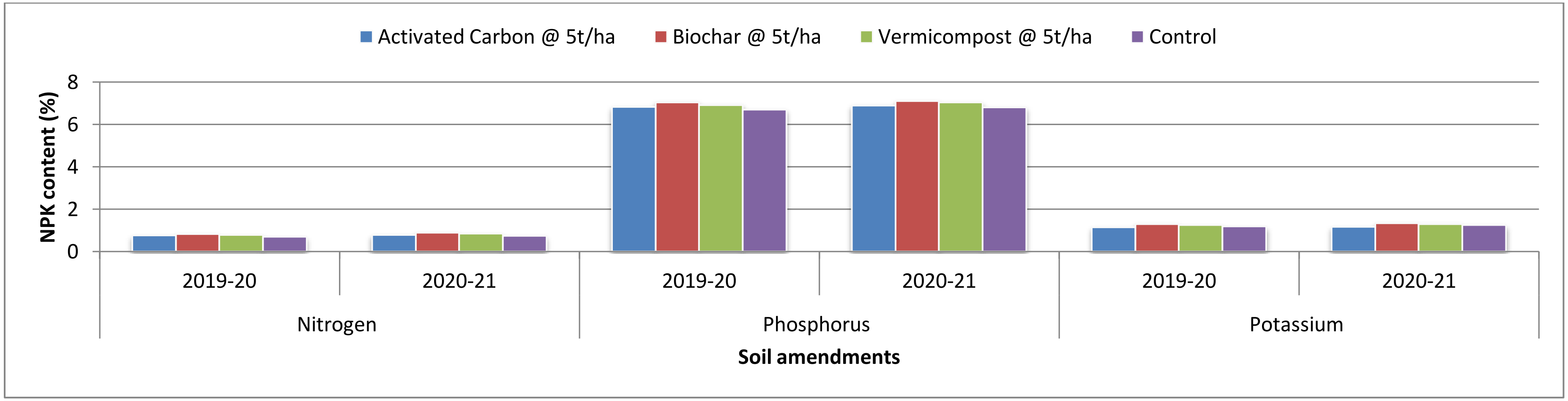


Fig. 4.6 Effect of irrigation treatments and soil amendments on N, P and K content (%) of fodder sorghum

While lowest nitrogen content was recorded with 100% ground water (0.71 & 0.74) during both the years of experiment. Application of raw Hindon water resulted in 2.2 & 2.6 (%) increase in nitrogen content of fodder as compared to 100% ground water during both the years.

Among different soil amendments, highest nitrogen content in fodder was noted with Biochar @ 5t ha^{-1} (0.82 & 0.88) which was statistically superior to vermicompost (0.78 & 0.84) followed by activated Carbon @ 5t ha^{-1} (0.75 & 0.78) while lowest nitrogen content was recorded in control (0.70 & 0.73) during both the years. There was increase of about 7.0 & 7.2 (%) in nitrogen content with application of biochar over control during both the years.

4.5.2 Phosphorous content

Irrigation water and soil amendments exhibited significant influence on phosphorous content of fodder sorghum during both the years **(Appendix-XII)**. However, the interaction between irrigation treatments and soil amendments was non-significant.

Perusal of data given in table 4.6 and illustrated in fig. 4.6 reveals that 100% Hindon water recorded highest phosphorous content in fodder (7.02 & 7.08) which was significantly superior to dilution of raw Hindon water with 50% ground water (6.90 & 7.01) followed by dilution of raw Hindon water with 50% ground water (6.80 & 6.88) while least value of phosphorous content was recorded with 100% ground water (6.73 & 6.82) during both the years of experiment.

Incorporation of different soil amendments resulted in higher phosphorous content in fodder as compared to control. Highest phosphorous content was noted with the application of biochar @ 5 tonnes ha^{-1} (7.05 & 7.10) which was statistically at par to vermicompost @ 5 tonnes ha^{-1} (6.92 & 7.03) and significantly superior to activated carbon @ 5 tonnes ha^{-1} (6.83 & 6.90) while least phosphorous content was recorded in control (6.70 & 6.80) during both the years.

4.5.3 Potassium content

Potassium content in fodder was not influenced by irrigation treatments and soil amendments for both the years **(Appendix- XII)**.

Perusal of data given in table 4.6 and illustrated in fig. 4.6 reveals that 100% Hindon water resulted in greatest potassium content against rest of the irrigation treatments, however variation was non- significant. Application of raw Hindon water recorded maximum potassium content in fodder (1.28 & 1.32) which was statistically at par to irrigation with 50 % Hindon + 50% ground water (1.25 & 1.29) and dilution of raw Hindon water with ground water in 1:3 ratio (1.23 & 1.26) while lowest potassium content was recorded with 100% ground water (1.20 & 1.25) during both the years of experiment.

Incorporation of different soil amendments resulted in higher potassium content in fodder as compared to control during both the years. Highest potassium content was recorded in biochar treatment (1.30 & 1.34) which was statistically at par to vermicompost (1.26 & 1.30) and activated carbon (1.22 & 1.27) while lowest potassium content was noted in control (1.18 & 1.24) for both the years.

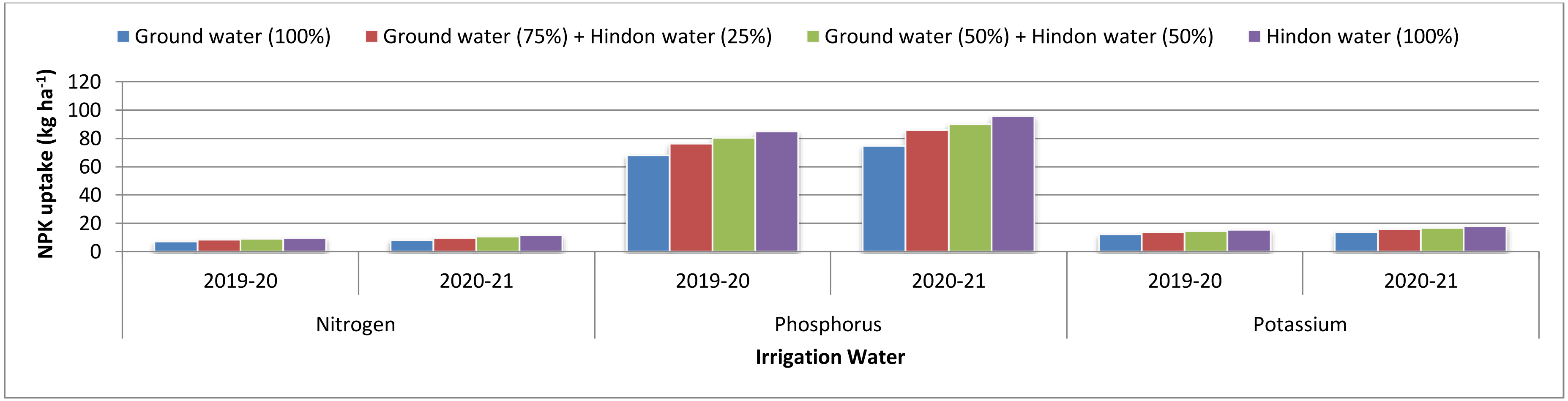
4.5.4 Nitrogen uptake

Nitrogen uptake in fodder varied significantly under different irrigation treatments and soil amendments **(Appendix-IX)**. However, the interaction between irrigation water and soil amendments was non-significant.

The data on nitrogen uptake in fodder sorghum is given in table 4.7 and illustrated in Fig. 4.7 for both the years. Irrigation treatment of 100% Hindon water resulted in maximum nitrogen uptake in sorghum (9.7 & 11.6)

Table 4.7 Effect of irrigation treatments and soil amendments on nitrogen, phosphorus and potassium uptake (kg ha^{-1}) of fodder sorghum

Treatments	NPK uptake (kg ha^{-1})					
	Nitrogen		Phosphorus		Potassium	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	71.7	80.7	21.2	23.98	117.2	128.6
Ground water (75%) + Hindon water (25%)	82.9	95.5	30.2	37.2	137.8	156.2
Ground water (50%) + Hindon water (50%)	89.3	105.0	38.3	44.8	145.0	165.1
Hindon water (100%)	97.2	116.1	42.0	48.6	153.6	178.2
SE(m)±	**0.015**	**0.019**	**1.10**	**1.18**	**3.26**	**3.57**
C.D (P=0.05)	**0.043**	**0.056**	**3.27**	**3.51**	**9.72**	**10.68**
B. Soil amendments						
Activated Carbon @ 5t/ha	85.5	95.2	22.8	25.62	130.0	141.5
Biochar @ 5t/ha	100.0	121.4	41.5	49.68	158.6	184.9
Vermicompost @ 5t/ha	92.0	107.5	35.4	40.96	148.7	166.4
Control	70.0	81.8	25.0	29.12	118.0	138.9
SE(m)±	**0.034**	**0.044**	**1.14**	**1.23**	**3.38**	**3.72**
C.D (P=0.05)	**0.117**	**0.153**	**3.40**	**3.66**	**10.12**	**11.12**



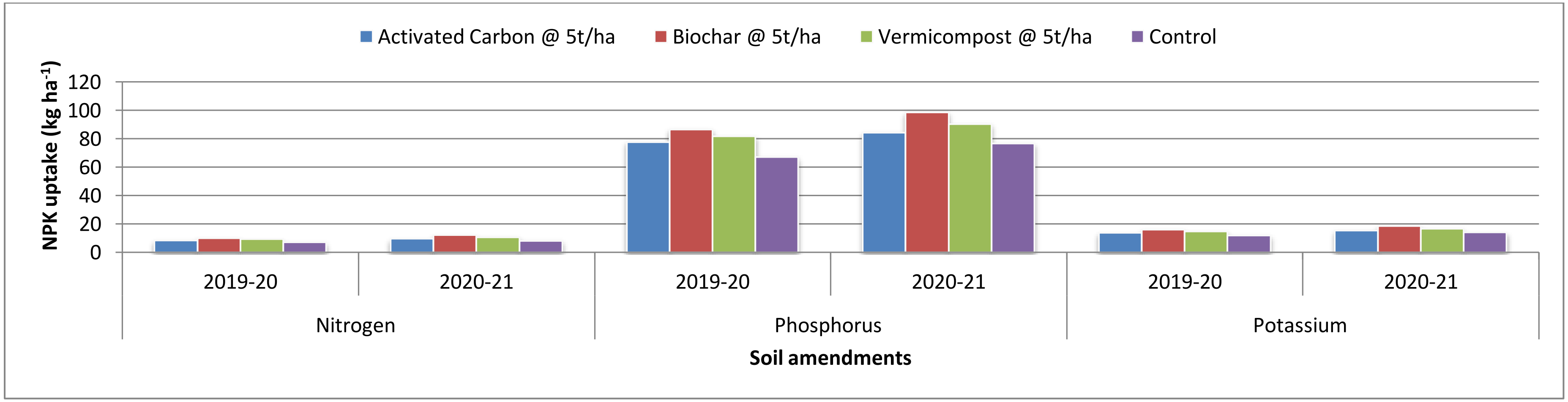


Fig. 4.7 Effect of irrigation treatments and soil amendments on N, P & K uptake (kg ha^{-1}) of fodder sorghum

Which was statistically superior to dilution of raw Hindon water with ground water in 1:1 ratio (8.9 & 10.5) followed by irrigation with 75% ground + 25 % Hindon water (8.2 & 9.6) while minimum nitrogen uptake in fodder was recorded with 100% ground water (7.1 & 8.1) during both the years of experiment. Irrigation with 100% Hindon water resulted in increase of 17.9 & 21.0 (%) in nitrogen uptake over 100 % ground water for both the years.

Among soil amendments, biochar @ 5 tonnes ha^{-1} (10.0 & 12.2) resulted in maximum nitrogen uptake in fodder which was significantly superior to vermicompost @ 5 tonnes ha^{-1} (9.2 & 10.7) and activated carbon (8.5 & 9.5) while lowest nitrogen uptake was recorded in control (7.0 & 8.2) during both the years.

4.5.5 Phosphorous uptake

Irrigation water and soil amendments significantly influenced the phosphorous uptake in sorghum **(Appendix-XI)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in table 4.7 and illustrated in Fig. 4.7 reveals that maximum phosphorous uptake in fodder was noted in irrigation treatment of 100% Hindon water in comparison to rest of the irrigation treatments. Application of raw Hindon water resulted in maximum phosphorous uptake in sorghum (84.8 & 95.7) which was significantly superior to Hindon & ground water in 1:1 ratio (80.5 & 90.0) followed by irrigation with Hindon & ground water in 1:3 ratio (76.1 & 85.8) while lowest phosphorous uptake was recorded with 100% ground water (68.0 & 74.7) during both the years of experiment.

Among different soil amendments, application of biochar @ 5 tonnes ha^{-1} (86.5 & 98.5) recorded significantly higher phosphorous uptake in fodder which was statistically superior to vermicompost @ 5 tonnes ha^{-1} (81.8 & 90.3) followed by activated carbon (77.8 & 84.4) while lowest phosphorous uptake was observed in control (67.0 & 76.7) for both the years. There was about 29.0 and 28.4 (%) increase in phosphorus uptake in fodder in biochar treatment over control during both the years.

4.5.6 Potassium uptake

Potassium uptake in sorghum was significantly affected by irrigation water and soil amendments for both the years **(Appendix-XII)**. However, the interaction between irrigation treatments and soil amendments was non-significant.

Perusal of data given in Table 4.7 and illustrated in Fig. 4.7 reveals that maximum potassium uptake in sorghum (15.4 & 17.8) was recorded with 100% Hindon water which was significantly superior to dilution of raw Hindon water with 50% ground water (14.6 & 16.5) followed by irrigation with 75% ground + 25 % Hindon water (13.7 & 15.7) while minimum potassium uptake was recorded with 100% ground water during both the years of experiment.

Among different soil amendments, biochar @ 5 tonnes ha^{-1} (15.9 & 18.6) recorded maximum potassium uptake in sorghum which was significantly superior to vermicompost @ 5 tonnes ha^{-1} (14.9 & 16.7) and activated carbon @ 5 tonnes ha^{-1} (13.9 & 15.5) while lowest potassium content was recorded in control (11.8 & 13.9) during both the years.

4.6.1 Arsenic content and uptake

Irrigation water and soil amendments exhibited significant influence on arsenic content & uptake of fodder during both the years **(Appendix-XIII)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Arsenic toxicity inhibits the growth of rumen bacteria in pure culture as well as reduces the fermentative activity. Chronic arsenic toxicity is mostly manifested in weight loss, capricious appetite, conjunctively and mucosal erythematic lesion including mouth ulceration and reduce milk yield in animals. The data pertaining to arsenic content in sorghum is presented in Table 4.8 and depicted in Fig 4.8, which reveals that arsenic concentration increased significantly with increased proportion of Hindon water in applied irrigation. Highest arsenic content and uptake in fodder was recorded with 100% Hindon water (0.09 & 0.05 and 1.1 & 0.7) which was significantly higher than dilution of raw Hindon water with 50% ground water (0.08 & 0.04 and 0.93 & 0.57) followed by dilution of raw Hindon water with 75% ground water (0.07 & 0.03 and 0.80 & 0.46) during both the years while lowest arsenic content (0.06 and 0.03 and 0.66 & 0.37) was recorded with 100% ground water during both the years. Irrespective of the irrigation treatments, the arsenic content in fodder was found below the permissible limit of 0.5 mg kg^{-1} for both years.

Among soil amendments**,** lowest arsenic content & uptake in sorghum was found with the application of biochar @ 5t ha^{-1} during both the years. Maximum arsenic content and uptake in fodder (0.08 & 0.09 and 1.10 & 0.64) was recorded in control which was significantly higher than vermicompost @ 5t ha^{-1} (0.07 & 0.04 and 0.93 & 0.62) followed by activated carbon (0.06 & 0.03 and 0.75 & 0.41) while lowest was found in biochar treatment (0.05 & 0.03 and 0.84 & 0.47) during both the years. Incorporation of biochar resulted in 45 % reduction of arsenic in fodder for both the years

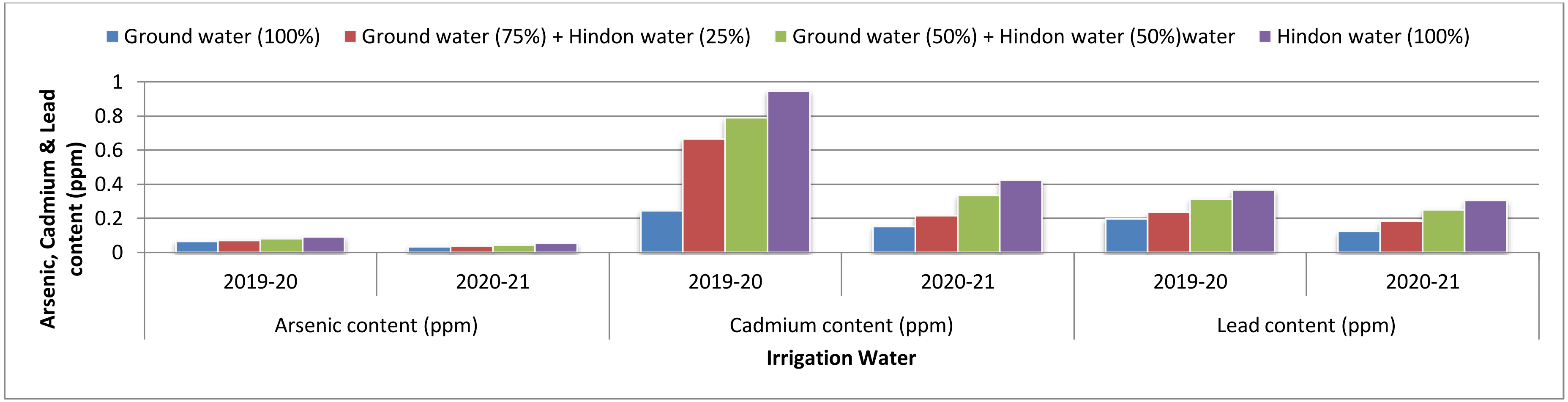
4.6.2 Cadmium content and uptake

Irrigation water and soil amendments exhibited significant influence on cadmium content and uptake in fodder for both the years **(Appendix-XIV)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Cadmium is a toxic to virtually every system in the animal body. The intake of fodder with elevated level of cadmium has potential threat to animal health.

Table 4.8 Effect of irrigation treatments and soil amendments on arsenic, cadmium and lead content (ppm) of fodder sorghum

Treatments	Arsenic content (ppm)		Cadmium content (ppm)		Lead content (ppm)	
	2019-20	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
A. Underground + Hindon Mixtures						
Ground water (100%)	0.065	0.034	0.245	0.153	0.198	0.122
Ground water (75%) + Hindon water (25%)	0.071	0.037	0.665	0.216	0.236	0.183
Ground water (50%) + Hindon water (50%)water	0.080	0.044	0.790	0.335	0.315	0.250
Hindon water (100%)	0.091	0.053	0.947	0.426	0.366	0.305
SE(m)±	**0.002**	**0.001**	**0.004**	**0.003**	**0.003**	**0.002**
C.D (P=0.05)	**0.007**	**0.003**	**0.013**	**0.007**	**0.010**	**0.007**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.063	0.038	0.430	0.221	0.242	0.188
Biochar @ 5t/ha	0.055	0.032	0.241	0.150	0.195	0.120
Vermicompost @ 5t/ha	0.074	0.046	0.710	0.342	0.310	0.256
Control	0.082	0.093	0.820	0.950	0.320	0.370
SE(m)±	**0.003**	**0.002**	**0.009**	**0.004**	**0.007**	**0.003**
C.D (P=0.05)	**0.009**	**0.006**	**0.029**	**0.012**	**0.022**	**0.009**



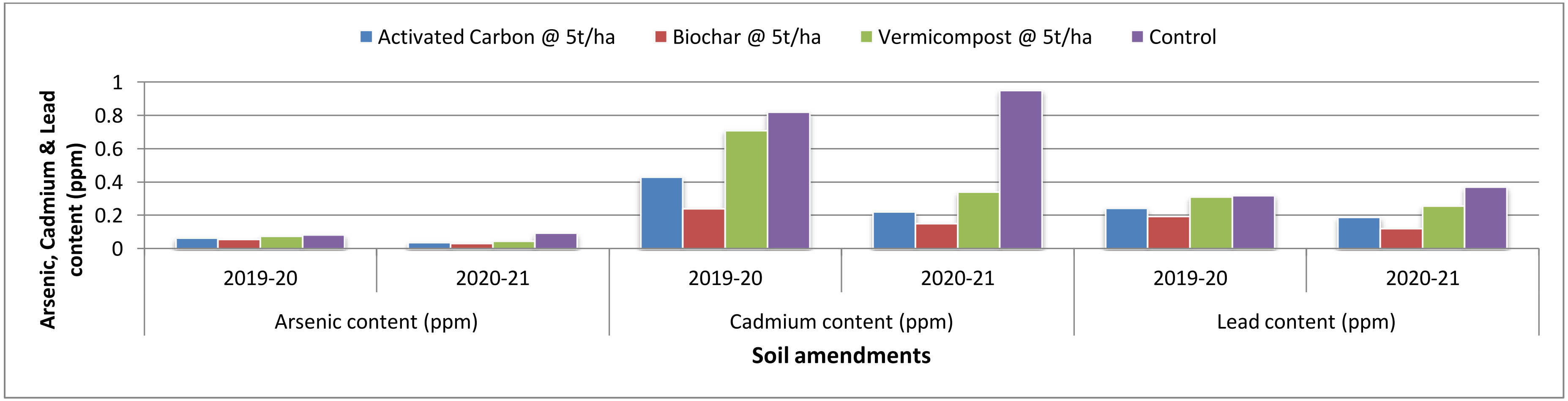


Fig. 4.8 Effect of irrigation treatments and soil amendments on arsenic, cadmium and lead content (ppm) in fodder sorghum

The data on cadmium content and uptake in fodder is given in table 4.8 and depicted in fig. 4.8, reveals that cadmium content & uptake in fodder increased significantly with increased proportion of Hindon water in applied irrigation. The cadmium content in fodder sorghum was found below the permissible limit of 0.5 mg kg^{-1} for both the years except for I_2, I_3 and I_4 treatments for the first year of experiment. Irrigation with raw Hindon water resulted in highest cadmium content & uptake in sorghum (0.94 & 0.42 and 11.4 & 5.7) which was significantly higher than 50 % Hindon + 50% ground water (0.79 & 0.33 and 9.2 & 4.3) followed by 75% ground water and 25% hindon water (0.66 & 0.21 and 7.4 and 2.7) while lowest cadmium content & uptake (0.24 & 0.15 and 2.4 & 1.6) was recorded with 100% ground water during both the years of experiment.

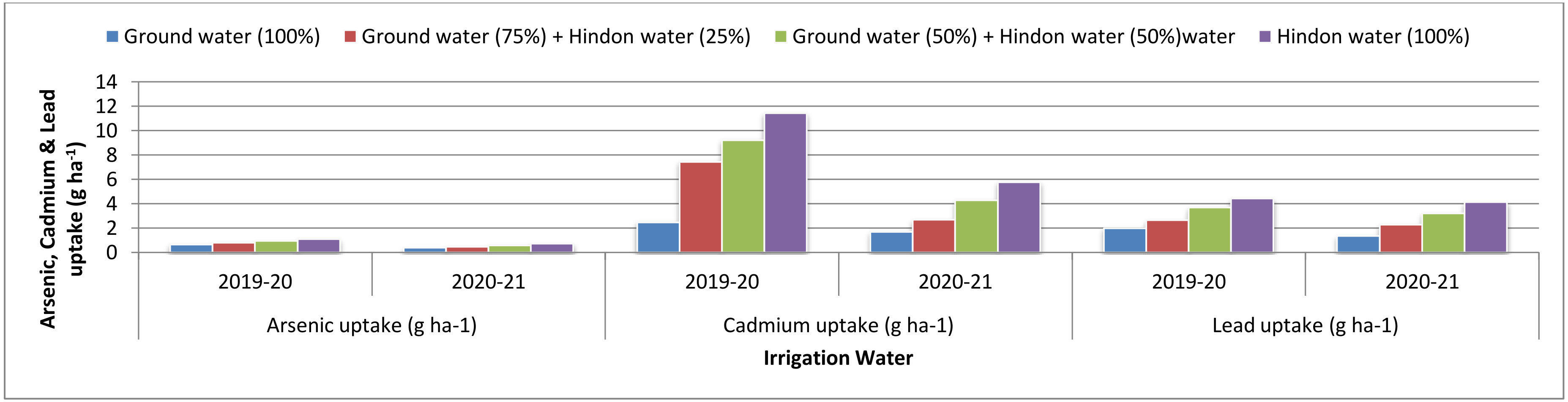
Application of various soil amendments resulted in lower content & uptake of cadmium in fodder as compared to control during both years. Among the soil amendments, lowest cadmium content & uptake was noticed with the application of biochar @ 5 tonnes ha^{-1} (0.24 & 0.15 and 2.8 & 1.9) followed by activated carbon (0.71 & 0.22 and 8.0 & 2.7) and vermicompost (0.82 & 0.34 and 10.0 & 4.7) while highest was found in control (0.95 & 0.43) during both the years. The cadmium content in sorghum was found above the permissible limit of 0.5 mg kg^{-1} in treatments S_1 for first year and S_3 for both years while in S_0 & S_2 cadmium was found below the permissible limit for both the years of experiment.

4.6.3 Lead content & uptake

Irrigation treatments and soil amendments caused significant variation in lead content & uptake of fodder sorghum **(Appendix-XV)**. However, the interaction between irrigation water and soil amendments was non- significant.

Table 4.9 Effect of irrigation treatments and soil amendments on arsenic, cadmium and lead uptake (g ha^{-1}) of fodder sorghum

Treatments	Arsenic uptake (g ha^{-1})		Cadmium uptake (g ha^{-1})		Lead uptake (g ha^{-1})	
	2019-20	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
A. Irrigation water						
Ground water (100%)	0.66	0.37	2.47	1.67	2.00	1.33
Ground water (75%) + Hindon water (25%)	0.80	0.46	7.45	2.68	2.64	2.27
Ground water (50%) + Hindon water (50%)water	0.93	0.56	9.16	4.29	3.65	3.20
Hindon water (100%)	1.09	0.72	11.36	5.75	4.39	4.12
SE(m)±	**0.02**	**0.01**	**0.05**	**0.03**	**0.04**	**0.03**
C.D (P=0.05)	**0.07**	**0.03**	**0.16**	**0.09**	**0.13**	**0.09**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.72	0.46	4.90	2.70	2.76	2.29
Biochar @ 5t/ha	0.67	0.44	2.94	2.07	2.38	1.66
Vermicompost @ 5t/ha	0.87	0.59	8.38	4.38	3.66	3.28
Control	0.82	1.04	8.20	10.64	3.20	4.14
SE(m)±	**0.03**	**0.02**	**0.09**	**0.05**	**0.08**	**0.05**
C.D (P=0.05)	**0.08**	**0.06**	**0.31**	**0.15**	**0.24**	**0.15**



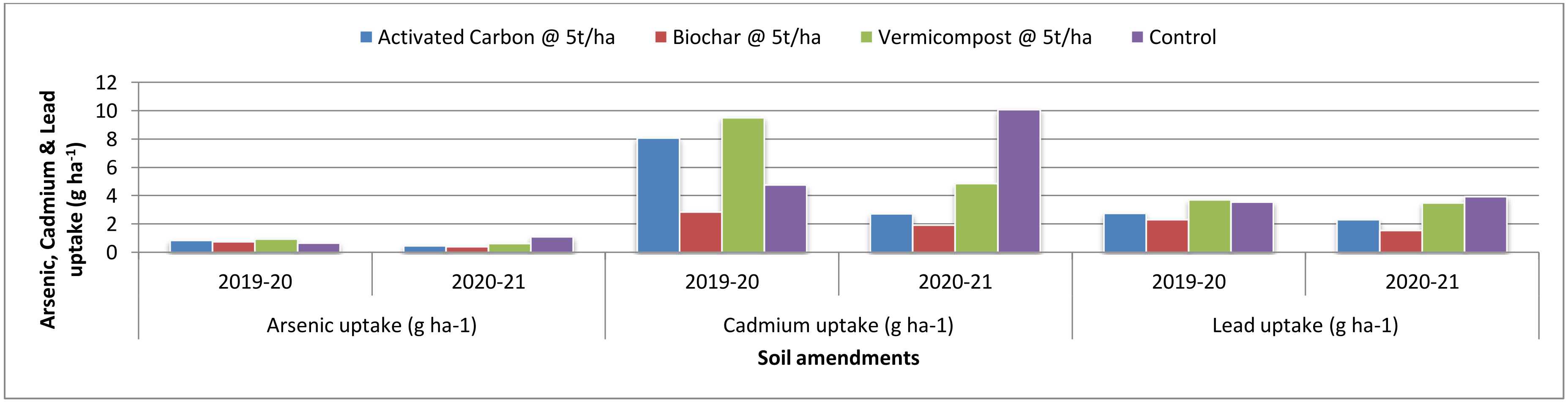


Fig. 4.9 Effect of irrigation treatments and soil amendments on arsenic, cadmium and lead uptake (g ha^{-1}) in fodder sorghum

The high concentration of lead in sorghum straws after harvesting presents risks to animal health. The problem of lead poisoning in animals has widely been recognized which needs a special attention for the environmentalist and health personnel. The data on lead content & uptake in fodder is given in table 4.8 and illustrated in fig. 4.8 reveals that irrigation treatments comprising of Hindon water alone or in mixture resulted in significantly higher lead content & uptake as compared to 100% ground water. Irrigation treatment of 100% Hindon water resulted in maximum lead content and uptake (0.36 & 0.30 and 4.4 & 4.1) which was significantly higher than Hindon & ground water in 1:1 ratio (0.31 & 0.25 and 3.6 & 3.2) followed by Hindon & ground water in 1:3 ratio (0.23 & 0.18 and 2.6 & 2.2) while lowest lead content & uptake was found with 100% ground water (0.19 & 0.12 and 2.0 & 1.3) during both the years of experiment. Regardless of the irrigation treatment, the lead concentration in fodder was below the permissible limit of 2.0 mg kg^{-1} for both years of experiment.

Incorporation of different soil amendments resulted in lower content and uptake of lead in fodder as compared to control during both the years. Lowest lead content and uptake was observed with the application of biochar @ 5 tonnes ha^{-1} (0.19 & 0.12 and 2.3 & 1.5) followed by activated carbon (0.24 & 0.18 and 2.7 & 2.3) and vermicompost (0.32 & 0.25 and 3.9 & 3.5) while highest was noted in control (0.37 & 0.31) during both the years.

4.6.4 Nickel content & uptake

Different irrigation treatments and soil amendments exhibited significant influence on nickel content & uptake in fodder **(Appendix XVI)**. However, the interaction between irrigation water and soil amendments was non- significant.

Perusal of data given in Table 4.10 and illustrated in Fig. 4.10 reveals that nickel concentration in sorghum fodder increased significantly with increased proportion of Hindon water in applied irrigation. Irrigation treatment of 100% Hindon water resulted in highest value of nickel content & uptake in sorghum (0.53 & 0.49 and 6.4 & 6.6) which was significantly higher than dilution of raw Hindon water with ground water in 1:1 ratio (0.420 & 0.426 and 4.91 & 5.47) followed by dilution of raw Hindon water with ground water in 1:3 ratio (0.337 & 0.350 and 3.77 & 4.37) while lowest nickel content & uptake (0.259 & 0.248 and 2.62 & 2.72) was recorded with 100% ground water (0.259 & 0.248 and 2.62 & 2.72) for both the years. The nickel content in fodder sorghum did not exceed WHO standards and was found below the permissible limit of 10.0 mg kg^{-1} for both years of experiment. Small amounts of nickel is necessary for plant growth and development (Akinyele and Shokunbi 2015), however it becomes toxic when present in excessive amounts (Cabrera et al. 2003).

Different soil amendments resulted in lower content and uptake of nickel in fodder as compared to control during both the years. Lowest nickel content and uptake was recorded with the application of biochar (0.25 & 0.24 and 3.02 & 3.15) followed by activated carbon (0.34 & 0.35 and 3.97 & 4.37) and vermicompost @ 5 tonnes ha^{-1} (0.42 & 0.43 and 5.26 & 6.0) while highest was recorded in control (0.49 & 0.53 and 5.3 & 5.5) for both the years.

4.6.6 Iron content & uptake (ppm)

Iron content and uptake in fodder was significantly influenced under different irrigation treatments and soil amendments **(Appendix-XVII)**. However, the interaction between irrigation water and soil amendments was non- significant.

The data on iron content in fodder is given in table 4.11 and depicted in Fig. 4.11 reveals that maximum iron content and uptake in sorghum was recorded with 100% Hindon water (150.3 & 148.2 and 1816.4 & 1620.5)

Table 4.10 Effect of irrigation treatments and soil amendments on nickel, iron, manganese and zinc content (ppm) of fodder sorghum

Treatments	Nickel content (ppm)		Iron content (ppm)		Manganese content (ppm)		Zinc content (ppm)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water								
Ground water (100%)	0.259	0.248	96.16	94.28	25.18	23.76	7.81	7.20
Ground water (75%) + Hindon water (25%)	0.350	0.337	118.35	116.03	30.26	27.45	9.40	9.18
Ground water (50%) + Hindon water (50%)	0.426	0.420	129.81	126.11	36.10	34.75	11.10	10.80
Hindon water (100%)	0.530	0.490	150.37	148.26	40.85	38.47	13.14	12.52
SE(m)±	**0.004**	**0.003**	**0.50**	**0.48**	**0.25**	**0.21**	**0.15**	**0.13**
C.D (P=0.05)	**0.013**	**0.007**	**1.46**	**1.37**	**0.72**	**0.63**	**0.45**	**0.40**
(B) Soil amendments								
Activated Carbon @ 5t/ha	0.357	0.348	120.10	118.15	32.54	28.20	9.75	9.20
Biochar @ 5t/ha	0.255	0.245	94.25	92.20	24.50	22.08	7.71	7.15
Vermicompost @ 5t/ha	0.432	0.428	131.74	128.31	37.62	35.16	11.48	11.10
Control	0.495	0.536	150.71	152.41	40.67	42.75	12.80	13.50
SE(m)±	**0.009**	**0.004**	**0.73**	**0.70**	**0.31**	**0.28**	**0.16**	**0.14**
C.D (P=0.05)	**0.029**	**0.012**	**2.51**	**2.12**	**1.07**	**0.85**	**0.50**	**0.42**

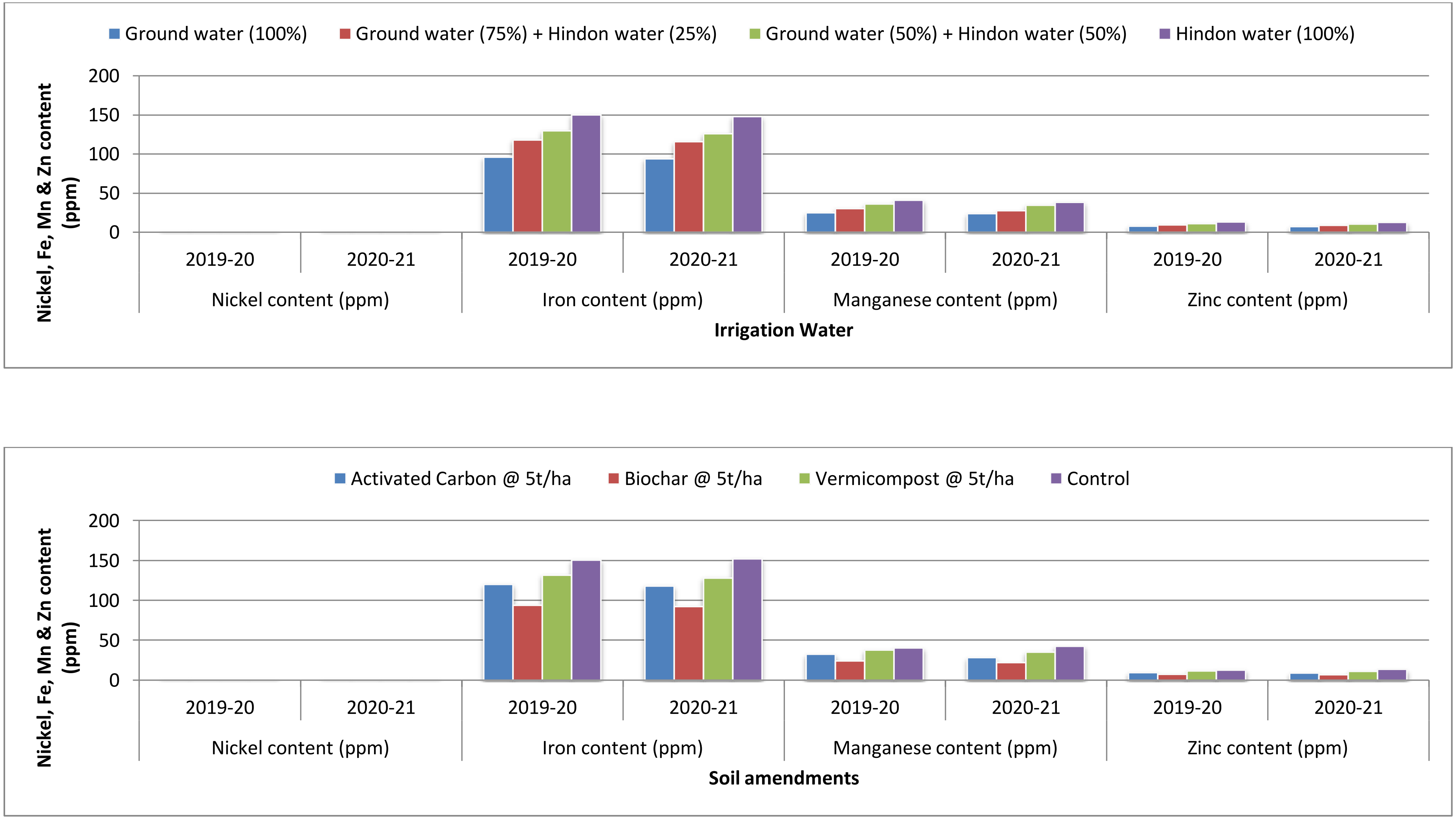


Fig. 4.10 Effect of irrigation treatments and soil amendments on nickel, iron, manganese and zinc content (ppm) in fodder sorghum

which was significantly superior to dilution of raw Hindon water with 50% ground water (129.1 & 126.1 and 1516.1 & 1620.5) followed by dilution of raw Hindon water with 75% ground water (118.3 & 116.0 and 1325.5 & 1448) while lowest iron content and uptake was noted with 100 % ground water (96.1 & 94.2 and 972.1 & 1033.1) during both the years of experiment. The iron content in fodder was found below the permissible limit of 150 mg kg $^{-1}$ for both years of experiment except in treatments I_4 for the first year.

Incorporation of different soil amendments resulted in lower content and uptake of iron in fodder as compared to control for both the years. Lowest iron content and uptake was recorded in biochar treatment @ 5 tonnes ha^{-1} (94.2 & 92.2 and 1114.9 & 1184.7) followed by vermicompost (131.7 & 128.3 and 1617.7 & 1780.9) and activated carbon (120.1 & 118.1 and 1369.1 & 1446.1) while highest was found in control (152.4 & 150.7 and 1525.6 & 1700) for both the years. The iron content in fodder was found below the permissible limit of 150 mg kg $^{-1}$ under all soil amendment options for both years except in control where it was 150.71 & 152.4 for first and second year of experiment.

4.6.7 Manganese content & uptake

Irrigation water and soil amendments exhibited significant influence on manganese content and uptake in fodder **(Appendix XVIII)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in table 4.10 and illustrated in Fig. 4.10 reveals that irrigation treatments comprising of Hindon water alone or in proportion with ground water resulted in significantly higher manganese content & uptake in comparison to 100% ground water. Greatest value of manganese content in fodder (40.8 & 38.4 and 493.4 & 520.1) was with 100% Hindon water which was significantly superior to dilution of raw Hindon water with 50% ground water (36.1 & 34.7 and 421.6 & 446.5) followed by dilution of raw Hindon water with 75% ground water (30.2 & 27.4 and 338.9 & 342.5) while lowest manganese content & uptake (25.1 & 23.7 and 254.5 & 260.4) was recorded with 100% ground water during both the years of experiment. Regardless of irrigation treatment, the manganese concentration in fodder was much above the permissible limit of 6.61 mg kg^{-1} in all the irrigation treatments for both years of experiment.

Incorporation of various soil amendments resulted in lower manganese content and uptake in fodder as compared to control. Lowest manganese content & uptake was recorded with the application of biochar @ 5 tonnes ha^{-1} (24.5 & 22 and 289.8 & 283.7) followed by activated carbon (32.5 & 28.2 and 370.9 & 345.1) and vermicompost (37.6 & 35.1 and 461.9 & 488) while highest was found in control (42.7 & 40.6 and 427.9 & 458.7) for both the years. The manganese concentration in fodder was much above the permissible limit of 6.61 mg kg^{-1} under all the soil amendments and control for both years of experiment.

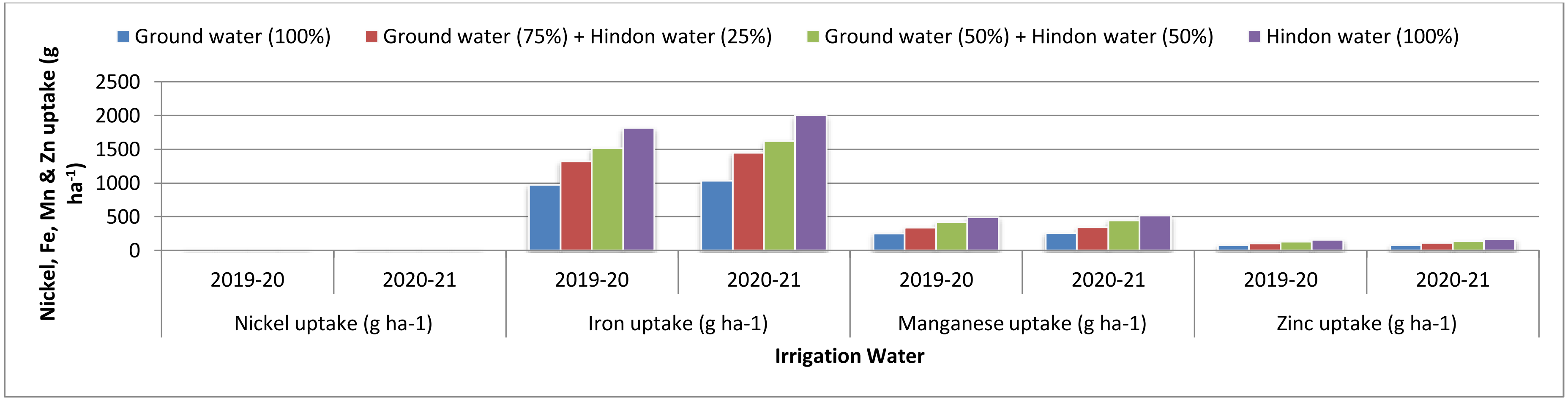
4.6.8 Zinc content & uptake

Significant variation was observed in zinc content and uptake in fodder under different irrigation treatments and soil amendments **(Appendix XIX)**. However, the interaction between irrigation water and soil amendments was non-significant.

Perusal of data given in table 4.10 and illustrated in Fig. 4.10 reveals that zinc concentration in wheat crop increased significantly with increased proportion of Hindon water in applied irrigation. Maximum zinc content & uptake in fodder was with 100% Hindon water (13.1 & 12.5 and 158.7 & 169.2) which was significantly superior to Hindon & ground water in 1:1 ratio (11.1 & 10.8 and 129.6 & 138.7) followed by Hindon & ground water in 1:3 ratio (9.4 & 9.1 and 105.2 & 114.5)

Table 4.11 Effect of irrigation treatments and soil amendments on nickel, iron, manganese and zinc uptake (g ha^{-1}) of fodder sorghum

Treatments	Nickel uptake (g ha^{-1})		Iron uptake (g ha^{-1})		Manganese uptake (g ha^{-1})		Zinc uptake (g ha^{-1})	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water								
Ground water (100%)	2.62	2.70	971.2	1027.7	254.3	259.0	78.9	78.5
Ground water (75%) + Hindon water (25%)	3.92	4.18	1325.5	1438.8	338.9	340.4	105.3	113.8
Ground water (50%) + Hindon water (50%)	4.94	5.38	1505.8	1614.2	418.8	444.8	128.8	138.2
Hindon water (100%)	6.36	6.62	1804.4	2001.5	490.2	519.3	157.7	169.0
SE(m)±	**0.05**	**0.03**	**5.18**	**6.20**	**2.70**	**2.80**	**1.70**	**1.80**
C.D (P=0.05)	**0.16**	**0.09**	**15.52**	**18.57**	**8.06**	**8.36**	**5.10**	**5.37**
(B) Soil amendments								
Activated Carbon @ 5t/ha	4.07	4.25	1369.1	1441.4	371.0	344.0	111.2	112.2
Biochar @ 5t/ha	3.11	3.38	1149.9	1272.4	298.9	304.7	94.1	98.7
Vermicompost @ 5t/ha	5.10	5.48	1554.5	1642.4	443.9	450.0	135.5	142.1
Control	4.95	6.00	1507.1	1707.0	406.7	478.8	128.0	151.2
SE(m)±	**0.09**	**0.05**	**6.48**	**8.10**	**3.30**	**3.70**	**2.10**	**2.20**
C.D (P=0.05)	**0.31**	**0.15**	**19.42**	**24.26**	**9.88**	**11.06**	**6.27**	**6.57**



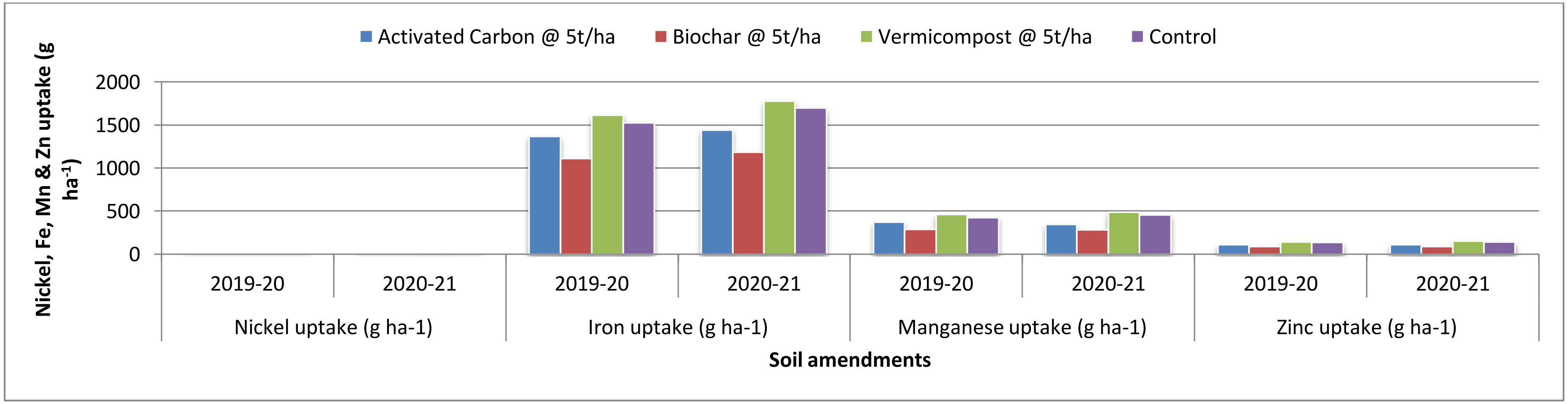


Fig. 4.11 Effect of irrigation treatments and soil amendments on nickel, iron, manganese and zinc uptake (g ha^{-1}) in fodder sorghum

While lowest zinc content and uptake in sorghum (7.8 & 7.2 and 78.91 & 78.96) was recorded with of 100% ground water during both the years of experiment. Irrespective of irrigation treatment, the zinc content in fodder sorghum was found above the permissible limit of 5.0 mg kg $^{-1}$ for both the years of experiment

Application of soil amendments resulted in lower content and uptake of zinc in fodder as compared to control during both the years. Maximum zinc content & uptake was noted in control (13.5 & 12.8) followed by vermicompost (11.4 & 11.1 and 10 & 4.7) and activated carbon (9.75 & 9.20 and 8.09 & 2.71) while lowest was with application of biochar @ 5 tonnes ha^{-1} (7.71 & 7.15 and 9.51 & 4.85) during both the years. Irrespective of the soil amendments, the zinc content in fodder sorghum was found above the permissible limit of 5.0 mg kg $^{-1}$ for both the years of experiment.

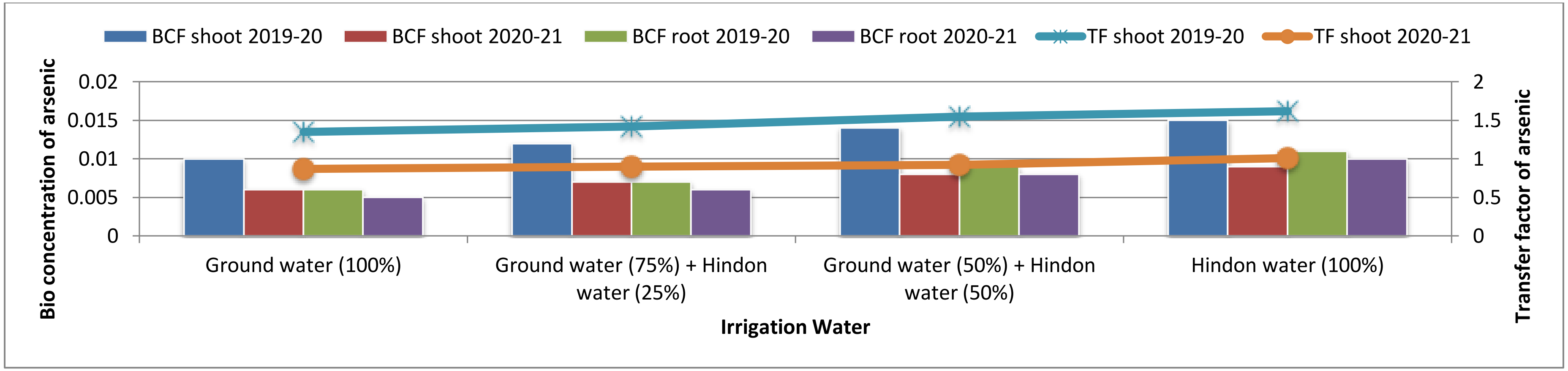
4.7.1 Bio-concentration Factor Arsenic

Irrigation water and soil amendments caused significant variation in bio-concentration of arsenic in roots and shoot of sorghum **(Appendix- XX)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

BCF represents the transfer potential of heavy metals from the soil to the plants, which depends on the properties of the metals and soils (Singh *et al*,. 2010). The bio-concentration factor of arsenic in roots and shoot of fodder under various treatments is shown in Table 4.11 and illustrated in figure 4.11 for both the years. The bio-concentration factor of arsenic in shoot was higher than that of roots, which indicated the higher translocation of arsenic from soil to above ground parts. Furthermore, the BCFs of fodder showed significant increase in bio-concentration factor of arsenic with increased proportion of Hindon water in applied irrigation. The order of arsenic accumulation in fodder was shoot > root.

Table 4.12 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of arsenic (BCF shoot, BCF root and TF shoot) in fodder sorghum

Treatments	BCF shoot		BCF root		TF shoot	
	2019-20	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
A. Irrigation water						
Ground water (100%)	0.010	0.006	0.006	0.005	1.35	0.87
Ground water (75%) + Hindon water (25%)	0.012	0.007	0.007	0.006	1.42	0.90
Ground water (50%) + Hindon water (50%)	0.014	0.008	0.009	0.008	1.55	0.92
Hindon water (100%)	0.015	0.009	0.011	0.010	1.62	1.01
SE(m)±	**0.0001**	**0.0002**	**0.0002**	**0.0001**	**0.014**	**0.015**
C.D (P=0.05)	**0.0004**	**0.0006**	**0.0006**	**0.0003**	**0.040**	**0.043**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.011	0.007	0.008	0.006	1.32	0.89
Biochar @ 5t/ha	0.010	0.006	0.005	0.004	1.04	0.84
Vermicompost @ 5t/ha	0.013	0.009	0.010	0.009	1.46	0.95
Control	0.014	0.016	0.011	0.012	1.58	1.64
SE(m)±	**0.0002**	**0.0002**	**0.0003**	**0.0002**	**0.024**	**0.022**
C.D (P=0.05)	**0.0005**	**0.0006**	**0.0008**	**0.0006**	**0.082**	**0.064**



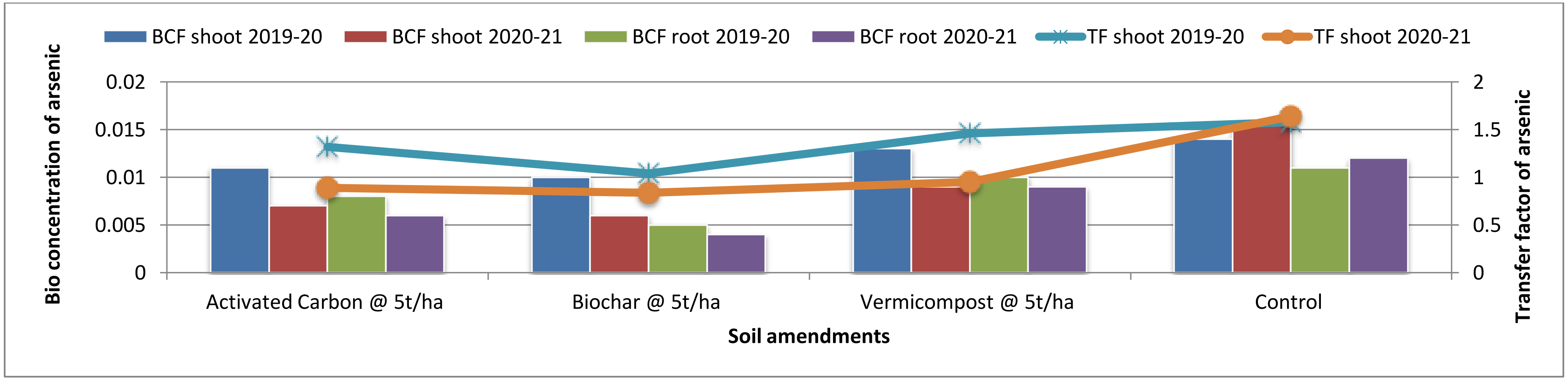


Fig. 4.12 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of arsenic (BCF shoot, BCF root and TF shoot) in fodder sorghum

The bio- concentration of arsenic in roots and shoot of fodder ranged from 0.011 to 0.006, 0.010 to 0.005 and 0.015 to 0.010, 0.009 to 0.006 for both the years respectively. Irrigation treatment of 100% Hindon water resulted in maximum bio-concentration factor of arsenic from soil to roots (0.011 & 0.010) and shoot(0.015 & 0.009) which was statistically higher than dilution of raw Hindon water with 50% ground water (0.009 & 0.008 and 0.014 & 0.008) followed by dilution of raw Hindon water with 75% ground water (0.007 & 0.006 and 0.012 & 0.007) while lowest bio-concentration of arsenic was noted with 100% ground water (0.006 & 0.005 and 0.010 & 0.006) respectively.

The BCFs of fodder showed an increase in control while the BCFs of arsenic decreased under soil amendment treatments. Application of different soil amendments resulted in lower bio-concentration of arsenic in roots and shoot of fodder in comparison to control for both the years. The trend in the BCF showed low transfer of arsenic in fodder treated with different soil amendments, which indicated low availability of heavy metals in the amended soils compared with the control. Highest value of BCF of arsenic in roots and shoot was recorded in control (0.011 & 0.012 and 0.014 & 0.016) followed by vermicompost (0.010 & 0.009 and 0.013 & 0.009) and activated carbon (0.008 & 0.006 and 0.011 & 0.007) while lowest was with the application of biochar (0.005 & 0.004 and 0.010 & 0.006) for both the years.

4.7.2 Transfer Factor Arsenic

Irrigation water and soil amendments exhibited significant influence on transfer factor of arsenic in fodder for both the years **(Appendix- XX)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Transfer factor (TF) was calculated to understand the extent of risk associated due to wastewater irrigation and consequent heavy metal accumulation in shoot of sorghum. The transfer factor of arsenic in fodder under various treatments is shown in Table 4.12 and illustrated in figure 4.12 for both the years. As given in table 4.12, the TF of arsenic increased with the increasing proportion of Hindon water in applied irrigation. The TFs were more than 1 for arsenic under different irrigation treatments for the first year suggesting greater ability of sorghum to transport heavy metals while TF was <1 for second year except in I_4 treatment. Sorghum showed higher transfer factor of arsenic in shoot and hence possibility of heavy metal exposure to animals through ingestion of these fodders is more. The transfer factor ratio was >1 in shoot which indicated that sorghum accumulated arsenic and can be used for phytoremediation purpose. Irrigation treatment of 100% Hindon water recorded maximum transfer factor of arsenic in fodder (1.62 & 1.01) which was statistically higher than Hindon & ground water in 1:1 ratio (1.55 & 0.92) followed by Hindon & ground water in 1:3 ratio (1.42 & 0.90) while lowest transfer factor of arsenic was noted with 100% ground water (1.35 & 0.87) during both the years of experiment.

Different soil amendments resulted in lower value of transfer factor of arsenic in fodder as compared to control for both the years. Application of different soil amendments decreased the transfer factor of arsenic in comparison to control for both the years. The TF in shoot was >1 for arsenic under different soil amendments and control for the first year while TF was <1 for second year except in control. Highest transfer factor of arsenic in fodder was found in control plots (1.58 & 1.64) followed by vermicompost (1.46 & 0.95) and activated carbon (1.32 & 0.89) while lowest was with the application of biochar (1.04 & 0.84) for both the years respectively.

4.7.3 Bio-concentration Factor Cadmium

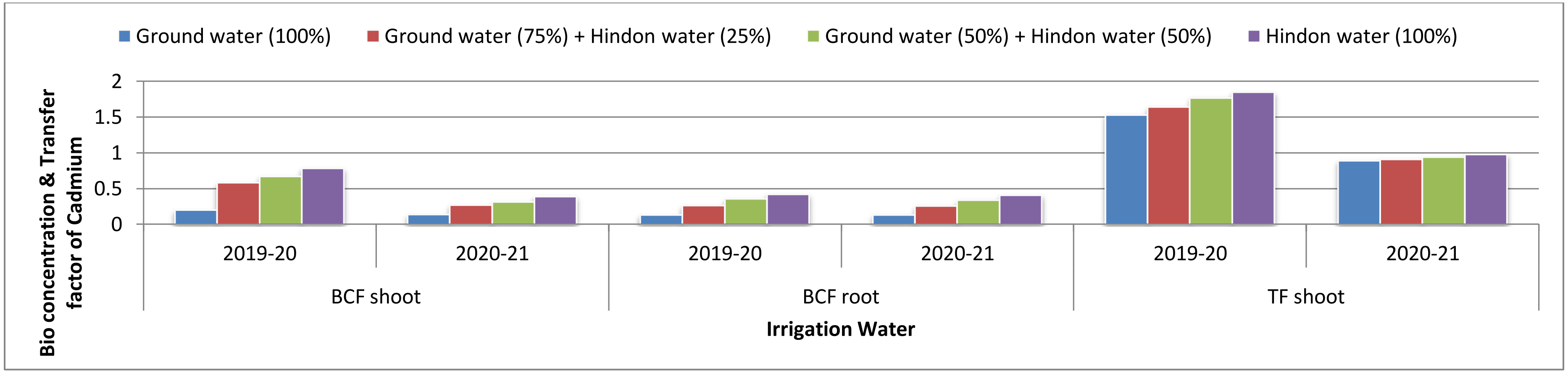
Irrigation water and soil amendments significantly influenced the bio-concentration of cadmium in roots and shoot of sorghum **(Appendix- XXI)**. However, the interaction between irrigation treatments and soil amendments was non- significant. The bio-concentration factor of cadmium in roots and shoot of fodder under various treatments is shown in Table 4.13 and illustrated in figure 4.13 for both the years. The bio-concentration factor of cadmium in shoot was higher than that of roots, which indicated the higher translocation of cadmium from soil to above ground parts. Furthermore, the BCFs of fodder showed significant increase in bio-concentration factor of arsenic with increased proportion of Hindon water in applied irrigation.

The order of cadmium accumulation in fodder was shoot > root. The BCF of cadmium found in shoot and roots of sorghum ranged from 0.202-0.784 & 0.135-0.390 and 0.132-0.420 & 0.134 -0.410 for both the years respectively. Irrigation treatment of 100% Hindon water (0.78 & 0.39 and 0.42 & 0.41) recorded maximum bio-concentration of cadmium in roots and shoot of sorghum which was statistically higher than 50% ground + 50% Hindon water (0.67 & 0.31 and 0.35 & 0.34) followed by 75% ground + 25% Hindon water (0.58 & 0.27 and 0.26 & 0.25) while lowest bio-concentration factor in roots and shoot was recorded with 100% ground water (0.202 & 0.135 and 0.132 & 0.134) during both the years.

Application of different soil amendments resulted in lower bio-concentration of cadmium in roots and shoot in comparison to control for both the years. Highest bio-concentration factor of cadmium in roots and shoot was found in control (0.415 & 0.425 and 0.397 & 0.790) which was statistically higher than vermicompost (0.361 & 0.350 and 0.676 & 0.310) and activated carbon (0.276 & 0.267 and 0.597 & 0.278).

Table 4.13 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of cadmium (BCF shoot, BCF root and TF shoot) in fodder sorghum

Treatments	BCF shoot		BCF root		TF shoot	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	0.202	0.135	0.132	0.134	1.53	0.89
Ground water (75%) + Hindon water (25%)	0.581	0.271	0.265	0.258	1.64	0.91
Ground water (50%) + Hindon water (50%)	0.670	0.316	0.355	0.340	1.77	0.94
Hindon water (100%)	0.784	0.390	0.420	0.410	1.85	0.98
SE(m)±	**0.004**	**0.003**	**0.004**	**0.003**	**0.006**	**0.007**
C.D (P=0.05)	**0.013**	**0.010**	**0.010**	**0.009**	**0.019**	**0.021**
(B) Soil amendments						
Activated Carbon @ 5t/ha	0.397	0.278	0.276	0.267	1.53	0.92
Biochar @ 5t/ha	0.200	0.130	0.130	0.136	1.0	0.89
Vermicompost @ 5t/ha	0.597	0.310	0.361	0.350	1.66	0.96
Control	0.676	0.790	0.415	0.425	1.78	1.86
SE(m)±	**0.005**	**0.006**	**0.005**	**0.004**	**0.012**	**0.013**
C.D (P=0.05)	**0.014**	**0.016**	**0.013**	**0.012**	**0.040**	**0.042**



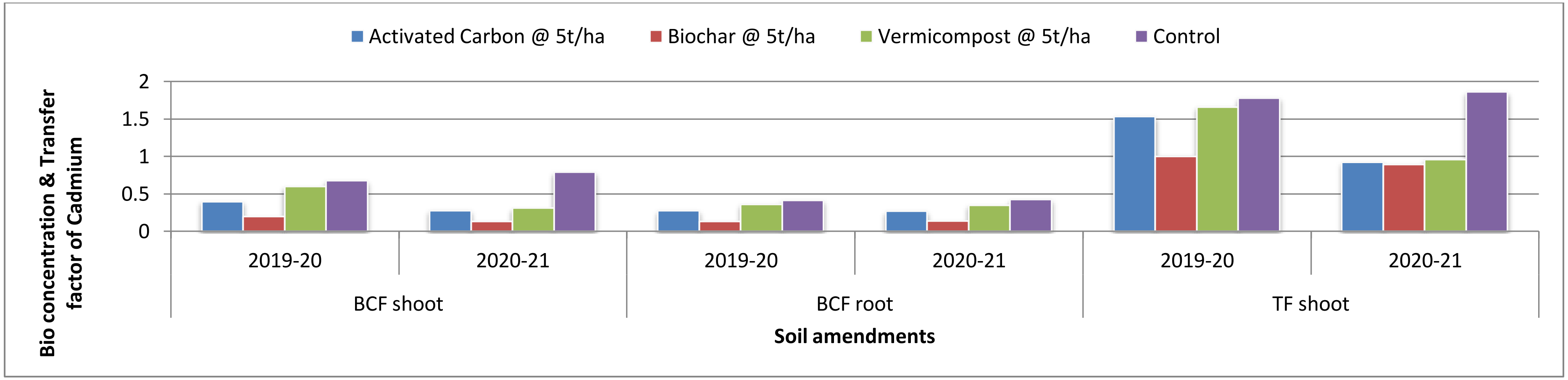


Fig. 4.13 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of cadmium (BCF shoot, BCF root and TF shoot) in fodder sorghum

While lowest was in biochar treatment @ 5 tonnes ha^{-1} (0.130 & 0.136 and 0.200 & 0.130) for both the years. The BCFs were lower in plots treated with different soil amendments, suggesting lower ability of fodder to transport heavy metals.

4.7.4 Bio-concentration Factor Lead

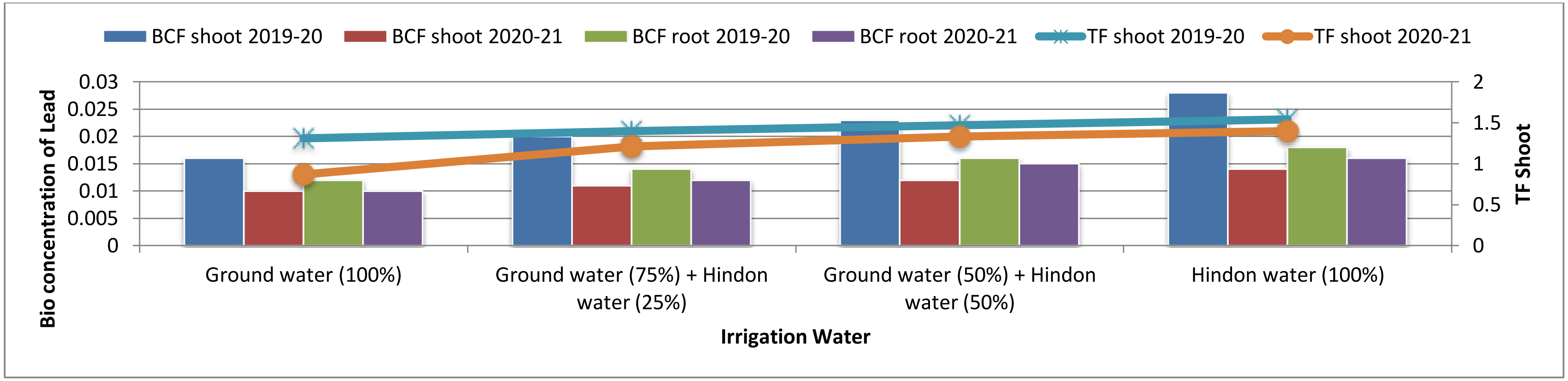
Irrigation water and soil amendments caused significant variation in bio-concentration of lead in roots and shoot of sorghum **(Appendix XXII)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

The bio-concentration factor of lead in roots and shoot of fodder under various treatments is shown in Table 4.14 and illustrated in figure 4.14 for both the years. The bio-concentration factor of lead in shoot was higher than that of roots, which indicated the higher translocation of lead from soil to above ground parts. Moreover, the BCFs of fodder showed significant increase in bio-concentration factor of lead with increased proportion of Hindon water in applied irrigation. Application of 100% Hindon water recorded maximum bio-concentration of lead in roots (0.018 & 0.016) and shoot (0.028 & 0.014) of sorghum which was significantly higher than Hindon & ground water in 1:1 ratio (0.016 & 0.015 and 0.023 & 0.012) followed by Hindon & ground water in 1:3 ratio (0.014 & 0.012 and 0.020 & 0.011) while least bio concentration of lead in roots and shoot was recorded with 100 % ground water (0.012 & 0.010 and 0.016 & 0.010) during both the years of experiment.

The BCFs of lead in fodder showed an increase in control while the BCFs of lead decreased in soil amendment treatments. Application of different soil amendments resulted in lower bio-concentration of lead in roots and shoot of fodder in comparison to control for both the years. Highest bio- concentration factor of lead in roots and shoot of sorghum was found in control (0.018 & 0.020 and 0.015 & 0.030)

Table 4.14 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of lead (BCF shoot, BCF root and TF shoot) in fodder sorghum

Treatments	BCF shoot		BCF root		TF shoot	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	0.016	0.010	0.012	0.010	1.31	0.87
Ground water (75%) + Hindon water (25%)	0.020	0.011	0.014	0.012	1.40	1.21
Ground water (50%) + Hindon water (50%)	0.023	0.012	0.016	0.015	1.47	1.33
Hindon water (100%)	0.028	0.014	0.018	0.016	1.54	1.40
SE(m)±	**0.002**	**0.001**	**0.003**	**0.004**	**0.006**	**0.005**
C.D (P=0.05)	**0.007**	**0.003**	**0.008**	**0.010**	**0.020**	**0.017**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.021	0.011	0.014	0.013	1.41	1.23
Biochar @ 5t/ha	0.014	0.008	0.010	0.012	1.31	0.85
Vermicompost @ 5t/ha	0.015	0.013	0.017	0.016	1.42	1.35
Control	0.025	0.030	0.018	0.020	1.48	1.56
SE(m)±	**0.003**	**0.002**	**0.004**	**0.005**	**0.008**	**0.006**
C.D (P=0.05)	**0.011**	**0.008**	**0.014**	**0.016**	**0.022**	**0.015**



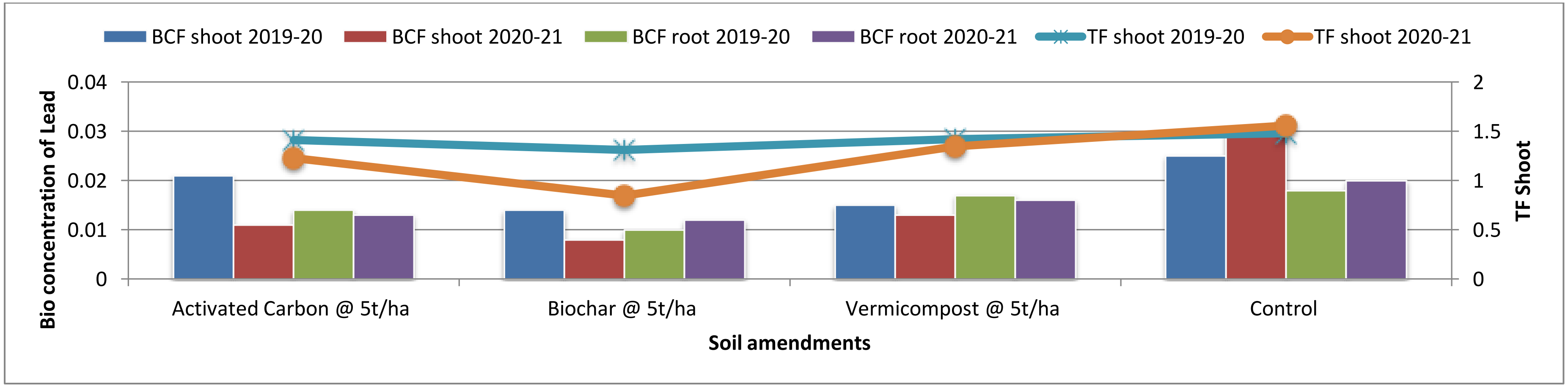


Fig. 4.14 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of lead (BCF shoot, BCF root and TF shoot) in fodder sorghum

Which was statistically higher than vermicompost (0.017 & 0.016 and 0.025 & 0.013) and activated carbon (0.014 & 0.013 and 0.021 & 0.011) while lowest was in biochar treatment @ 5 tonnes ha^{-1} (0.010 & 0.012 and 0.014 & 0.008) for both the years.

4.7.5 Transfer Factor Lead

Irrigation treatments and soil amendments exhibited significant variation on transfer factor of lead in fodder for both the years **(Appendix XXII)**. However, the interaction between irrigation water and soil amendments was non- significant.

The transfer factor of lead in fodder under various treatments is shown in table 4.14 and illustrated in figure 4.14 for both the years. The transfer factor of lead from root to shoot represents ratio of mean concentration of heavy metals in shoot to its concentration in roots. The transfer factor of lead in fodder increased significantly in treatments comprising of Hindon water alone or in proportion with ground water. Transfer ratio of heavy metals varied among all the treatments that may be because the translocation of metals is a metabolic process controlled by the physicochemical condition of the soil. Sorghum showed higher transfer factor of lead in shoot and hence possibility of lead exposure to animals through ingestion of these fodders is more. As given in Table 4.14, the TF for lead in shoot was more than 1 under different irrigation treatments for both the years suggesting higher ability of sorghum to transport heavy metals and can be used for phytoremediation purpose. Irrigation treatment of 100% Hindon water recorded maximum transfer factor of lead in fodder (1.54 & 1.40) which was statistically higher than dilution of raw Hindon water with 50% ground water (1.47 & 1.33) followed by dilution of raw Hindon water with 75% ground water (1.40 & 1.21) while lowest transfer factor of lead was recorded with 100% ground water (1.30 & 0.87) during both the years of experiment.

Application of different soil amendments resulted in lower transfer factor of lead in fodder as compared to control during both the years. Highest transfer of lead in fodder was found in control (1.56 & 1.42) which was significantly higher than vermicompost (1.48 & 1.35) and activated carbon (1.41 & 1.23) while lowest was with the application of biochar (1.31 & 0.85) for both the years respectively.

4.7.6 Bio-concentration Factor Nickel

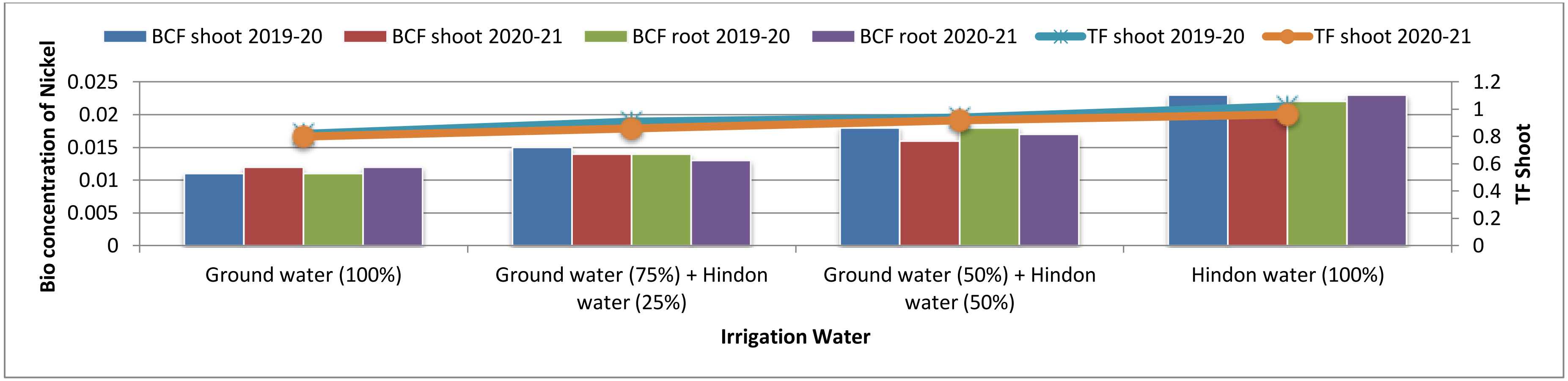
Irrigation water and soil amendments exhibited significant influence on bio-concentration of nickel in roots and shoot of sorghum for both the years **(Appendix-XXIII)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

The data on bio-concentration of nickel in fodder is given in table 4.15 and depicted in fig. 4.15 reveals that bio-concentration factor of nickel in roots was higher than that of shoot, which indicates higher translocation of nickel from soil to above ground parts. Moreover, the BCFs of fodder showed significant increase in bio-concentration factor of nickel with increased proportion of Hindon water in applied irrigation. Irrigation treatment of 100% Hindon water recorded maximum bio-concentration of nickel in roots (0.022 & 0.023) and shoot (0.023& 0.021) of sorghum which was statistically higher than dilution of raw Hindon water with 50% ground water (0.018 & 0.017 and 0.018 & 0.016) followed by dilution of raw Hindon water with ground water in 1:3 ratio (0.014 & 0.013 and 0.015 & 0.014)while lowest bio-concentration of nickel in roots and shoot was recorded in irrigation treatment of 100% ground water (0.011 & 0.012 and 0.011 & 0.012) during both the years of experiment.

The BCFs of fodder showed an increase in control while the BCFs of nickel decreased in soil amendment treatments.

Table 4.15 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of nickel (BCF shoot, BCF root and TF shoot) in fodder sorghum

Treatments	BCF shoot		BCF root		TF shoot	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	0.011	0.012	0.011	0.012	0.82	0.80
Ground water (75%) + Hindon water (25%)	0.015	0.014	0.014	0.013	0.91	0.86
Ground water (50%) + Hindon water (50%)	0.018	0.016	0.018	0.017	0.94	0.92
Hindon water (100%)	0.023	0.021	0.022	0.023	1.02	0.96
SE(m)±	**0.002**	**0.001**	**0.003**	**0.004**	**0.010**	**0.009**
C.D (P=0.05)	**0.006**	**0.002**	**0.011**	**0.014**	**0.033**	**0.030**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.016	0.014	0.016	0.015	0.91	0.87
Biochar @ 5t/ha	0.011	0.010	0.014	0.012	0.81	0.79
Vermicompost @ 5t/ha	0.020	0.018	0.021	0.020	0.95	0.93
Control	0.022	0.025	0.023	0.024	0.97	1.03
SE(m)±	**0.003**	**0.001**	**0.004**	**0.005**	**0.012**	**0.011**
C.D (P=0.05)	**0.008**	**0.003**	**0.010**	**0.013**	**0.033**	**0.031**



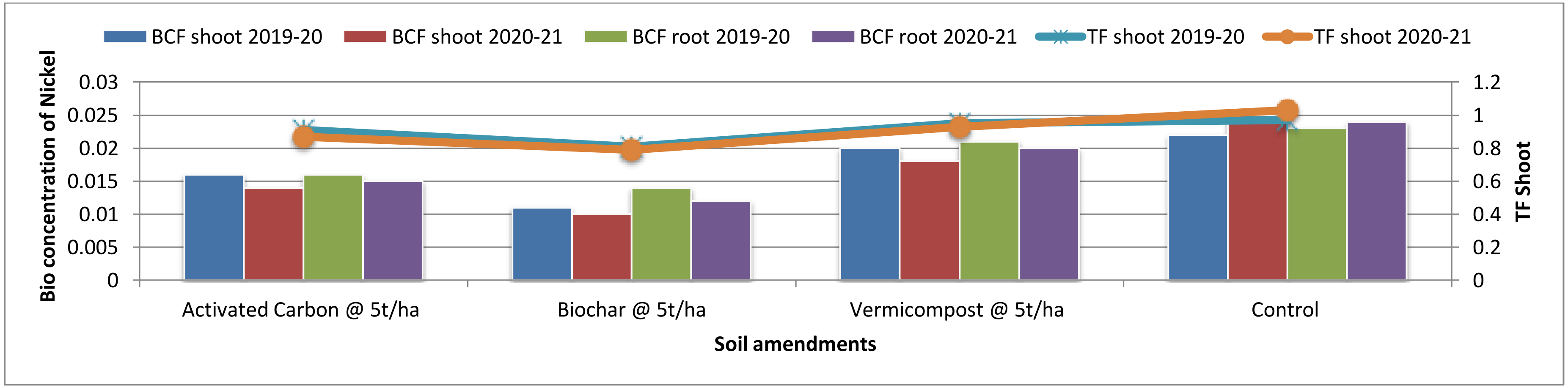


Fig. 4.15 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of nickel (BCF shoot, BCF root and TF shoot) in fodder sorghum

Application of different soil amendments resulted in lower bio-concentration of nickel in roots and shoot of sorghum as compared to control during both the years. Lowest bio-concentration of nickel in roots and shoot of sorghum was with the application of biochar (0.012 & 0.014 and 0.010 & 0.011) followed by activated carbon (0.016 & 0.015 and 0.016 & 0.014) and vermicompost (0.021 & 0.020 and 0.020 & 0.018) while highest bio-concentration of nickel in roots and shoot of sorghum was noted in control (0.023 & 0.024 and 0.022 & 0.025) for both the years.

4.7.7 Transfer Factor Nickel

Irrigation water and soil amendments exhibited significant influence on transfer factor of nickel in fodder for both the years **(Appendix XXIII)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Irrigation with 100% Hindon water resulted in highest transfer factor of nickel in fodder (1.02 & 0.96) which was statistically higher than Hindon & ground water in 1:1 ratio (0.94 & 0.92) followed by Hindon & ground water in 1:3 ratio (0.91 & 0.86) while lowest transfer factor of nickel in fodder was recorded with 100% ground water (0.82 & 0.80) during both the years of experiment.

Various soil amendments resulted in lower transfer factor of nickel in sorghum as compared to control plots. Highest transfer factor of nickel in fodder was found in control plots (1.03 & 0.97) while lowest was with the application of Biochar (0.81 & 0.79) followed by activated carbon (0.91 & 0.87) and vermicompost (0.95 & 0.93) for both the years of experiment.

4.7.8 Bio-concentration Factor Iron

Irrigation water and soil amendments significantly influenced the bio-concentration of iron in stem, root, leaves and straw of sorghum **(Appendix-XXIV)**.

The interaction between irrigation strategies and soil amendment options was non-significant.

The bio-concentration factor of iron in roots shoot was higher in than that of shoot, which indicated the lower translocation of iron from soil to above ground parts. The BCFs of fodder showed significant increase in bio-concentration factor of iron with increased proportion of Hindon water in applied irrigation. Irrigation treatment of applying raw Hindon water resulted in greatest bio-concentration factor of iron in roots (0.070 & 0.066) and shoot (0.068 & 0.065) of sorghum which was significantly higher than 50 % Hindon & 50% ground water (0.063 & 0.061 and 0.057 & 0.056) followed by 75% ground + 25 % Hindon water (0.057 & 0.054 and 0.050 & 0.048) while lowest bio-concentration factor of iron in sorghum was recorded with 100 % ground water (0.052 & 0.050 and 0.043 & 0.042) during both the years of experiment.

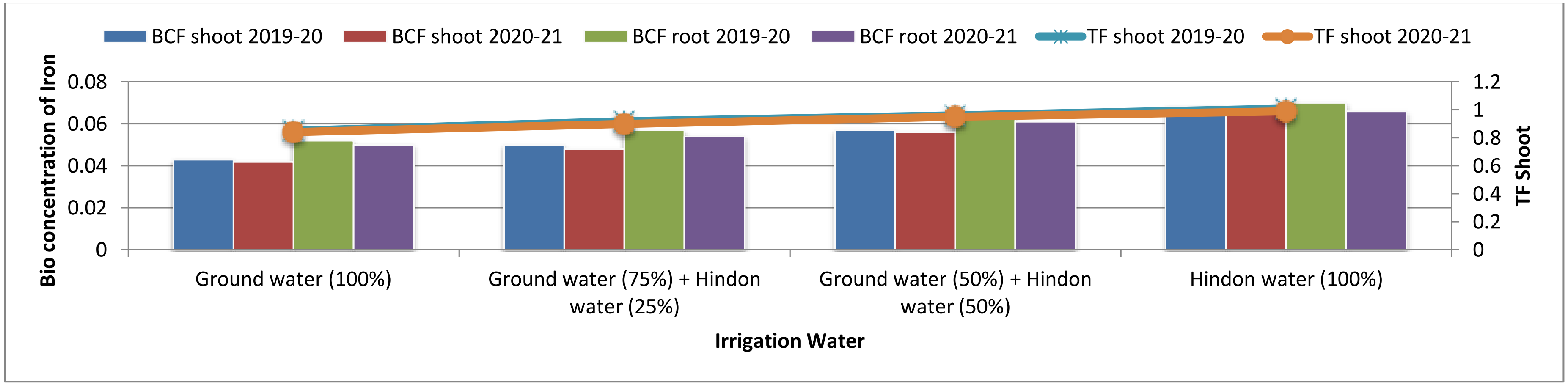
Application of various soil amendments resulted in lower bio-concentration of iron in roots and shoot of sorghum as compared to control for both the years. The BCFs of fodder showed an increase in control while the BCFs of iron decreased in soil amendment treatments. Lowest bio-concentration of iron in roots and shoot of sorghum was with the application of biochar @ five tonnes ha $^{-1}$ (0.051 & 0.050 and 0.044 & 0.040) followed by activated carbon (0.058 & 0.055 and 0.052 & 0.050) and vermicompost (0.065 & 0.063 and 0.061 & 0.060) while highest bio-concentration of iron in roots and straw (0.068 & 0.072 and 0.068 & 0.070) was found in control during both the years.

4.7.9 Transfer Factor Iron

Different irrigation treatments and soil amendments caused significant variation in transfer factor of iron in fodder for both the years **(Appendix- XXIV)**.

Table 4.16 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of iron (BCF shoot, BCF root and TF shoot) in fodder sorghum

Treatments	BCF shoot		BCF root		TF shoot	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	0.043	0.042	0.052	0.050	0.85	0.84
Ground water (75%) + Hindon water (25%)	0.050	0.048	0.057	0.054	0.92	0.90
Ground water (50%) + Hindon water (50%)	0.057	0.056	0.063	0.061	0.96	0.95
Hindon water (100%)	0.068	0.065	0.070	0.066	1.01	0.99
SE(m)±	**0.002**	**0.001**	**0.003**	**0.004**	**0.007**	**0.006**
C.D (P=0.05)	**0.006**	**0.003**	**0.009**	**0.011**	**0.024**	**0.020**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.052	0.050	0.058	0.055	0.93	0.92
Biochar @ 5t/ha	0.044	0.040	0.051	0.050	0.84	0.83
Vermicompost @ 5t/ha	0.061	0.060	0.065	0.063	0.97	0.96
Control	0.068	0.070	0.068	0.072	1.00	1.03
SE(m)±	**0.003**	**0.002**	**0.004**	**0.005**	**0.007**	**0.008**
C.D (P=0.05)	**0.010**	**0.007**	**0.013**	**0.017**	**0.019**	**0.021**



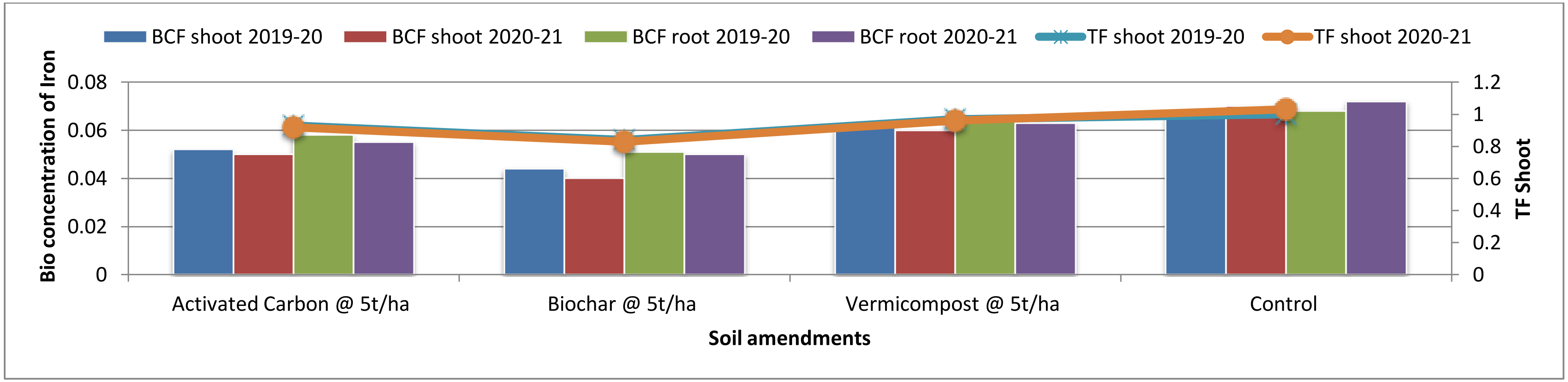


Fig. 4.16 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of iron (BCF shoot, BCF root and TF shoot) in fodder sorghum

However, the interaction between irrigation water and soil amendments was non- significant. Transfer factor of iron was calculated to determine the extent of risk associated due to wastewater irrigation and consequent heavy metal accumulation in shoot of sorghum. Sorghum showed higher transfer factor of iron in shoot and hence possibility of heavy metal exposure to animals through ingestion of these fodders was more. The transfer factor ratio was >1 in shoot which indicated that sorghum accumulated higher iron in shoot. Application of 100% Hindon water recorded maximum transfer of iron from root to shoot (1.01 & 0.99) which was significantly higher than Hindon & ground water in 1:1 ratio (0.96 & 0.95) followed by irrigation with Hindon & ground water in 1:3 ratio (0.92 & 0.90) while lowest transfer factor of iron in fodder was noted with 100% ground water (0.85 & 0.84) during both the years of experiment.

Different soil amendments resulted in lower transfer factor of iron in fodder as compared to control for both the years. Highest transfer factor of iron in fodder was found in control (1.0 & 1.03) followed by vermicompost (0.97 & 0.96) and activated carbon (0.93 & 0.92) while lowest was with the application of biochar @ five tonnes ha^{-1} (0.84 & 0.83) for both the years of experiment.

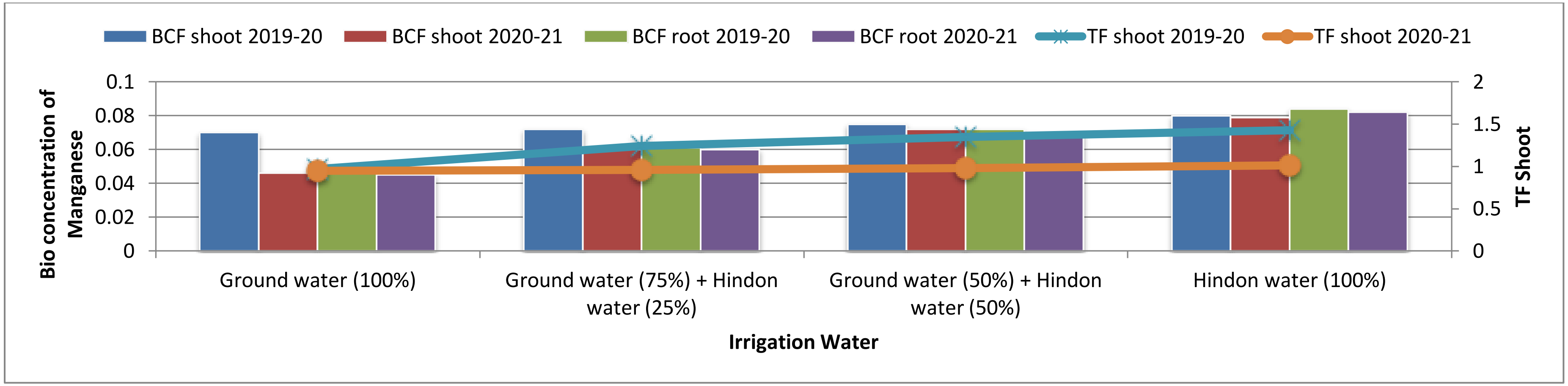
4.7.10 Bio-concentration Factor Manganese

Irrigation water and soil amendments exhibited significant influence on bio-concentration factor of manganese in roots and straw of sorghum **(Appendix XXV)**. However, the interaction between irrigation treatments and soil amendments was non-significant.

Perusal of data given in Table 4.17 and illustrated in Fig. 4.17 reveals that the bio-concentration factor of manganese in shoot was higher than that of roots, which indicated the higher translocation of manganese from soil to above ground parts.

Table 4.17 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of manganese (BCF shoot, BCF stem, BCF root, BCF leaves and TF shoot) in fodder sorghum

Treatments	BCF shoot		BCF root		TF shoot	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	0.070	0.046	0.047	0.045	0.97	0.95
Ground water (75%) + Hindon water (25%)	0.072	0.060	0.061	0.060	1.24	0.96
Ground water (50%) + Hindon water (50%)	0.075	0.072	0.072	0.070	1.35	0.98
Hindon water (100%)	0.080	0.079	0.084	0.082	1.43	1.01
SE(m)±	**0.002**	**0.001**	**0.002**	**0.001**	**0.006**	**0.005**
C.D (P=0.05)	**0.006**	**0.004**	**0.006**	**0.003**	**0.019**	**0.017**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.070	0.062	0.065	0.061	1.23	0.97
Biochar @ 5t/ha	0.068	0.045	0.045	0.043	0.96	0.94
Vermicompost @ 5t/ha	0.076	0.074	0.074	0.072	1.37	0.98
Control	0.081	0.082	0.084	0.086	1.44	1.04
SE(m)±	**0.002**	**0.002**	**0.003**	**0.002**	**0.006**	**0.007**
C.D (P=0.05)	**0.005**	**0.006**	**0.008**	**0.006**	**0.016**	**0.020**



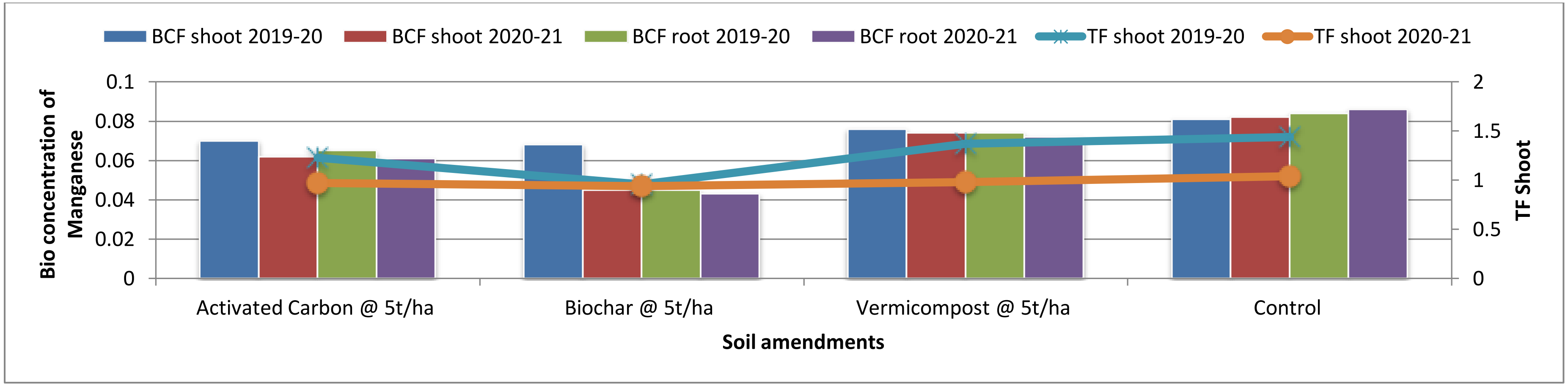


Fig. 4.17 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of manganese (BCF shoot, BCF root and TF shoot) in fodder sorghum

Moreover, the BCFs of fodder showed significant increase in bio-concentration factor of arsenic with increased proportion of Hindon water in applied irrigation. Irrigation with 100% Hindon water resulted in greatest bio- concentration factor of manganese from soil to roots (0.084 & 0.082) and shoot (0.080 & 0.079) of sorghum which was significantly higher than Hindon & ground water in 1:1 ratio (0.072 & 0.070 and 0.075 & 0.072) followed by Hindon & ground water in 1:3 ratio (0.061 & 0.060 and 0.072 & 0.060) while lowest bio- concentration of manganese in sorghum was recorded with 100% ground water (0.047 & 0.045 and 0.070 & 0.046) during both the years of experiment.

Soil amendments resulted in lower bio- concentration of manganese in roots and shoot of sorghum as compared to control for both the years. The BCFs of manganese in fodder showed an increase in control while the BCFs of manganese decreased in soil amendment treatments. Lowest bio- concentration of manganese in roots and straw of sorghum was with the application of biochar (0.045 & 0.043 and 0.068 & 0.045) while highest was found in control (0.084 & 0.086 and 0.081 & 0.082) followed by vermicompost @ 5 tonnes ha^{-1} (0.074 & 0.072 and 0.076 & 0.074) and activated carbon @ 5 tonnes ha^{-1}(0.065 & 0.061 and 0.070 & 0.062) for both the years.

4.7.11 Transfer Factor Manganese

Irrigation water and soil amendments exhibited significant influence on Transfer Factor of manganese in sorghum **(Appendix-XXV)**. The interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in Table 4.17 and illustrated in Fig. 4.17 reveals that 100% Hindon water resulted in maximum transfer factor of manganese in fodder (1.43 & 1.01) compared to different irrigation treatments during both the years and was significantly superior to dilution of raw Hindon water with 50% ground water (1.35 &

0.98) followed by dilution of raw Hindon water with ground water in 1:3 ratio (1.24 & 0.96) while lowest transfer factor of manganese in fodder was recorded with 100% ground water (0.97 & 0.95) during both the years of experiment. Sorghum showed higher transfer factor of manganese *i.e* more than 1 which indicated that sorghum accumulated greater manganese in shoot and hence possibility of manganese exposure to animals through this fodder would be higher.

Different soil amendments resulted in lower transfer factor of manganese in fodder as compared to control during both the years. Highest transfer factor of manganese in fodder was in control (1.44 & 1.04) followed by vermicompost (1.37 & 0.98) and activated carbon @ 5 tonnes ha^{-1} (1.23 & 0.97) while lowest was with the application of biochar @ 5 tonnes ha^{-1} (0.96 & 0.94) during both the years.

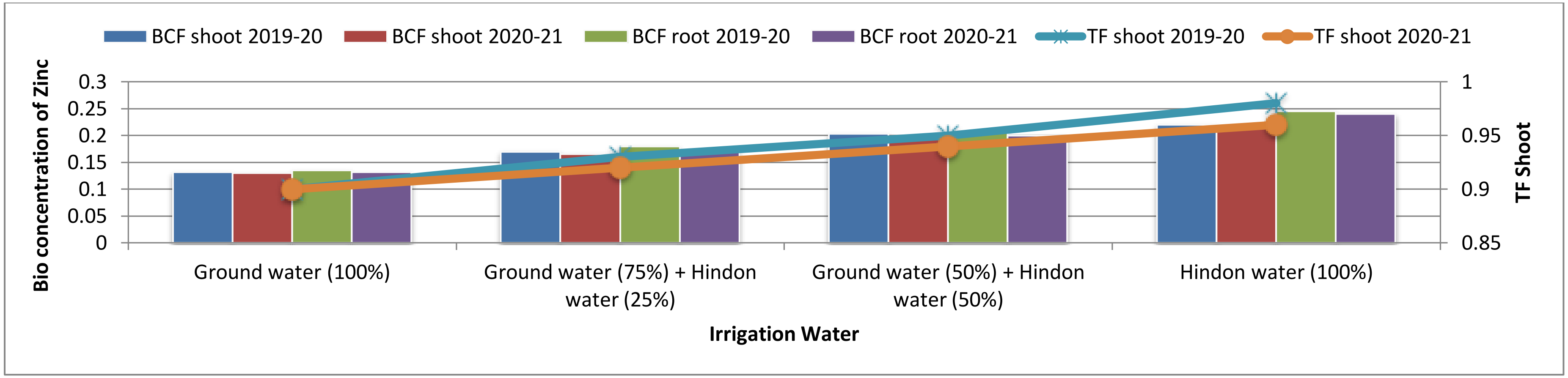
4.7.11 Bio-concentration Factor Zinc

Irrigation water and soil amendments exhibited significant influence on bio-concentration of zinc in roots and straw of sorghum **(Appendix XXVI)**. The interaction between irrigation treatments and soil amendments was non- significant.

The bio-concentration factor of zinc in roots was higher than that of shoot, which indicated the lower translocation of zinc from soil to above ground parts. Furthermore, the BCFs of fodder showed significant increase in bio-concentration factor of arsenic with increased proportion of Hindon water in applied irrigation. Irrigation with 100% Hindon water recorded maximum bio- concentration of zinc in roots (0.245 & 0.240) and shoot (0.220 & 0.218) of sorghum and was statistically superior to Hindon & ground water in 1:1 ratio (0.206 & 0.200 and 0.203 & 0.196) followed Hindon & ground water in 1:3 ratio (0.180 & 0.172 and 0.170 & 0.165) while lowest bio- concentration of zinc in fodder was recorded in irrigation treatment of 100 % ground water (0.135 & 0.132 and 0.132 & 0.130) during both the years.

Table 4.18 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of zinc (BCF shoot, BCF root and TF shoot) in fodder sorghum

Treatments	BCF shoot		BCF root		TF shoot	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water						
Ground water (100%)	0.132	0.130	0.135	0.132	0.90	0.90
Ground water (75%) + Hindon water (25%)	0.170	0.165	0.180	0.172	0.93	0.92
Ground water (50%) + Hindon water (50%)	0.203	0.196	0.206	0.200	0.95	0.94
Hindon water (100%)	0.220	0.218	0.245	0.240	0.98	0.96
SE(m)±	**0.004**	**0.003**	**0.004**	**0.003**	**0.007**	**0.007**
C.D (P=0.05)	**0.013**	**0.010**	**0.010**	**0.009**	**0.023**	**0.024**
B. Soil amendments						
Activated Carbon @ 5t/ha	0.176	0.171	0.184	0.178	0.93	0.92
Biochar @ 5t/ha	0.130	0.128	0.132	0.130	0.91	0.90
Vermicompost @ 5t/ha	0.210	0.205	0.211	0.205	0.96	0.95
Control	0.222	0.226	0.243	0.250	0.97	0.98
SE(m)±	**0.005**	**0.006**	**0.005**	**0.004**	**0.008**	**0.009**
C.D (P=0.05)	**0.014**	**0.016**	**0.013**	**0.012**	**0.021**	**0.025**



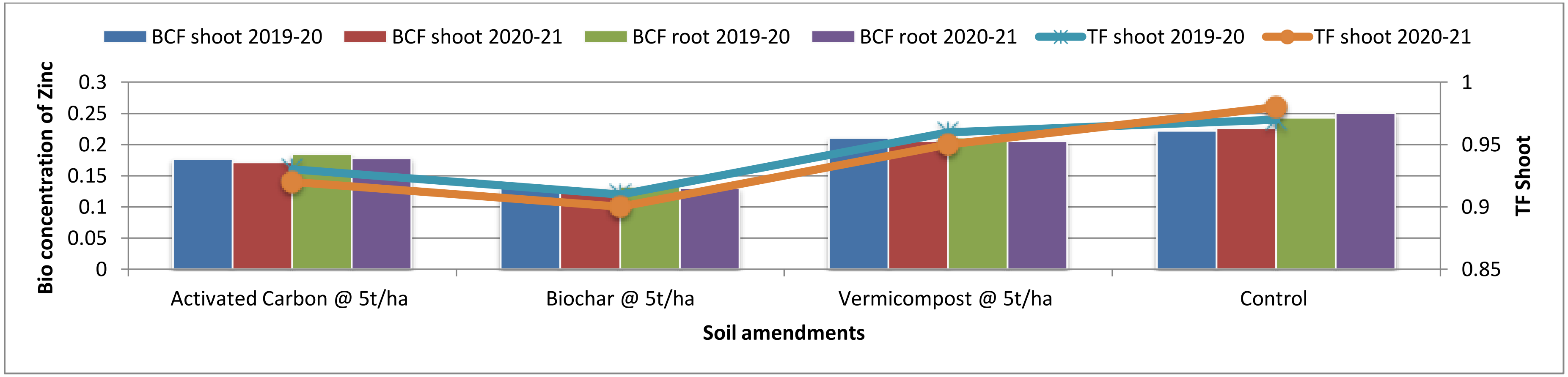


Fig. 4.18 Effect of irrigation treatments and soil amendments on bio concentration factor and transfer factor of zinc (BCF shoot, BCF root and TF shoot) in fodder sorghum

Application of different soil amendments resulted in lower bio- concentration of zinc in stem, root, leaves and straw of sorghum as compared to control for both the years. Lowest bio- concentration of zinc in roots and shoot of sorghum was with the application of biochar (0.132 & 0.130 and 0.130 & 0.128) while highest was found in control (0.243 & 0.250 and 0.222 & 0.226) followed by vermicompost @ 5 tonnes ha^{-1} (0.211 & 0.205 and 0.210 & 0.205) and activated carbon @ 5 tonnes ha^{-1} (0.184 & 0.178 and 0.176 & 0.171) for both the years.

4.7.12 Transfer Factor Zinc

Irrigation water and soil amendments exhibited significant influence on Transfer of zinc from root to straw of sorghum **(Appendix- XXVI)**. The interaction between irrigation treatments and soil amendments was non- significant.

Sorghum showed higher transfer factor of zinc *i.e* more than 1 which indicated that sorghum accumulated greater manganese in shoot and hence possibility of zinc exposure to animals through this fodder would be higher. Irrigation with 100% Hindon water recorded maximum Transfer Factor of zinc in fodder (0.98 & 0.96) followed by dilution of raw Hindon water with 50% ground water (0.95 & 0.94) and dilution of raw Hindon water with 75% ground water (0.93 & 0.92) while lowest Transfer Factor of zinc in sorghum was with 100% ground water (0.90 & 0.90) during both the years of experiment.

Different soil amendments resulted in lower Transfer Factor of zinc in sorghum as compared to control for both the years**.** Lowest Transfer Factor of zinc in sorghum was with the application of biochar @ 5 tonnes ha^{-1} (0.91 & 0.90) while highest was in control (0.97 & 0.98) followed by vermicompost (0.96 & 0.95) and activated carbon (0.93 & 0.92) for both the years of experiment.

4.8 Population studies

Plant population of wheat varied significantly under different irrigation treatments and soil amendments **(Appendix- XXVII).** However, the interaction between irrigation water and soil amendments was found to be non-significant.

The data on plant population of wheat is given in table 4.19 and depicted in Fig. 4.19, reveals that irrigation treatments comprising of Hindon water alone or in mixture resulted in significantly higher plant population at initial and harvest stages during both the years. The highest number of plants m^{-2} was noted with 100% Hindon water (57 & 58) which was statistically at par to dilution of raw Hindon water with ground water in 1:1 ratio (55 & 56) and significantly superior to Hindon & ground water in 1:3 ratio (53 & 54) & 100 % ground water (48 & 50)respectively.

Among the soil amendments, biochar @ 5t ha^{-1} (58 &59) produced significantly higher plant population at initial and harvest stages which was statistically superior to vermicompost @ 5t $ha-^{1}$ (53 & 55) and activated carbon @ 5t ha^{-1} (50 & 52)while lowest plant population was recorded in control (38 & 40) against all soil amendments during both the years.

4.9 Growth Parameters

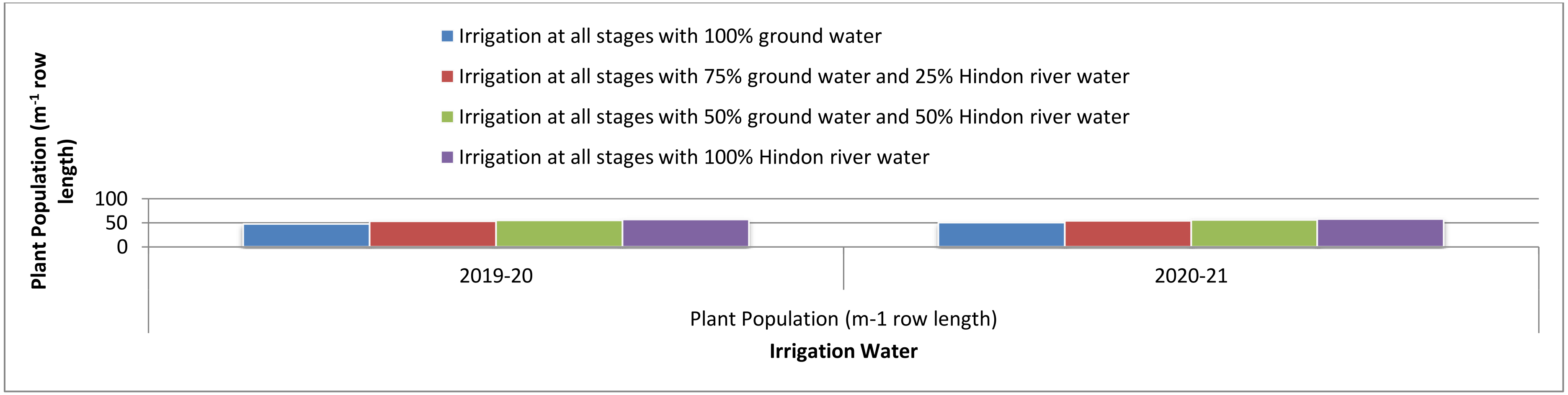
Observations on plant height, number of tillers m^{-2} and dry matter concentration were recorded at various stages of growth in sorghum and wheat presented as following:

4.9.1 Plant height (cm)

Plant height in wheat differed significantly among different irrigation treatments and soil amendments at all the stages of crop growth **(Appendix-XXVIII).** However, the interaction between irrigation water and soil amendments was non-significant.

Table 4.19 Effect of irrigation treatments and soil amendments on plant population of wheat

Treatments	**Plant Population (m^{-1} row length)**	
	2019-20	**2020-21**
(A) Underground + Hindon Mixtures		
Ground water (100%)	48	50
Ground water (75%) + Hindon water (25%)	53	54
Ground water(50%)+ Hindon water (50%)	55	56
Hindon water (100%)	57	58
SE(m)±	**0.40**	**0.64**
C.D (P=0.05)	**1.15**	**1.88**
(B) Soil amendments		
Activated Carbon @ 5t/ha	50	52
Biochar @ 5t/ha	58	59
Vermicompost @ 5t/ha	53	55
Control	38	40
SE(m)±	**0.47**	**0.70**
C.D (P=0.05)	**1.39**	**2.09**



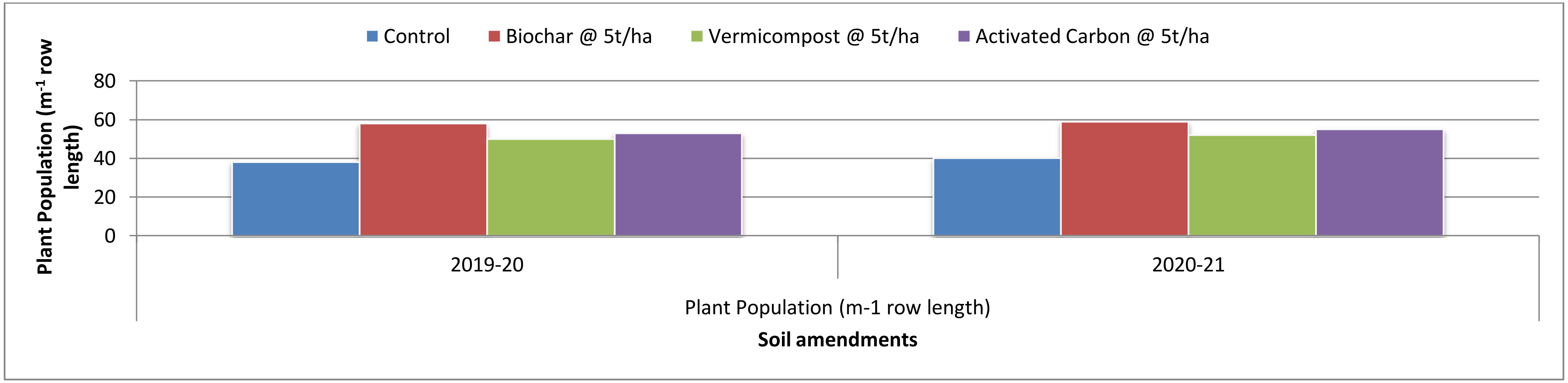
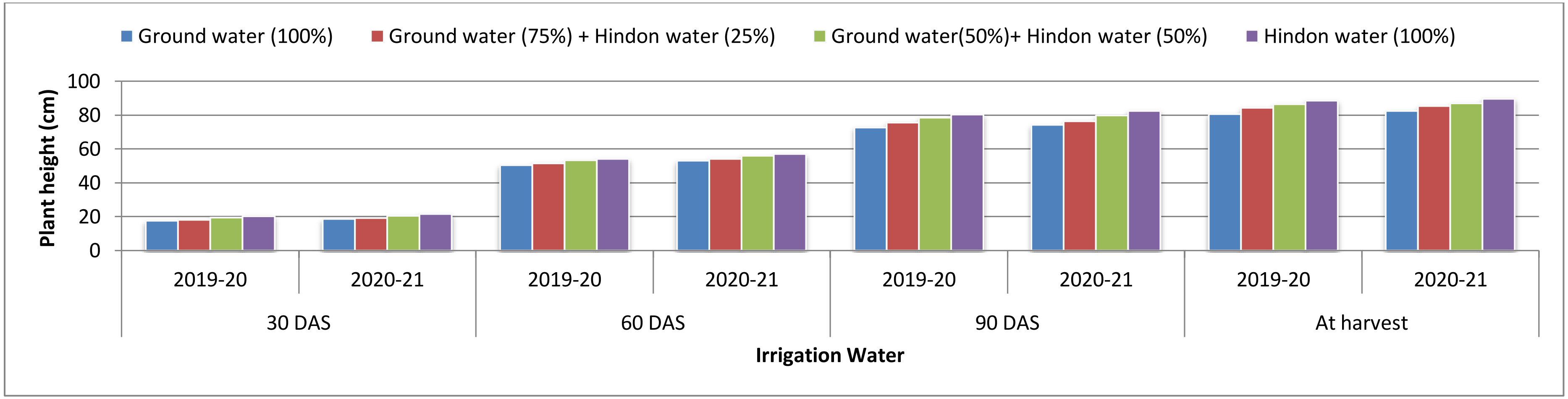


Fig. 4.19 Effect of irrigation treatments and soil amendments on plant population (m^{-1} row length) of wheat

Table 4.20 Effect of irrigation treatments and soil amendments on plant height (cm) of wheat

Treatments	Plant height (cm)							
	30 DAS		60 DAS		90 DAS		At harvest	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A: Irrigation water								
Ground water (100%)	17.5	18.6	50.4	53.0	72.8	74.3	80.7	82.4
Ground water (75%) + Hindon water (25%)	18.2	19.3	51.6	54.2	75.6	76.4	84.3	85.3
Ground water(50%)+ Hindon water (50%)	19.4	20.6	53.3	56.1	78.5	79.8	86.4	87.1
Hindon water (100%)	20.3	21.5	54.2	57.0	80.4	82.5	88.6	89.7
SE(m)±	**0.48**	**0.51**	**0.60**	**0.63**	**0.81**	**0.86**	**1.24**	**1.28**
C.D (P=0.05)	**1.40**	**1.49**	**2.08**	**2.19**	**2.41**	**2.62**	**3.75**	**3.85**
B: Soil amendments								
Activated Carbon @ 5t/ha	18.9	20.1	51.5	54.2	74.3	76.7	85.3	86.7
Biochar @ 5t/ha	20.1	21.3	55.0	57.8	80.8	81.6	89.7	90.4
Vermicompost @ 5t/ha	19.2	20.4	53.9	56.7	77.4	78.3	87.3	89.3
Control	17.2	18.2	49.1	51.6	70.3	72.4	81.1	82.4
SE(m)±	**0.50**	**0.53**	**0.89**	**0.93**	**1.22**	**1.35**	**1.47**	**1.54**
C.D (P=0.05)	**1.73**	**1.83**	**2.59**	**2.72**	**3.63**	**4.02**	**4.38**	**4.60**



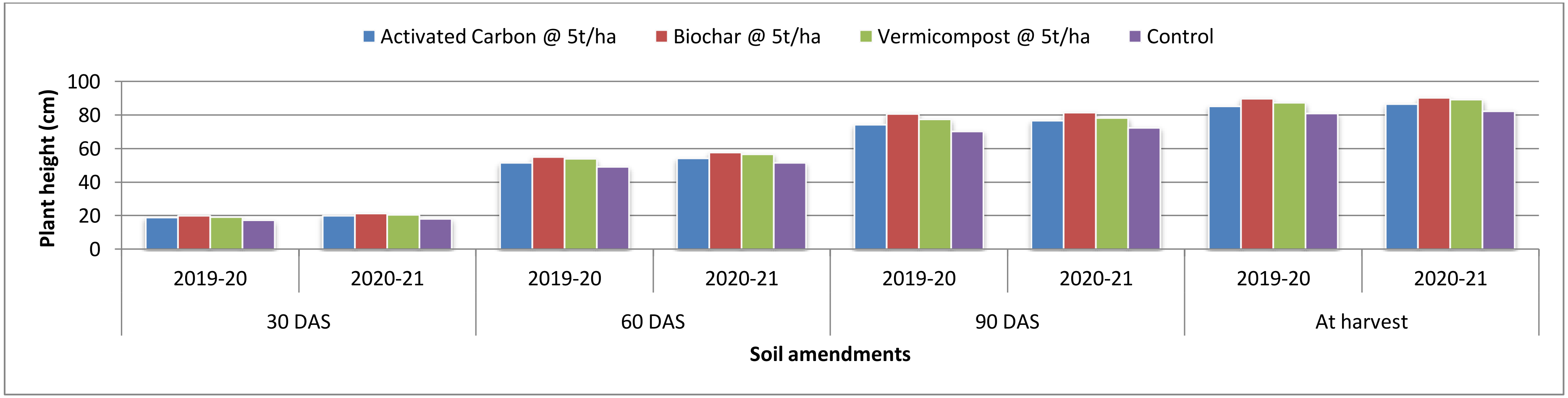


Fig. 4.20 Effect of irrigation treatments and soil amendments on plant height (cm) of wheat

The data on plant height of wheat is given in table 4.20 and depicted in Fig. 4.20 for both the years respectively. Plant height of wheat increased with the advancement of crop age and reached maximum at harvest, irrespective of the treatments. The height of wheat plants under different irrigation treatments varied from 17.5 to 20.3 & 18.6 to 21.5, 50.7 to 54.2 & 53.0 to 57.0, 67.4 to 72.5 & 70.2 to 75.5 cm and 71.1 to 77.7 & 73.4 to 80.2 cm at 30, 60, 90 days after sowing and at harvest during both the years, respectively. The tallest wheat plants (20.3 & 21.5, 54.2 & 57.0, 80.4 & 82.5, 88.6 & 89.7) at 30, 60 and 90 days after sowing and at harvest were recorded with application of 100% Hindon water which was statistically at par to Hindon & ground water in 1:1 ratio (19.4 & 20.62, 53.3 & 56.1, 78.5 & 79.8, 86.4 & 87.1) and significantly superior to dilution of raw Hindon water with ground water in 1:3 ratio and 100 % ground water (17.5 &18.6, 50.4 & 53, 72.8 & 74.3 and 80.7 & 82.4) respectively. Application of 100% Hindon water resulted in percent increase of 15.47 & 15.53, 7.65 & 7.65, 10.4 & 11.0 and 9.8 & 8.8 (%) in plant height as compared 100 % ground water at 30, 60, 90 days after sowing and at harvest during both years, 2019-20 and 2020-21 respectively.

Among the soil amendments, biochar @ 5t ha^{-1} produced significantly taller wheat plants (20.1 & 21.3, 55.0 & 57.8, 80.8 & 81.6, 89.7 & 90.4 cm) at 30, 60 and 90 days after sowing and at harvest stages & was statistically at par to vermicompost @ 5t ha^{-1}(19.2 & 20.4, 53.9 & 56.7, 74.3 &76.7, 85.3 & 86.7) and significantly superior to activated carbon @ 5t ha^{-1}(18.9 & 20.1, 51.5 & 54.2, 77.4 & 78.3 and 87.3 & 89.3) at 30, 60 and 90 days after sowing and at harvest stages during both the years of experiment. Lowest plant height was observed in control (17.2 &18.2, 49.1 & 51.6, 70.3 & 72.4, 81.1 & 82.4) against all soil amendments used during both the years. There was percent increase of about 17.0 & 17.0, 12.0 & 12.0, 14.9 & 12.7 & 9.7 in plant height with the application of biochar over control at 30, 60, 90 days after sowing and at harvest during both the years respectively.

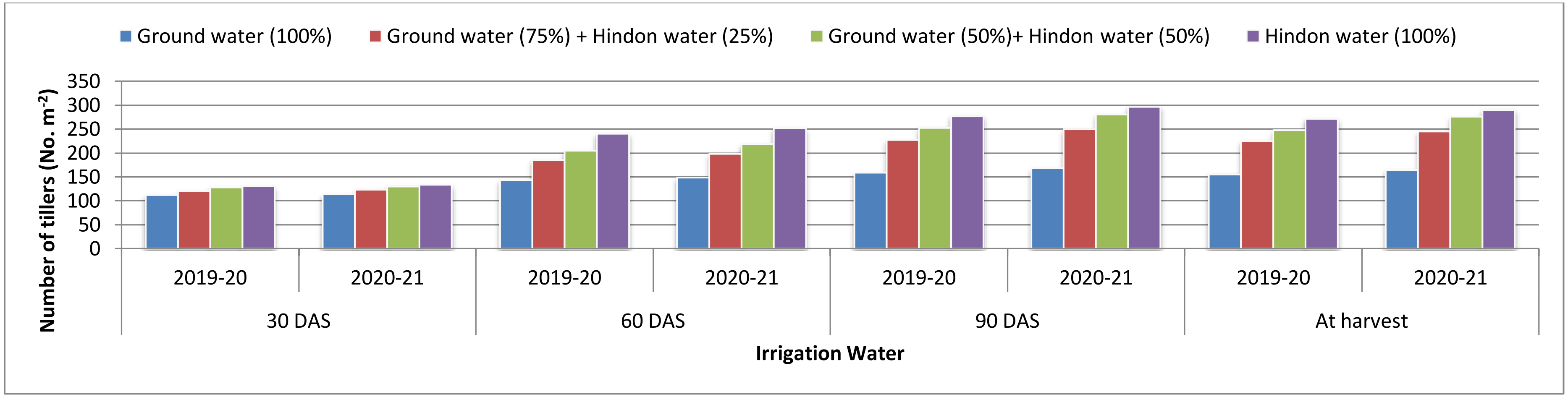
4.9.2 Number of tillers m^{-2}

Irrigation water and soil amendments significantly influenced the number of tillers per meter row length in wheat crop during both the years of experiment **(Appendix-XXIX).** However, the interaction between irrigation treatments and soil amendments was non-significant.

The number of tillers per meter row length increased as the crop advanced til 60 days after sowing as being presented in Table 4.21 and illustrated in Fig. 4.21 Among the various irrigation treatments, maximum number of tillers per meter row length was recorded with 100% Hindon water (130.5 & 133.2, 240.7 & 251.3, 277.3 & 296.3) at 30, 60, 90 days after sowing during both years and was significantly superior to rest of the irrigation treatments while least number of tillers per meter row length was recorded with 100% ground water (111.8 & 114.1, 143.3 & 148.4, 159.3 & 168.4) at 30, 60, 90 days after sowing during both the years of experiment. The maximum number of tillers in wheat plants was recorded at 60 days after sowing with 100% Hindon water **(**240.7 and 251**)** which was statistically superior to dilution of raw Hindon water with 50% ground water (204.4 and 218.4) followed by irrigation with Hindon & ground water in 1:3 ratio (185.4 and 193.3) and 100% ground water (143.3 &148.4). Applying 100% Hindon water to wheat plants resulted in percent increase of 16.7 & 16.7, 67.9 & 69.3 and 74.0 & 75.9 **(%)** over irrigation with 100% ground water at 30, 60 and 90 days stage during both the years respectively.

Table 4.21 Effect of irrigation treatments and soil amendments on number of tillers (No. m^{-2}) of wheat

Treatments	Number of tillers (No. m^{-2})							
	30 DAS		60 DAS		90 DAS		At harvest	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water								
Ground water (100%)	111.8	114.1	143.3	148.4	159.3	168.4	155.4	164.2
Ground water (75%) + Hindon water (25%)	120.6	123.1	185.4	198.3	227.4	249.6	224.6	245.3
Ground water (50%)+ Hindon water (50%)	127.7	130.3	204.4	218.4	252.7	280.4	247.5	275.5
Hindon water (100%)	130.5	133.2	240.7	251.3	277.3	296.3	271.6	290.1
SE(m)±	**2.99**	**3.06**	**4.87**	**4.96**	**2.78**	**2.84**	**2.7**	**2.80**
C.D (P=0.05)	**10.34**	**10.56**	**14.58**	**14.90**	**8.36**	**8.54**	**8.14**	**8.37**
B. Soil amendments								
Activated Carbon @ 5t/ha	120.3	122.8	191.4	205.4	256.4	263.3	228.2	258.4
Biochar @ 5t/ha	136.8	139.7	244.7	254.3	284.2	301.6	278.3	295.5
Vermicompost @ 5t/ha	131.2	134.0	218.6	233.4	259.5	278.7	253.8	272.1
Control	102.2	104.3	140.3	145.3	164.3	232.4	151.5	218.3
SE(m)±	**4.23**	**4.32**	**7.91**	**7.98**	**5.48**	**5.62**	**5.42**	**5.28**
C.D (P=0.05)	**12.37**	**12.63**	**23.70**	**23.96**	**14.99**	**16.84**	**16.24**	**15.80**



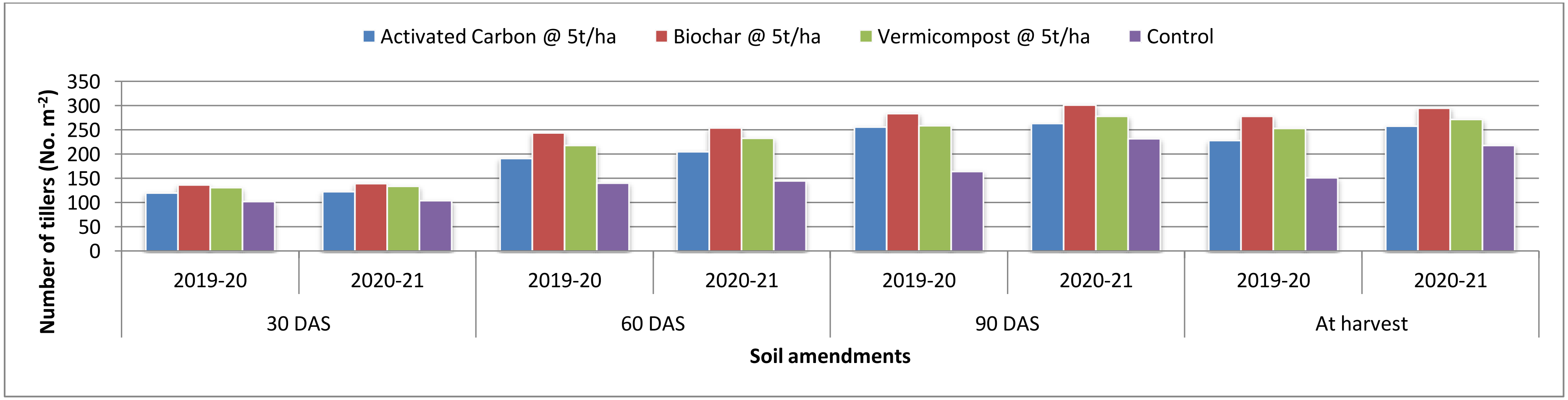


Fig. 4.21 Effect of irrigation treatments and soil amendments on number of tillers (No. m^{-2}) of wheat

Among various soil amendments, maximum number of tillers per meter row length at 30, 60 and 90 days after sowing was recorded with incorporation of biochar @ 5t ha-1(136.8 & 139.7, 244.7 & 254.3, 284.2 & 301.6) which was statistically superior to vermicompost @ 5t ha^{-1} (131.2 & 134.0, 218.6 & 233.4, 259.5 & 278.7) and activated Carbon @ 5t ha^{-1}(120.3 & 122.8, 191.4 & 205.4, 232.4 & 263.3) during both the years. Lowest number of tillers per meter row was recorded in control (102.2 & 104.3, 140.3 & 145.3, 256.4 & 164.3) at 30, 60 and 90 days after sowing for both the years of experiment. There was about 33.8 & 33.8, 74.3 & 74.9 and 22.4 & 83.5 (%) increase in number of tillers in biochar treatment in comparison to control at 30, 60 and 90 days stage of wheat during both the years respectively.

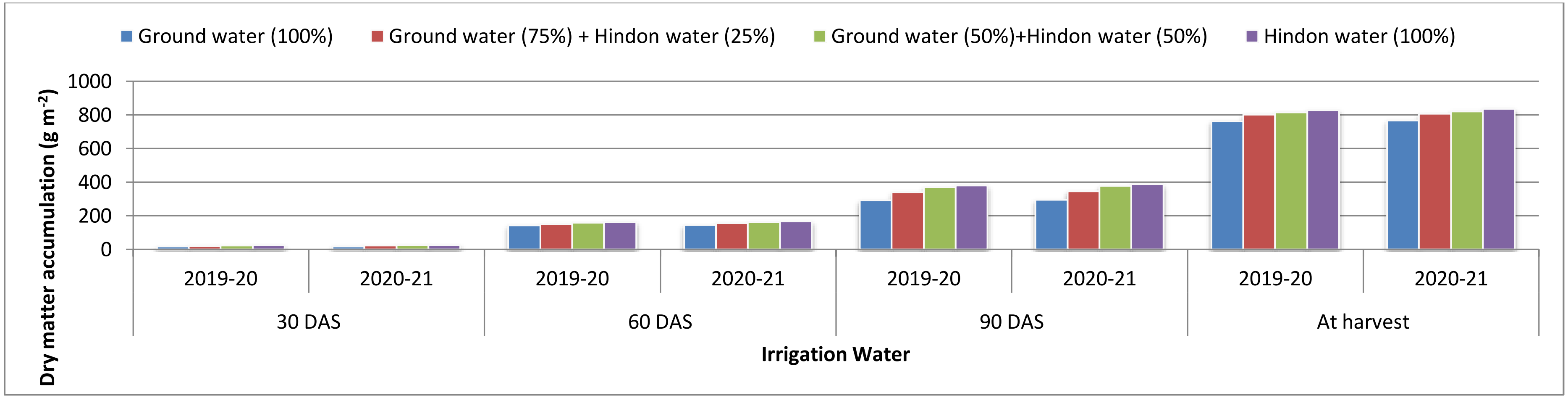
4.9.3 Dry matter accumulation (g m^{-2})

Accumulation of dry matter in wheat was significantly influenced under different irrigation treatments and soil amendments **(Appendix- XXX)**. No significant interaction was found between irrigation water and soil amendments with respect to dry matter accumulation during both the years of experiment.

Perusal of data given in Table 4.22 and illustrated in Fig. 4.22 reveals that maximum concentration of dry matter (25.1 & 27.2, 163.2 & 167.2, 380.3 & 388.1 and 828.7 & 836.2) at 30, 60, 90 days after sowing and at harvest was noted in raw Hindon water treatment being statistically at par to Hindon & ground water irrigation in 1:1 ratio and significantly superior to Hindon & ground water irrigation in 1:3 ratio while minimum concentration of dry matter was recorded in wheat plants receiving 100 % ground water (16.7 & 18.4, 143.4 & 146.1, 292.1 & 295.3 and 763 & 767.3 g m^{-2}) at 30, 60, 90 days after sowing and at harvest stages during both the years of experiment.

Table 4.22 Effect of irrigation treatments and soil amendments on dry matter accumulation (g m^{-2}) of wheat

Treatments	Dry matter accumulation (g m^{-2})							
	30 DAS		60 DAS		90 DAS		At harvest	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water								
Ground water (100%)	16.7	18.4	143.4	146.1	292.1	295.3	763.1	767.3
Ground water (75%) + Hindon water (25%)	21.4	22.8	150.3	157.2	341.2	346.1	801.3	807.2
Ground water (50%)+Hindon water (50%)	23.2	25.1	158.4	162.1	371.3	378.4	815.6	821.4
Hindon water (100%)	25.1	27.2	163.3	167.2	380.3	388.1	828.7	836.2
SE(m)±	**0.42**	**0.47**	**3.18**	**3.34**	**6.47**	**6.56**	**8.24**	**8.32**
C.D (P=0.05)	**1.28**	**1.42**	**9.56**	**10.04**	**19.43**	**19.75**	**24.74**	**24.97**
B. Soil amendments								
Activated Carbon @ 5t/ha	20.4	21.9	152.1	155.1	344.0	350.2	795.6	803.4
Biochar @ 5t/ha	26.4	28.6	165.7	171.7	383.2	390.1	832.4	842.3
Vermicompost @ 5t/ha	22.3	23.7	160.8	164.8	374.3	381.4	820.5	827.1
Control	15.1	16.2	142.3	145.2	290.7	294.2	760.1	764.2
SE(m)±	**0.78**	**0.85**	**6.58**	**6.67**	**12.52**	**12.63**	**14.85**	**14.93**
C.D (P=0.05)	**2.32**	**2.52**	**19.73**	**19.97**	**37.51**	**37.86**	**44.53**	**44.75**



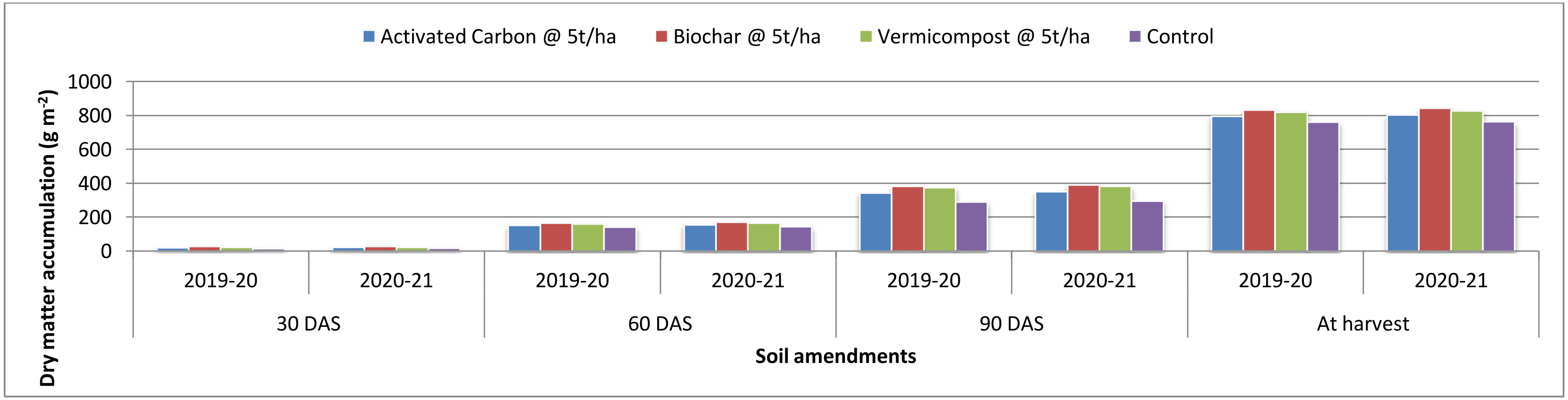


Fig. 4.22 Effect of irrigation treatments and soil amendments on dry matter accumulation (g m^{-2}) of wheat

Application of 100% Hindon water resulted in percent increase of 50.6 & 48.0, 13.8 & 14.4, 30.1 & 31.4 and 8.5 & 8.9 in dry matter compared to 100% ground water at 30, 60, 90 days after sowing and at harvest stages during the year, 2019-20 and 2020-21 respectively.

With respect to various soil amendments, maximum dry matter (26.4 & 28.6, 165.7 & 171.7, 383.2 & 390.1, 832.4 & 842.3 g m^{-2}) at 30, 60, 90 days after sowing and harvest stage was recorded in Biochar treatment (5t ha^{-1}) which was significantly superior to vermicompost (22.3 & 23.7, 160.8 & 164.8, 374.3 & 381.4, 820.5 & 827.1) followed by activated carbon @ 5t ha-1(20.4 & 21.9, 152.1 & 155.1, 344.0 & 350.2, 795.6 & 803.4 g m^{-2}) at 30, 60, 90 days after sowing and at harvest during both the years respectively. Lowest dry matter in wheat was recorded in control (15.1 & 16.2, 142.3 & 145.2, 290.7 & 294.2, 760.1 & 764.2) at 30, 60, 90 days after sowing and harvest respectively. There was about 74.2 & 76.0, 16.4 & 18.2, 31.8 & 32.5 and 9.5 & 10.2 (%) increase of in dry matter of wheat in biochar treatment as compared to control at 30, 60, 90 days after sowing and at harvest during both the years of experiment.

4.10 Yield attributes and Yield

4.10.1 Spike length (cm)

Significant variation was observed in spike length of wheat under different irrigation water treatments and soil amendments respectively (**Appendix-XXXI**). However, the interaction between irrigation water and soil amendments was non-significant.

The data on spike length of wheat is given in Table 4.23 and depicted in Fig. 4.23 respectively. Longest spike in wheat plants was measured with 100% Hindon water (12.3 and 13.0 cm) which was significantly superior to Hindon & ground water in 1:1 ratio (11.2 and 11.9 cm) followed by Hindon & ground water in 1:3 ratio (9.6 and

10.2 cm) while lowest spike length was measured with 100% ground water (8.1 and 8.6) during both the years of experiment. There was about 51.0 & 51.1 **(%)** increase in spike length of wheat with 100% Hindon water in comparison to 100 % ground water during both the years respectively.

Among the soil amendments, longest spike length in wheat was recorded in Biochar treatment @ 5t ha^{-1} (11.6 and 12.3 cm) which was statistically at par to vermicompost @ 5t ha^{-1} (11.2 and 11.9 cm) and significantly superior to activated Carbon @ 5t ha-1(10.7 and 11.4)**.** Least value of spike length was recorded in control (7.7 & 8.2) during both the years of experiment. There was percent increase of about 49.4 & 49.5 in spike length with the application of Biochar in comparison to control during both the years respectively.

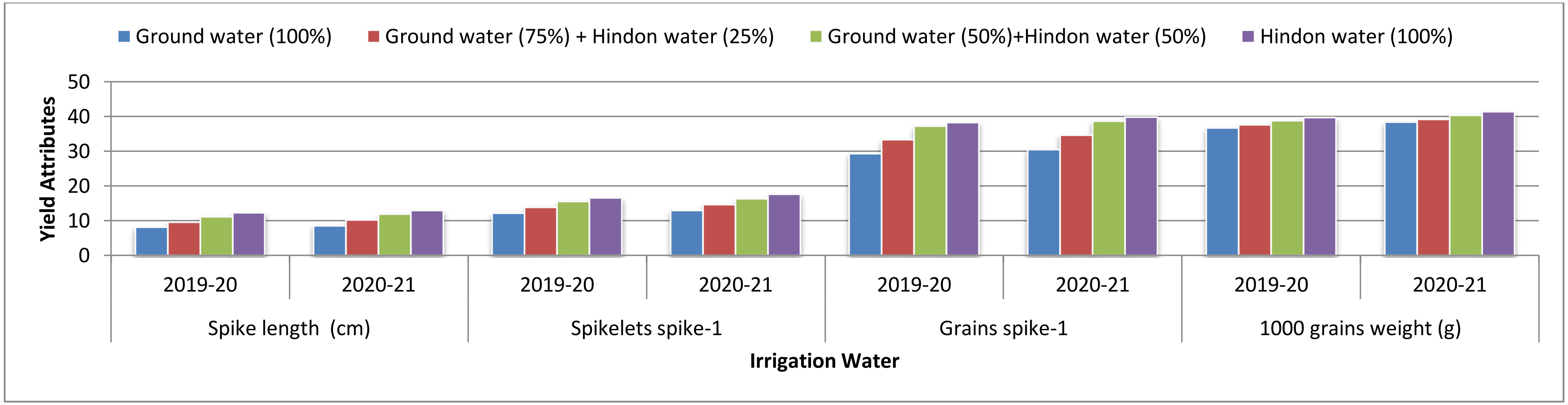
4.10.2 Spikelets spike^{-1}

Irrigation water and soil amendments caused significant variation in number of spikelets $spike^{-1}$ in wheat during both the years **(Appendix-XXXI).** However, the interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in Table 4.23 and illustrated in Fig. 4.23 reveals that highest number of spikelets $spike^{-1}$ in wheat was noted with the raw Hindon water irrigation (16.6 and 17.6) which was statistically at par to dilution of raw Hindon water with 50% ground water (15.5 and 16.4) and significantly superior to irrigation with 75% ground water and 25% Hindon water (13.9 and 14.7) while lowest number of spikelets $spike^{-1}$ was recorded with 100% ground water (12.2 and 12.9) during both the years of experiment. Application of 100% Hindon water resulted in 35.6 & 35.7 (%) increase in spikelet's $spike^{-1}$ over 100% ground water.

Table 4.23 Effect of irrigation treatments and soil amendments on yield attributing characters of wheat

Treatments	Yield attributes							
	Spike length (cm)		Spikelets spike^{-1}		Grains spike^{-1}		1000 grains weight (g)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water								
Ground water (100%)	8.1	8.6	12.2	12.9	29.3	30.5	36.8	38.4
Ground water (75%) + Hindon water (25%)	9.6	10.2	13.9	14.7	33.3	34.7	37.7	39.2
Ground water (50%)+Hindon water (50%)	11.2	11.9	15.5	16.4	37.2	38.7	38.8	40.4
Hindon water (100%)	12.3	13.0	16.6	17.6	38.3	39.8	39.7	41.4
SE(m)±	**0.13**	**0.14**	**0.15**	**0.16**	**0.30**	**0.31**	**0.40**	**0.42**
C.D (P=0.05)	**0.46**	**0.49**	**0.51**	**0.55**	**1.04**	**1.09**	**1.41**	**1.46**
B. Soil amendments								
Activated Carbon @ 5t/ha	10.7	11.4	15.7	16.7	37.1	38.6	38.7	40.4
Biochar @ 5t/ha	11.6	12.3	17.2	18.3	41.1	42.8	40.4	42.1
Vermicompost @ 5t/ha	11.2	11.9	16.4	17.4	39.1	40.7	39.3	40.9
Control	7.7	8.2	8.8	9.3	20.7	21.6	34.6	36.1
SE(m)±	**0.17**	**0.18**	**0.25**	**0.27**	**0.61**	**0.64**	**0.79**	**0.82**
C.D (P=0.05)	**0.50**	**0.53**	**0.74**	**0.79**	**1.79**	**1.87**	**2.31**	**2.41**



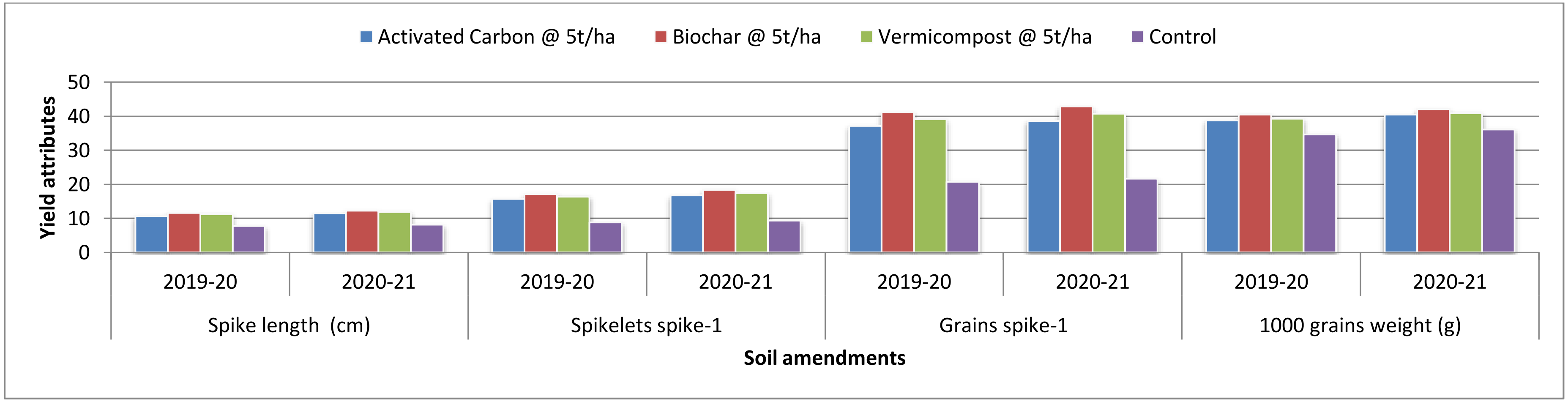


Fig. 4.23 Effect of irrigation treatments and soil amendments on yield attributing characters of wheat

Various soil amendments resulted in higher number spikelets spike^{-1} in comparison to control. Maximum number of spikelets spike^{-1} in wheat was recorded with the application of biochar @ 5 t ha^{-1} (17.2 and 18.3) which was statistically at par to vermicompost @ 5t ha^{-1} (16.4 and 17.4) and significantly superior to activated carbon @ 5t ha^{-1} (15.7 and 16.7) during both the years of experiment.

4.10.3 Grains spike^{-1}

Grains spike^{-1} in wheat was significantly affected by irrigation water and soil amendments (**Appendix-XXXI**). However, the interaction between irrigation treatments and soil amendments was non-significant.

The data on number of grains spike^{-1} is given in Table 4.23 and depicted in Fig. 4.23 during both the years respectively. Maximum number of grains spike^{-1} was recorded in wheat plants given 100% Hindon water (38.3 and 39.8) which was statistically at par to dilution of raw Hindon water with 50% ground water (37.2 and 38.7) and significantly superior to application of Hindon & ground water in 1:3 ratio (33.3 and 34.7) while minimum number of grains spike^{-1} was recorded with 100% ground water (29.3 and 30.5) during both the years of experiment. Application of 100% Hindon water resulted in 30.6 & 30.6 (%) increase in number of grains spike^{-1} over 100% ground water during the years, 2019-2020 and 2020-2021 respectively.

In regard to different soil amendments, highest number of grains spike^{-1} was recorded with the application of biochar @ 5t ha^{-1}(41.1 and 42.8) which was statistically at par to vermicompost @ 5t ha^{-1} (39.1 and 40.7) and significantly superior to activated carbon @ 5t ha^{-1} (37.1 and 38.6) while lowest grains spike^{-1} was noted in control (20.7 & 21.6) during both the years of experiment.

4.10.4 Test weight (g)

Significant variation was observed in test weight of wheat under different irrigation treatments and soil amendments (**Appendix-XXXI**). However, the interaction between irrigation water and soil amendments was non- significant.

The data on test weight of wheat is given in Table 4.23 and depicted in Fig. 4.23 during the consecutive years, 2019-20 and 2020-21 respectively. Greatest value of test weight of wheat was recorded with 100% Hindon water (39.7 and 41.4 g) which was statistically at par to Hindon & ground water in 1:1 ratio (38.8 and 40.4 g) and significantly superior to irrigation with Hindon & ground water in 1:3 ratio (37.7 & 39.2) while lowest test weight was recorded with 100% ground water (36.8 & 38.4) during both the years of experiment. Irrigation with 100% Hindon water resulted in 7.8 & 7.8 (%) increase in test weight in comparison to 100% ground water respectively.

Among soil amendments, highest value of test weight was noticed with the application of Biochar @ 5t ha^{-1}(40.4 and 42.1 g) which was at par to vermicompost (39.3 & 40.9) and activated carbon @ 5t ha^{-1} (38.7 and 40.4 g) during both the years respectively.

4.11 Yields

4.11.1 Grain yield (q ha^{-1})

Grain yield of wheat was significantly influenced by different irrigation treatments and soil amendments (**Appendix- XXXII**). The interaction between irrigation water and soil amendments was found to be non-significant.

Perusal of data on grain yield given in Table 4.24 and illustrated in Fig. 4.24 reveals that wheat crop given 100% Hindon water produced maximum grain yield (43.0 and 45.1 q ha^{-1}) which was statistically at par to dilution of raw Hindon water with 50% ground water (40.3 and 42.3 q ha^{-1}) and significantly superior to dilution of raw Hindon water with ground water in 1:3 ratio (39.0 and 41.0 q ha^{-1}) while minimum grain yield was recorded with 100% ground water (35.1 and 36.9 q ha^{-1}) for both years. There was percent increase of 22.3 & 33.3 (%) in grain yield with 100% Hindon water in comparison to 100% ground water respectively.

Among the soil amendments used, maximum grain yield was produced with the application of biochar @ 5t ha^{-1}(46.0 and 48.4 q ha^{-1}) which was statistically superior to vermicompost @ 5t ha^{-1}(43.0 and 45.2 q ha^{-1}) and activated carbon @ 5t ha^{-1}(40.7 and 42.7) while lowest grain yield was found in control (27.8 & 29.2) during both the years. There was about 65.5 & 66.4 (%) increase in grain yield in biochar treatment as compared to control during the years, 2019-2020 and 2020-2021 respectively.

4.11.2 Straw yield (q ha^{-1})

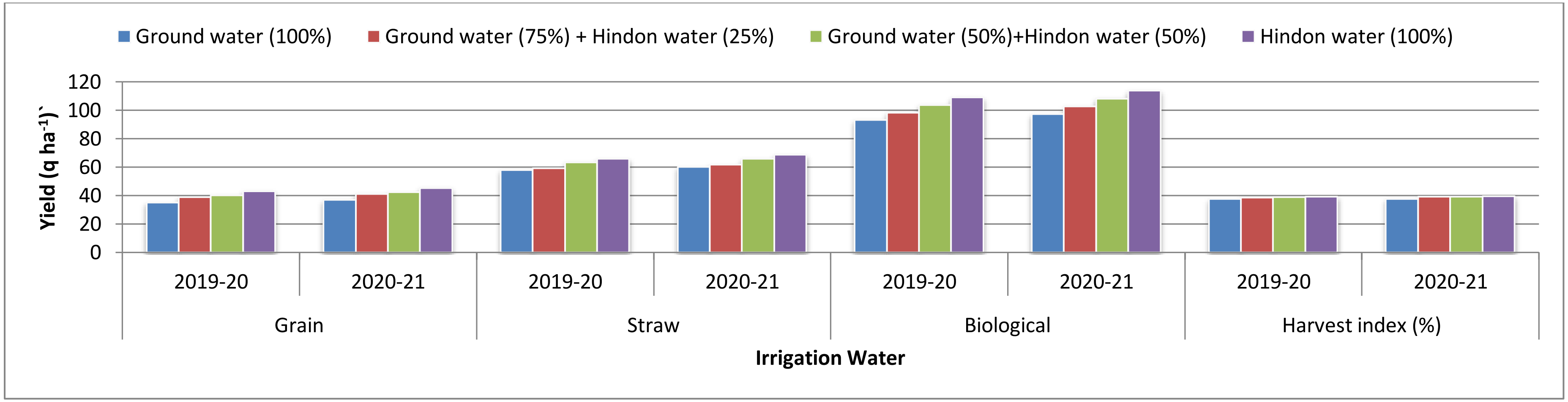
Significant variation was observed in straw yield of wheat under different irrigation treatments and soil amendments (**Appendix-XXXII**). However, interaction between irrigation water and soil amendments was non-significant.

The data on straw yield of wheat is given in table 4.24 and depicted in Fig. 4.24 for both the years of experiment. Application of raw Hindon water produced highest straw yield of 66.0 and 68.7 q ha^{-1} which was statistically superior to Hindon & ground water in 1:1 ratio (63.4 and 65.9 q ha^{-1}) followed by irrigation with 75% ground & 25 % Hindon water (59.4 and 61.8 q ha^{-1}) while lowest straw yield was recorded with 100% ground water (58.0 and 60.2 q ha^{-1}) during both the years. Application of raw Hindon water resulted in 22.3 & 13.9 (%) increase in straw yield in comparison to 100% ground water.

Among different soil amendments, maximum straw yield was produced in plots treated with Biochar @ 5t ha^{-1}(72.6 and 75.5 q ha^{-1})

Table 4.24 Effect of irrigation treatments and soil amendments on yield (q ha^{-1}) and harvest index (%) of wheat

Treatments	Yield (q ha^{-1})`						Harvest index (%)	
	Grain		Straw		Biological			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water								
Ground water (100%)	35.1	36.9	58.0	60.3	93.2	97.3	37.5	37.8
Ground water (75%) + Hindon water (25%)	39.0	41.0	59.4	61.8	98.5	102.8	38.7	39.2
Ground water (50%)+Hindon water (50%)	40.3	42.3	63.4	65.9	103.7	108.3	38.9	39.4
Hindon water (100%)	43.0	45.2	66.1	68.7	109.1	113.9	39.4	39.7
SE(m)±	**0.79**	**0.80**	**0.60**	**0.62**	**1.32**	**0.81**	**0.74**	**0.76**
C.D (P=0.05)	**2.72**	**2.78**	**2.06**	**2.14**	**4.56**	**2.82**	**2.29**	**2.36**
B. Soil amendments								
Activated Carbon @ 5t/ha	40.7	42.7	63.1	65.6	103.8	108.3	39.1	39.4
Biochar @ 5t/ha	46.1	48.4	72.6	75.5	118.7	123.8	38.8	39.0
Vermicompost @ 5t/ha	43.0	45.2	66.7	69.6	110.0	114.8	39.1	39.3
Control	27.8	29.2	44.2	46.0	72.1	75.3	38.5	38.7
SE(m)±	**1.12**	**1.18**	**1.54**	**1.61**	**1.76**	**1.99**	**0.96**	**1.02**
C.D (P=0.05)	**3.28**	**3.45**	**4.52**	**4.70**	**5.14**	**5.82**	**NS**	**NS**



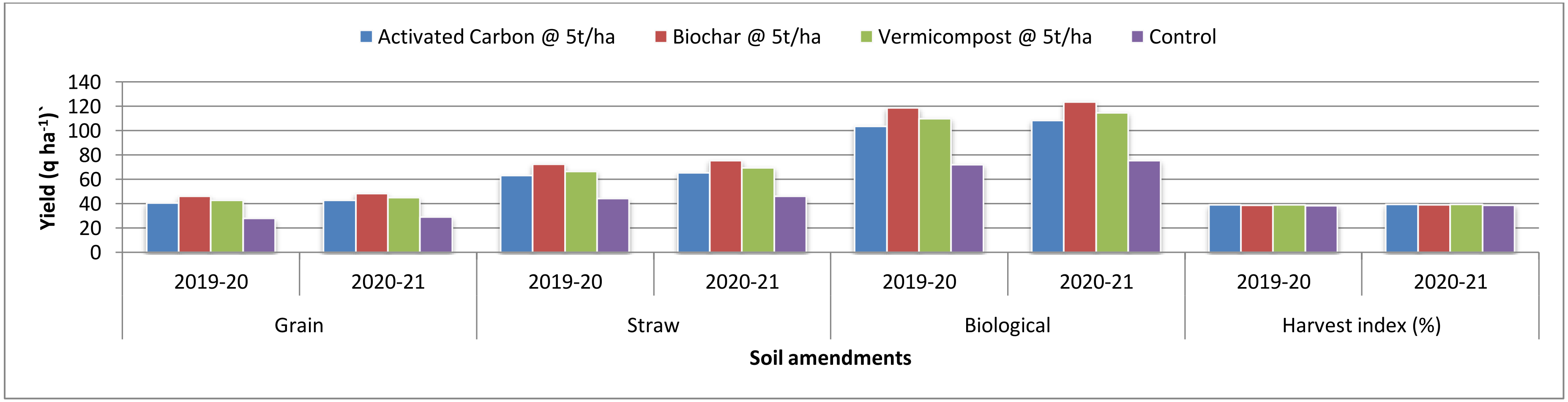


Fig. 4.24 Effect of irrigation treatments and soil amendments on yield (q ha^{-1}) and harvest index (%) of wheat

Which was statistically superior to vermicompost (66.7 & 69.6 q ha^{-1}) and activated carbon @ 5t ha^{-1} (63.1 & 65.6 q ha^{-1}) for both the years. There was about 63.6 & 64.9 (%) increase in straw yield in biochar treatment as compared to control during the years 2019-2020 and 2020-2021, respectively.

4.11.3 Biological yield (q ha^{-1})

Biological yield was significantly affected by different irrigation treatments and soil amendments. No significant interaction was observed between irrigation water and soil amendments (**Appendix-XXXII**).

Perusal of data given in Table 4.24 and illustrated in Fig. 4.24 reveals that 100% Hindon water produced highest biological yield (109.1 and 113.9 q ha^{-1}) which was significantly superior to irrigation with 50 % Hindon + 50% ground water (103.7 and 108.3 q ha^{-1}) followed by irrigation with Hindon & ground water in 1:3 ratio (98.5 and 102.8 q ha^{-1}). Lowest biological yield was recorded with 100% ground water (93.2 & 97.3 q ha^{-1}) during both the years of experiment. Use of raw Hindon water resulted in 17.2 & 16.5 (%) increase in biological yield compared to 100% ground water.

Among the different soil amendments, highest biological yield was produced with the application of Biochar @ 5t ha^{-1}(118.7 and 123.8 q ha^{-1}) which was statistically superior to vermicompost @ 5t ha^{-1}(110.0 and 114.8 q ha^{-1}) and activated carbon (103.8 & 108.3 q ha^{-1}) during both the years. There was about 63.8 & 64.5 (%) increase in biological yield in biochar treatment as compared to control during both the years of experiment.

4.11.4 Harvest index (%)

Irrigation water and soil amendments cause significant variation in harvest index of wheat. (**Appendix-XXXII**). However, the interaction effect of irrigation treatments and soil amendments was non-significant.

The data on harvest index is given in Table 4.24 and depicted in Fig. 4.24 for both the years. Irrigation with raw Hindon water at all the stages resulted in highest value of harvest index (39.4 and 39.7%) which was statistically at par to dilution of raw Hindon water with 50% ground water (38.9 and 39.1 %) and dilution of raw Hindon water with ground water in 1:3 ratio (39.6 and 39.8 %) while lowest harvest index was with 100% ground water (37.5 & 37.8 %) during both the years. Use of 100% Hindon water resulted in 5.03 & 5.02 (%) increase over 100% ground water during both the years respectively.

Among different soil amendments, highest value of harvest index was observed with the application of Biochar @ 5t ha^{-1}(38.8 and 39.0 %) which was statistically at par to vermicompost and activated Carbon @ 5t/ha.

4.12.1 Protein content (%)

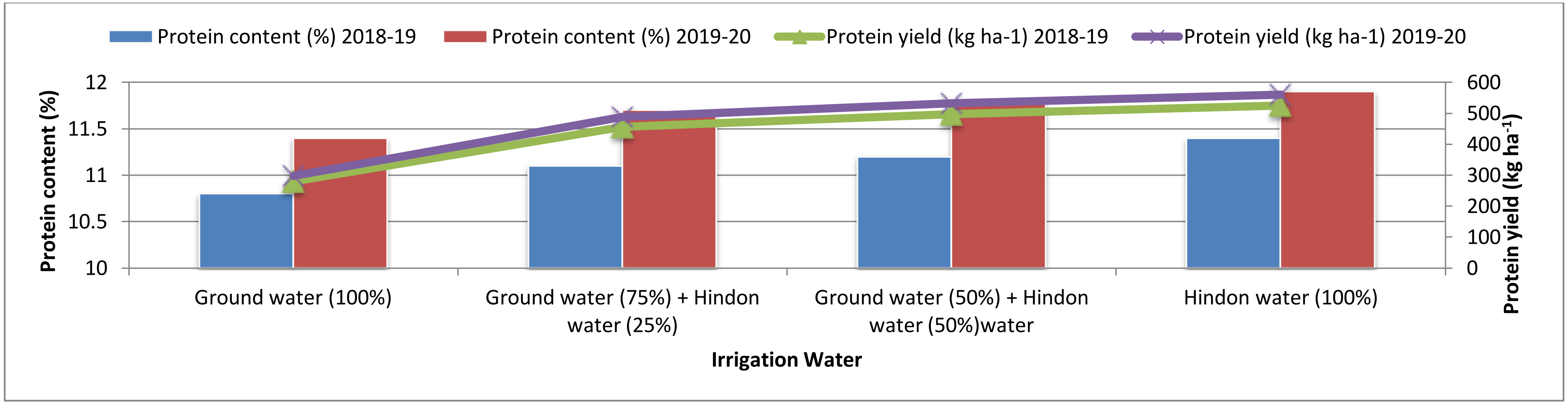
Irrigation water and soil amendments exhibited non significant effect on protein content of wheat. The interaction effect of irrigation treatments and soil amendments was found to be non- significant.

Perusal of data on protein content of wheat given in Table 4.25 and illustrated in Fig. 4.25 reveals that greatest value of protein content was recorded with 100% Hindon water (11.4 & 11.9) followed by 50 % Hindon & 50% ground water (11.2 & 11.8) followed by dilution of raw Hindon water with ground water in 1:3 ratio (11.1 & 11.7) while lowest protein content was recorded with 100% ground water (10.8 & 11.4) during both the years of experiment.

With respect to various soil amendments, biochar @ 5 tonnes ha^{-1} recorded maximum protein content (11.4 & 12.0) followed by vermicompost @ 5 tonnes ha^{-1} (11.3 & 11.9) and activated carbon @ 5 tonnes ha^{-1} (11.2 & 11.7) while lowest was found in control (10.7 & 11.2) during both the years.

Table 4.25 Effect of irrigation treatments and soil amendments on protein content (%) and protein yield (kg ha^{-1}) in grain at harvest

Treatments	Protein content (%)		Protein yield (kg ha^{-1})	
	2018-19	2019-20	2018-19	2019-20
A. Irrigation water				
Ground water (100%)	6.8	6.9	237.3	253.7
Ground water (75%) + Hindon water (25%)	8.0	8.2	312.9	335.9
Ground water (50%) + Hindon water (50%)water	8.5	8.6	341.8	363.6
Hindon water (100%)	8.8	8.9	379.4	404.0
SEm ±	**0.21**	**0.23**	**24.40**	**28.35**
C.D. (P=0.05)	**0.61**	**0.66**	**73.16**	**85.02**
B. Soil amendments				
Activated Carbon @ 5t/ha	8.1	8.3	331.2	354.8
Biochar @ 5t/ha	8.9	9.0	409.4	435.4
Vermicompost @ 5t/ha	8.7	8.8	372.0	396.3
Control	6.9	6.9	191.2	202.5
SEm ±	**0.24**	**0.26**	**26.12**	**30.28**
C.D. (P=0.05)	**0.71**	**0.76**	**78.32**	**90.81**



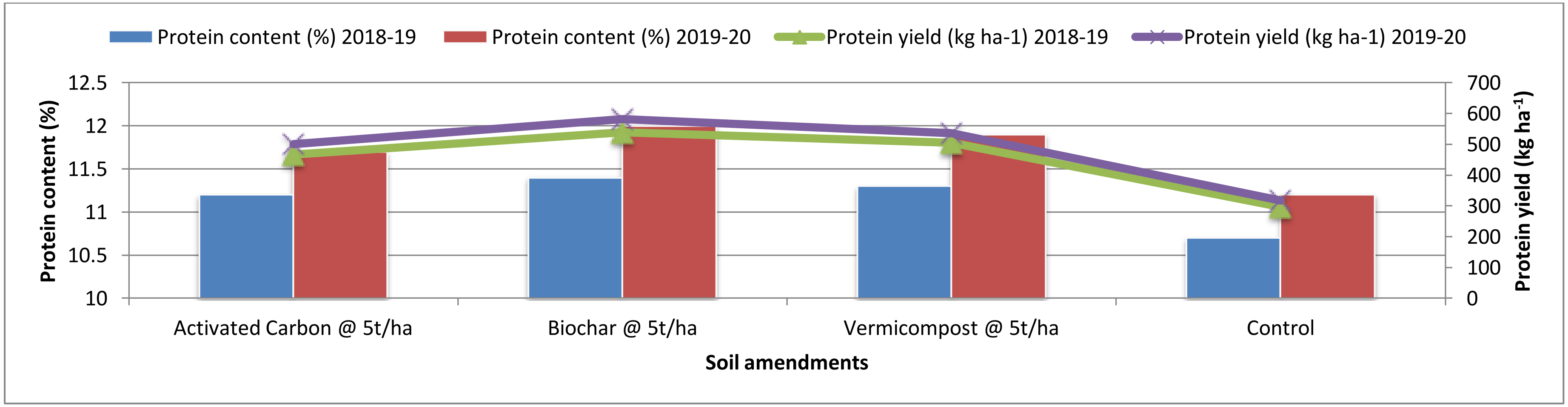


Fig. 4.25 Effect of irrigation treatments and soil amendments on protein content (%) and protein yield (kg ha^{-1}) in wheat

4.12.2 Protein yield (kg ha^{-1})

Irrigation water and soil amendments exhibited significant influence on protein yield of wheat. The interaction effect of irrigation treatments and soil amendments was non- significant.

Highest protein yield in wheat was recorded in plots given 100% Hindon water in comparison to rest of the irrigation treatments. Application of raw Hindon water resulted in highest protein yield (524.8 & 560.7) which was statistically at par to dilution of raw Hindon water with ground water in 1:1 ratio (497.5 & 532.9) and significantly superior to Hindon & ground water in 1:3 ratio (455.5 & 487.8) while lowest protein yield in wheat was recorded in 100% ground water (279.7 & 297.6) during both the years.

Application of biochar @ 5 tonnes ha^{-1} recorded highest protein yield (539.6 & 582.4) which was statistically at par to vermicompost @ 5 tonnes ha^{-1} (505.2 & 582.4) and significantly superior to activated carbon @ 5 tonnes ha^{-1} (467.1 & 501.1) while lowest protein yield was recorded in control (296.9 & 317.0) for both the years of experiment. An increase of about 81.7 and 83.7 (%) in protein yield (kg ha^{-1}) was noted with application of biochar in comparison to control during both the years.

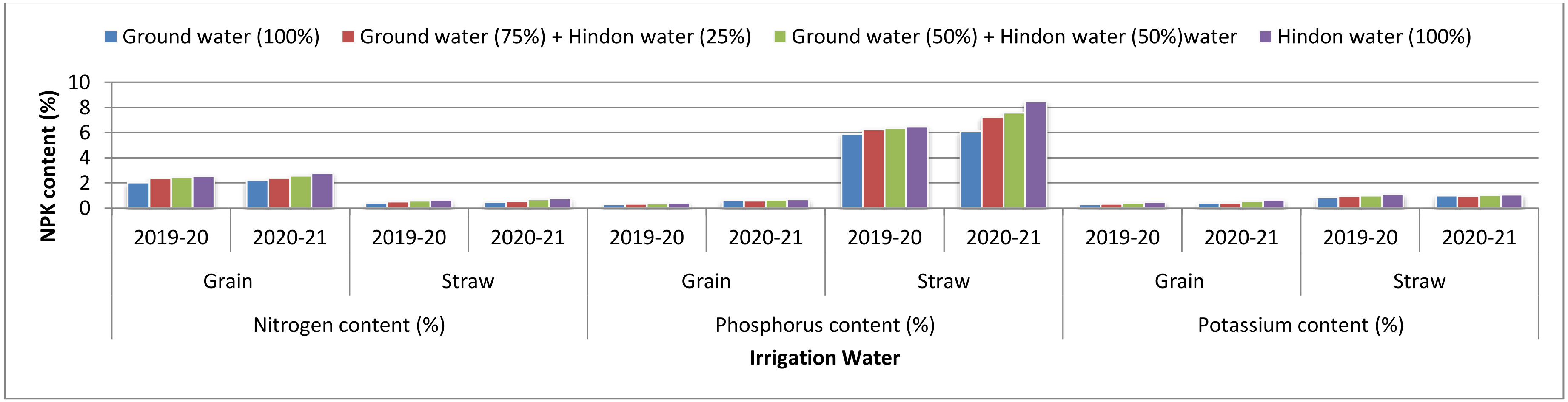
4.13.1 Nitrogen content in grain and straw

Nitrogen content in grain and straw of wheat varied significantly among different irrigation treatments and soil amendments **(Appendix-XXXIII)**. The interaction between irrigation water and soil amendments was non-significant.

The data on nitrogen content in grain and straw of wheat is given in Table 4.26 and illustrated in Fig. 4.26 during both years, 2019-20 and 2020-21 respectively. Irrigation treatment comprising of 100% Hindon water resulted in highest nitrogen content in grain and straw (2.53 & 2.77 and 0.65 & 0.78) of wheat.

Table 4.26 Effect of irrigation treatments and soil amendments on nitrogen, phosphorus and potassium content (%) in wheat

Treatments	Nitrogen content (%)				Phosphorus content (%)				Potassium content (%)			
	Grain		Straw		Grain		Straw		Grain		Straw	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water												
Ground water (100%)	1.18	1.20	0.40	0.49	0.18	0.20	0.08	0.09	0.30	0.40	0.82	0.98
Ground water (75%) + Hindon water (25%)	1.40	1.43	0.51	0.54	0.28	0.31	0.12	0.13	0.34	0.42	0.94	0.96
Ground water (50%) + Hindon water (50%)water	1.48	1.50	0.60	0.68	0.32	0.34	0.13	0.15	0.41	0.56	0.99	1.03
Hindon water (100%)	1.54	1.56	0.65	0.78	0.35	0.37	0.15	0.16	0.47	0.66	1.08	1.07
SE(m)±	**0.01**	**0.02**	**0.003**	**0.004**	**0.002**	**0.003**	**0.001**	**0.002**	**0.003**	**0.003**	**0.009**	**0.010**
C.D (P=0.05)	**0.03**	**0.06**	**0.009**	**0.012**	**0.006**	**0.009**	**0.003**	**0.006**	**0.010**	**0.009**	**0.028**	**0.030**
B. Soil amendments												
Activated Carbon @ 5t/ha	1.42	1.45	0.53	0.58	0.30	0.32	0.13	0.14	0.36	0.46	0.96	1.12
Biochar @ 5t/ha	1.55	1.57	0.67	0.80	0.36	0.38	0.16	0.17	0.48	0.68	1.10	1.28
Vermicompost @ 5t/ha	1.51	1.53	0.62	0.70	0.33	0.34	0.14	0.15	0.43	0.60	1.01	1.21
Control	1.20	1.21	0.41	0.47	0.16	0.17	0.07	0.08	0.28	0.38	0.80	0.91
SE(m)±	**0.02**	**0.02**	**0.004**	**0.005**	**0.003**	**0.003**	**0.002**	**0.003**	**0.002**	**0.002**	**0.006**	**0.007**
C.D (P=0.05)	**0.05**	**0.06**	**0.012**	**0.014**	**0.008**	**0.009**	**0.006**	**0.009**	**0.006**	**0.007**	**0.019**	**0.021**



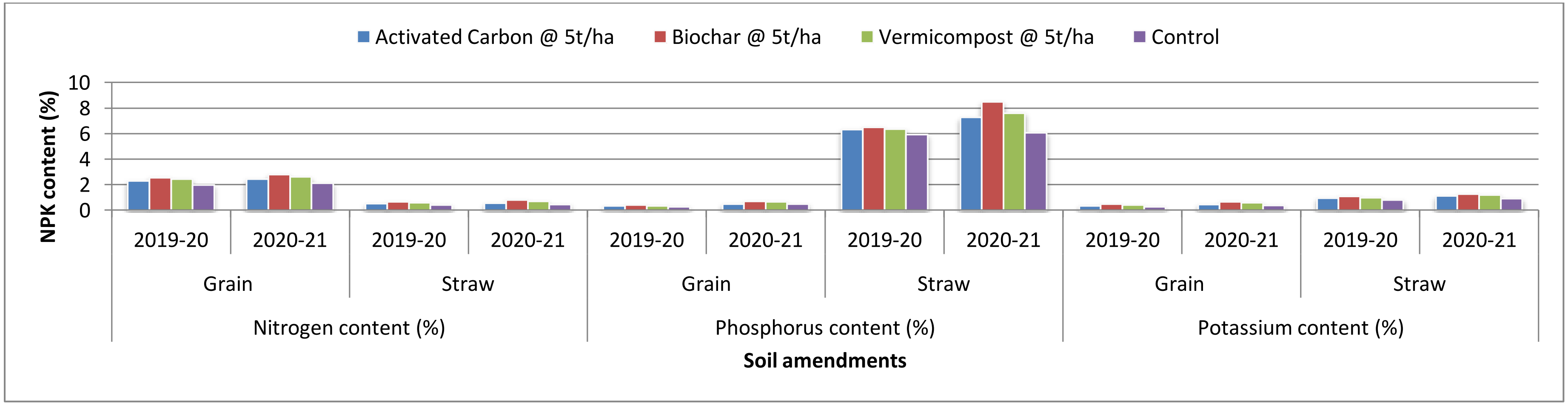


Fig. 4.26 Effect of irrigation treatments and soil amendments on nitrogen, phosphorus and potassium content (%) in wheat

Which was statistically superior to Hindon & ground water in 1:1 ratio (2.43 & 2.55 and 0.60 & 0.68) followed by dilution of raw Hindon water with ground water in 1:3 ratio (2.35 & 2.40 and 0.51 & 0.54) while lowest nitrogen content in grain and straw of wheat (2.03 & 2.20 and 0.40 & 0.49) was recorded with 100% ground water during both the years of experiment. Application of raw Hindon water resulted in 2.4 & 3.1 and 27.4 & 44.4 (%) increase of nitrogen content in grain and straw of wheat as compared to 100% ground water during both the years.

Among different soil amendments, highest nitrogen content in grain and straw of wheat was noted with Biochar @ 5t ha^{-1}(2.5 & 2.8 and 0.67 & 0.80) which was statistically superior to vermicompost (2.45 & 2.62 and 0.62 & 0.70) followed by activated Carbon @ 5t ha-1(2.32 & 2.45 and 0.53 & 0.58). Lowest nitrogen content in grain and straw was recorded in control (2.0 & 2.14 and 0.41 & 0.47) during both the years. An increase of about 7.0 & 7.2 and 63.4 & 70.2 (%) of nitrogen content in grain and straw was noted with application of biochar in comparison to control during both the years of experiment.

4.13.2 Phosphorous content in grain and straw

Irrigation water and soil amendments exhibited significant influence on phosphorous content in grain and straw of wheat **(Appendix XXXIV)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in Table 4.26 and illustrated in Fig. 4.26 reveals that application of 100% Hindon water resulted in greatest content of phosphorous against rest of the irrigation treatments during both the years. Irrigation with raw Hindon water recorded highest phosphorous content in grain and straw of wheat (0.40 & 0.70 and 6.46 & 8.47) which was significantly superior to dilution of raw Hindon water with 50% ground water (0.35 & 0.64 and 6.35 & 7.57) followed by dilution of raw Hindon water with 50% ground water (0.32 & 0.58 and 6.24 & 7.21) while least value of phosphorous content in grain and straw of wheat was recorded with 100% ground water (0.30 & 0.62 and 5.88 & 6.10) during both the years of experiment. Application of raw Hindon water resulted in 25.0 & 20.6 and 3.5 & 17.4 (%) increase in phosphorus content in grain and straw compared to 100% ground water.

Incorporation of different soil amendments resulted in higher phosphorous content in grain and straw of wheat in comparison to control. Among the soil amendments used, highest phosphorous content was registered with the application of Biochar @ 5 tonnes ha^{-1} (0.41 & 0.72 and 6.50 & 8.50) which was significantly superior to application of vermicompost @ 5 tonnes ha^{-1} (0.37 & 0.67 and 6.36 & 7.60) and activated carbon @ 5 tonnes ha^{-1} (0.34 & 0.50 and 6.34 & 7.28) while least phosphorous content in grain and straw of wheat was recorded in control (0.29 & 0.51 and 5.93 & 6.08). An increase of about 41.3 & 41.1 and 9.6 & 20 (%) in phosphorus content of grain and straw was observed with application of biochar over control.

4.13.3 Potassium content in grain and straw

Potassium content in grain and straw of wheat showed significant variation among different irrigation treatments and soil amendments **(Appendix- XXXV)**. However, the interaction between irrigation water and soil amendments was non-significant.

Perusal of data given in Table 4.26 and illustrated in Fig. 4.26 reveals that applying 100% Hindon water resulted in greatest content of potassium against rest of the irrigation treatments. Application of raw Hindon water recorded highest value of potassium content in grain and straw of wheat (0.47 & 0.66 and 1.08 & 1.07) which was statistically at par to irrigation with 50 % Hindon + 50% ground water (0.41 & 0.56 and 0.99 & 1.03) and significantly superior to dilution of raw Hindon water with ground water in 1:3 ratio (0.34 & 0.42 and 0.94 & 0.96) while lowest potassium content in grain and straw of wheat was recorded with 100% ground water (0.30 & 0.40 and 0.82 & 0.98) during both the years of experiment. Usage of 100% Hindon water resulted in 38.2 & 57.1 and 14.8 & 11.4 (%) increase of potassium content in grain and straw as compared to 100% ground water during both the years of experiment.

Application of different soil amendments resulted in higher potassium content in grain and straw of wheat as compared to control. Highest potassium content in grain and straw of wheat was noted with application of biochar @ 5 tonnes ha^{-1} (0.48 & 0.68 and 1.10 & 1.28) which was statistically superior to vermicompost @ 5 tonnes ha^{-1} (0.43 & 0.60 and 1.01 & 1.21) and activated carbon @ 5 tonnes ha^{-1} (0.36 & 0.46 and 0.96 & 1.12) while lowest was found in control (0.28 & 0.38 and 0.80 & 0.91) during both years. An increase of about 71.4 & 78.9 and 37.5 & 40.6 (%) of potassium content in grain and straw was recorded with the application of biochar in comparison to control during both the years of experiment.

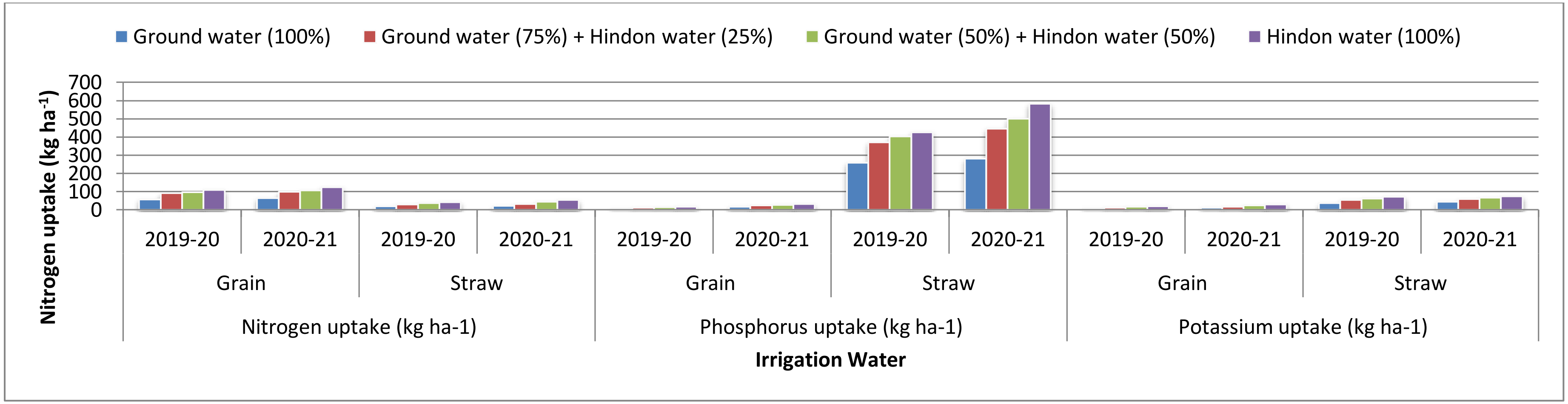
4.13.4 Nitrogen uptake in grain and straw

Nitrogen uptake in grain and straw of wheat varied significantly among different irrigation water and soil amendments (Appendix- XXXIII). However, the interaction between irrigation treatments and soil amendments was non-significant.

The data on nitrogen uptake in grain and straw is given in Table 4.27 and illustrated in Fig. 4.27 respectively. Irrigation with 100% Hindon water resulted in maximum nitrogen uptake in grain and straw of wheat (108.8 & 125.18 and 42.9 & 53.6) which was statistically superior to dilution of raw Hindon water with ground water in 1:1 ratio (97.9 & 107.94 and 38.0 & 44.8) followed by irrigation with 75% ground + 25 % Hindon water (91.8 & 98.4 and 30.3 & 33.3) while minimum nitrogen uptake in grain and straw of wheat was recorded with 100% ground water (56.4 & 64.2 and 18.6 & 22.5) during both the years of experiment.

Table 4.27 Effect of irrigation treatments and soil amendments on nitrogen, phosphorus and potassium uptake (kg ha^{-1}) in wheat

Treatments	Nitrogen uptake (kg ha^{-1})				Phosphorus uptake (kg ha^{-1})				Potassium uptake (kg ha^{-1})			
	Grain		Straw		Grain		Straw		Grain		Straw	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Underground + Hindon Mixtures												
Ground water (100%)	41.42	44.28	23.20	29.55	6.32	7.38	4.64	5.43	10.53	14.76	47.56	59.09
Ground water (75%) + Hindon water (25%)	54.60	58.63	30.29	33.37	10.92	12.71	7.13	8.03	13.26	17.22	55.84	59.33
Ground water (50%) + Hindon water (50%)	59.64	63.45	38.04	44.81	12.90	14.38	8.24	9.89	16.52	23.69	62.77	67.88
Hindon water (100%)	66.22	70.51	42.97	53.59	15.05	16.72	9.92	10.99	20.21	29.83	71.39	73.51
SE(m)±	**1.18**	**1.24**	**0.76**	**0.90**	**0.10**	**0.12**	**0.07**	**0.08**	**0.47**	**0.67**	**1.18**	**1.34**
C.D (P=0.05)	**3.52**	**3.70**	**2.27**	**2.71**	**0.30**	**0.35**	**0.20**	**0.23**	**1.42**	**2.01**	**3.56**	**3.98**
B. Soil amendments												
Activated Carbon @ 5t/ha	57.79	61.92	33.44	38.05	12.21	13.66	8.20	9.18	14.65	19.64	60.58	73.47
Biochar @ 5t/ha	71.46	75.99	48.64	60.40	16.60	18.39	11.62	12.84	22.13	32.91	79.86	96.64
Vermicompost @ 5t/ha	64.93	69.16	41.35	48.72	14.19	15.37	9.34	10.44	18.49	27.12	67.37	84.22
Control	33.36	35.33	18.12	21.62	4.45	4.96	3.09	3.68	7.78	11.10	35.36	41.86
SE(m)±	**1.25**	**1.28**	**0.85**	**0.97**	**0.12**	**0.13**	**0.08**	**0.10**	**0.84**	**0.96**	**1.68**	**1.92**
C.D (P=0.05)	**3.73**	**3.82**	**2.53**	**2.87**	**0.24**	**0.37**	**0.23**	**0.30**	**2.48**	**2.86**	**5.01**	**5.72**



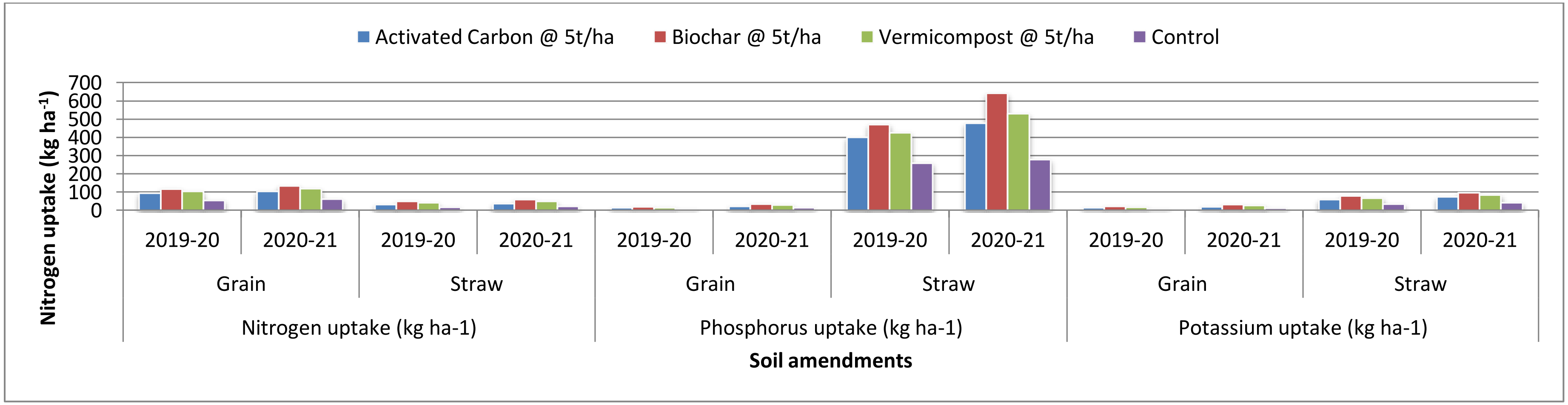


Fig. 4.27 Effect of irrigation treatments and soil amendments on nitrogen, phosphorus and potassium uptake (kg ha^{-1}) in wheat

In comparison to control, application of Biochar @ 5 tonnes ha^{-1} (117.9 & 135.46 and 48.6 & 60.3) resulted in maximum nitrogen uptake in grain and straw of wheat which was significantly superior to vermicompost @ 5 tonnes ha^{-1} (105.4 & 118.3 and 41.5 & 48.7) and activated carbon (94.3 & 104.64 and 33.4 & 38.0) during both the years, respectively. Lowest nitrogen uptake in grain and straw (55.6 & 62.3 and 17.8 & 21.6) was recorded in control during both the years.

4.13.5 Phosphorous uptake in grain and straw

Irrigation water and soil amendments significantly influenced the phosphorous uptake in grain and straw of wheat **(Appendix XXXIV)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in Table 4.27 and illustrated in Fig. 4.27 reveals that maximum value of phosphorous uptake in grain and straw of wheat was noted with the application of 100% Hindon water in comparison to rest of the irrigation treatments. Application of raw Hindon water resulted in maximum phosphorous uptake in grain and straw (17.2 & 31.6 and 426.8 & 582) which was significantly superior to Hindon & ground water in 1:1 ratio (14.1 & 27 and 402.8 & 499.4) followed by irrigation with Hindon & ground water in 1:3 ratio (12.5 & 23.80 and 370.9 & 445.6) while lowest phosphorous uptake in grain and straw of wheat was recorded with 100% ground water (8.3 & 18.1, 260.1 & 280.9) during both the years of experiment. Application of 100% Hindon water resulted in 37.7 & 32.9 , 15.0 & 30.6 (%) increase in phosphorus uptake in grain and straw of wheat in comparison to 100 % ground water during both the years of experiment.

With regard to different soil amendments, application of biochar@5 tonnes ha^{-1} recorded significantly higher phosphorous uptake in grain and straw of wheat (18.8 & 34.8 and 471.8 & 641.6) which was statistically superior to vermicompost @ 5 tonnes ha^{-1} (15.9 & 30.2 and 426 & 529.4) and activated carbon(13.8 & 21.3 and 399.9 & 477.7). Lowest phosphorous uptake in grain and straw of wheat was recorded in control (8.0 & 14.9 and 258.6 & 278.5).

4.13.5 Potassium uptake in grain and straw

Potassium uptake in grain and straw of wheat was significantly affected by irrigation water and soil amendments **(Appendix XXXV)**. The interaction between irrigation treatments and soil amendments was non-significant.

Perusal of data given in Table 4.27 and illustrated in Fig. 4.27 reveals that maximum potassium uptake in grain and straw of wheat (20.2 & 29.8 and 71.3 & 73.5) was recorded with 100% Hindon water which was significantly superior to dilution of raw Hindon water with 50% ground water (16.5 & 23.7, 62.8 & 67.9) followed by irrigation with 75% ground + 25 % Hindon water (13.2 & 17.2, 55.8 & 59.3) while least value of potassium uptake in grain and straw of wheat was recorded with 100% ground (8.3 & 11.6 and 36.2 & 45.1) water during both the years of experiment.

Among different soil amendments, biochar @ 5 tonnes ha^{-1} (22.1 & 32.9 and 79.8 & 96.6) recorded maximum potassium uptake in grain and straw of wheat which was significantly superior to soil incorporation of vermicompost @ 5 tonnes ha^{-1}(18.5 & 27.1 and 67.6 & 84.3) and activated carbon @ 5 tonnes ha^{-1} (14.6 & 19.6 and 60.5 & 73.4). Lowest potassium content in grain and straw was recorded in control (9.8 & 14.0, 46.4 & 54.8) during both the years of experiment.

4.14.1 Arsenic content (ppm)

Irrigation water and soil amendments exhibited significant influence on arsenic content in grain and straw of wheat during both the years **(Appendix-XXXVI)**. However, the interaction between irrigation treatments and soil amendments was non-significant.

Table 4.28 Effect of irrigation treatments and soil amendments on arsenic content (ppm), uptake and total uptake (g ha^{-1}) in wheat

Treatments	Arsenic content (ppm)				Arsenic uptake (g ha^{-1})				Total uptake (g ha^{-1})	
	Grain		Straw		Grain		Straw			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
(A) Irrigation water										
Ground water (100%)	0.001	0.001	0.020	0.019	0.0035	0.0037	0.1160	0.1146	0.1195	0.1183
Ground water (75%) + Hindon water (25%)	0.004	0.003	0.032	0.024	0.0156	0.0123	0.1901	0.1483	0.2057	0.1606
Ground water (50%) + Hindon water (50%)	0.006	0.005	0.038	0.030	0.0242	0.0212	0.2409	0.1977	0.2651	0.2189
Hindon water (100%)	0.010	0.008	0.048	0.039	0.0430	0.0362	0.3173	0.2679	0.3603	0.3041
SE(m)±	***0.0002***	***0.0003***	***0.005***	***0.004***	***0.006***	***0.005***	***0.009***	***0.008***	***0.014***	***0.012***
C.D (P=0.05)	***0.0006***	***0.0009***	***0.015***	***0.012***	***0.018***	***0.015***	***0.026***	***0.022***	***0.041***	***0.034***
(B) Soil amendments										
Activated Carbon @ 5t/ha	0.006	0.004	0.032	0.025	0.0244	0.0171	0.2019	0.1640	0.2263	0.1811
Biochar @ 5t/ha	0.001	0.001	0.022	0.020	0.0046	0.0048	0.1597	0.1510	0.1643	0.1558
Vermicompost @ 5t/ha	0.008	0.006	0.041	0.032	0.0344	0.0271	0.2735	0.2227	0.3079	0.2498
Control	0.007	0.008	0.038	0.046	0.0195	0.0234	0.1680	0.2116	0.1874	0.2350
SE(m)±	***0.0001***	***0.0002***	***0.004***	***0.005***	***0.006***	***0.007***	***0.008***	***0.009***	***0.015***	***0.013***
C.D (P=0.05)	***0.0003***	***0.0005***	***0.010***	***0.013***	***0.018***	***0.021***	***0.023***	***0.025***	***0.044***	***0.037***

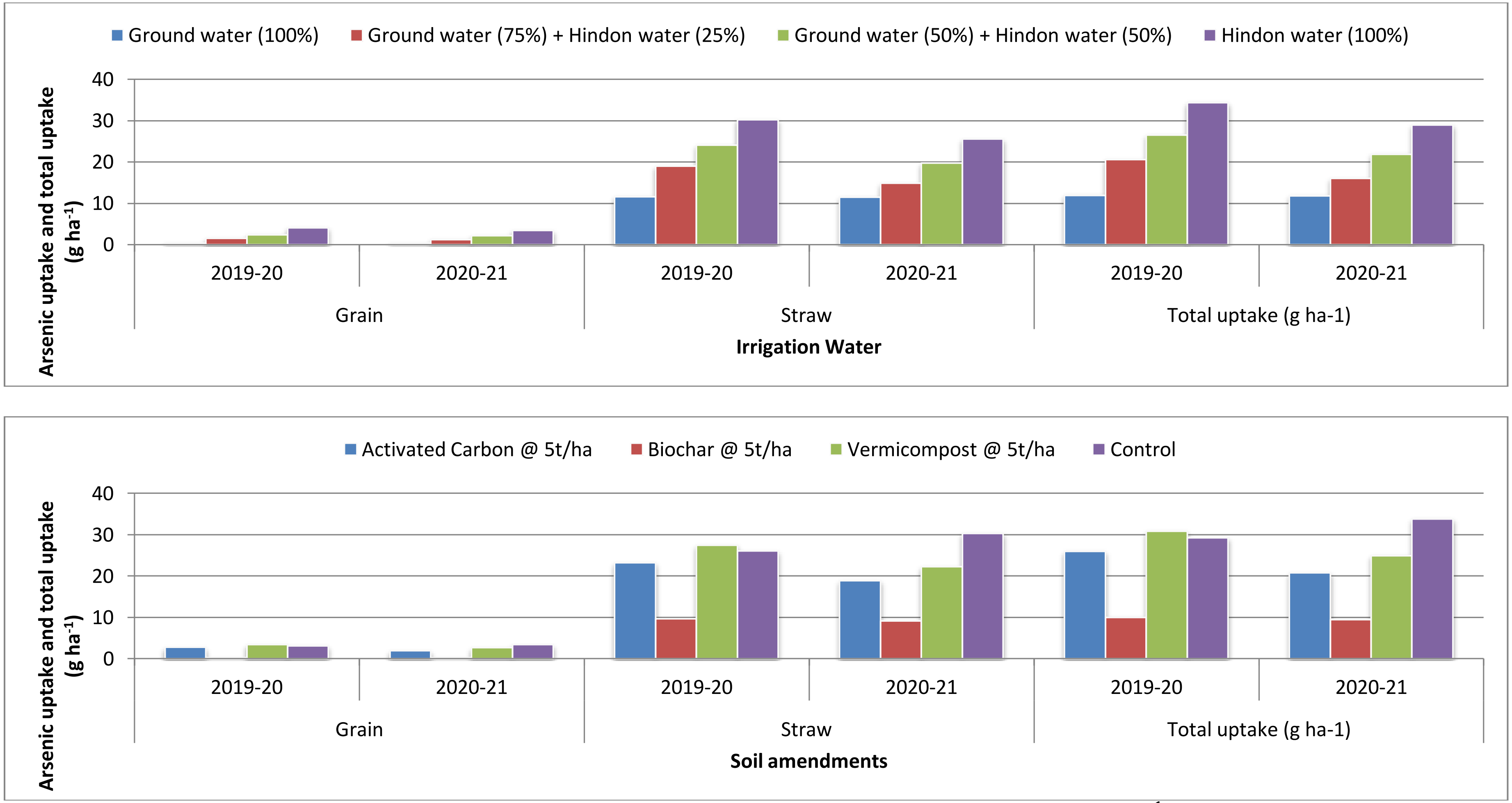


Fig. 4.28 Effect of irrigation treatments and soil amendments on Arsenic uptake and total uptake (g ha^{-1}) in wheat

The data pertaining to arsenic content in grain and straw of wheat is presented in Table 4.28 and depicted in Fig 4.28. Arsenic concentration in wheat crop increased significantly with increased proportion of Hindon water in applied irrigation. Highest arsenic content in grain (0.010 and 0.008 ppm) and straw (0.048 and 0.039) was recorded with 100% Hindon water followed by dilution of raw Hindon water with 50% ground water (0.03 & 0.02 and 0.354 & 0.306) and dilution of raw Hindon water with 75% ground water (0.02 & 0.01 and 0.301 & 0.265) during both the years while lowest arsenic content in grain (0.001 and 0.001) and straw (0.020 and 0.019) was recorded with 100% ground water.

Among soil amendments**,** lowest arsenic content in grain as well as straw was found with the application of Biochar @ 5t ha^{-1} during both years. Maximum arsenic content (0.008 and 0.007 ppm) in grain and straw (0.046 and 0.038 ppm) was recorded in control followed vermicompost @ 5t ha^{-1} during both years while lowest arsenic content in grain (0.001 and 0.001 ppm) and straw (0.022 and 0.020 ppm) was noted with application of Biochar @ 5t ha^{-1} treatment. The cadmium concentration in wheat grain comprising Hindon water alone or in mixture was found to be above permissible limit of 0.20 mg kg^{-1}.

4.14.2 Arsenic uptake (g ha^{-1})

Irrigation water and soil amendments exhibited significant influence on arsenic uptake in grain and straw of wheat **(Appendix-XXXVI)**. However, the interaction between irrigation water and soil amendments was non- significant.

The data on arsenic uptake in grain and straw of wheat is given in table 4.28 and illustrated in Fig. 4.28. Irrigation treatments comprising of Hindon water alone or in mixtures resulted in significantly higher uptake of arsenic in grain & straw in comparison to 100% ground water. Maximum arsenic uptake in grain (4.07 and 3.42 g ha^{-1}) and straw (30.28 & 25.59 g ha^{-1}) was recorded with 100% Hindon water which was significantly superior to rest of the treatments during both the years while lowest arsenic uptake in grain (0.35 & 0.37 g ha^{-1}) and (11.60 & 11.46 g ha^{-1}) straw was noted with 100% ground water at all the stages.

In comparison to soil amendments, control plots recorded significantly higher arsenic uptake in grain & straw of wheat during both the years. Maximum arsenic uptake by grain (3.44 & 3.16 g ha^{-1}) and straw (30.40 & 26.11 g ha^{-1}) was recorded in control plots, which was statistically at par to vermicompost @ 5t ha-1during both years while lowest arsenic uptake in grain (0.28 & 0.29 g ha^{-1}) and straw (9.73 & 9.21 g ha^{-1}) was recorded in Biochar treatment.

4.14.3 Cadmium content (ppm)

Irrigation water and soil amendments exhibited significant influence on cadmium content in grain and straw of wheat **(Appendix-XXXVII)**. However, their interaction was non- significant.

Cadmium is a very toxic metal and also known as carcinogens. High level of cadmium causes lung damage, kidney disease, diarrhea, vomiting and breathing problems. The result of this experiment indicated that cadmium content in wheat grains was below the permissible limit of 0.2 mg kg^{-1} for both the years except in treatments T_4 and T_3 for the first year. Perusal of data given in Table 4.29 and illustrated in Fig. 4.29 reveals that highest concentration of cadmium in grain and straw (0.05 and 0.02, 0.405 and 0.346) was recorded with the application of raw Hindon water followed by irrigation with 50 % Hindon + 50% ground water (0.03 & 0.02 and 0.354 & 0.306) followed by dilution of raw Hindon water with 75% ground water (0.02 & 0.01 and 0.301 & 0.265) during both the years while least value of cadmium content in grain and straw (0.001 and 0.000, 0.145 and 0.130) was noted with 100% ground water during both the years of experiment.

Table 4.29 Effect of irrigation treatments and soil amendments on cadmium content (ppm), uptake and total uptake (g ha^{-1}) in wheat

Treatments	Cadmium content (ppm)				Cadmium uptake (g ha^{-1})				Total uptake (g ha^{-1})	
	Grain		Straw		Grain		Straw			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water										
Ground water (100%)	0.01	0.00	0.145	0.130	0.035	0.000	0.84	0.78	0.88	0.78
Ground water (75%) + Hindon water (25%)	0.02	0.01	0.301	0.265	0.078	0.041	1.79	1.64	1.87	1.68
Ground water (50%) + Hindon water (50%)	0.03	0.02	0.354	0.306	0.121	0.085	2.24	2.02	2.37	2.10
Hindon water (100%)	0.05	0.02	0.405	0.346	0.215	0.090	2.68	2.38	2.89	2.47
SE(m)±	**0.002**	**0.003**	**0.004**	**0.005**	**0.002**	**0.001**	**0.02**	**0.01**	**0.02**	**0.03**
C.D (P=0.05)	**0.006**	**0.009**	**0.012**	**0.015**	**0.006**	**0.003**	**0.05**	**0.03**	**0.06**	**0.08**
B. Soil amendments										
Activated Carbon @ 5t/ha	0.02	0.01	0.310	0.270	0.081	0.043	1.96	1.77	2.04	1.81
Biochar @ 5t/ha	0.00	0.00	0.149	0.134	0.000	0.000	1.08	1.01	1.08	1.01
Vermicompost @ 5t/ha	0.03	0.02	0.338	0.312	0.129	0.090	2.25	2.17	2.38	2.26
Control	0.04	0.04	0.360	0.401	0.111	0.117	1.59	1.84	1.70	1.96
SE(m)±	**0.001**	**0.002**	**0.003**	**0.004**	**0.003**	**0.002**	**0.03**	**0.02**	**0.03**	**0.04**
C.D (P=0.05)	**0.003**	**0.005**	**0.009**	**0.010**	**0.009**	**0.006**	**0.09**	**0.06**	**0.09**	**0.13**

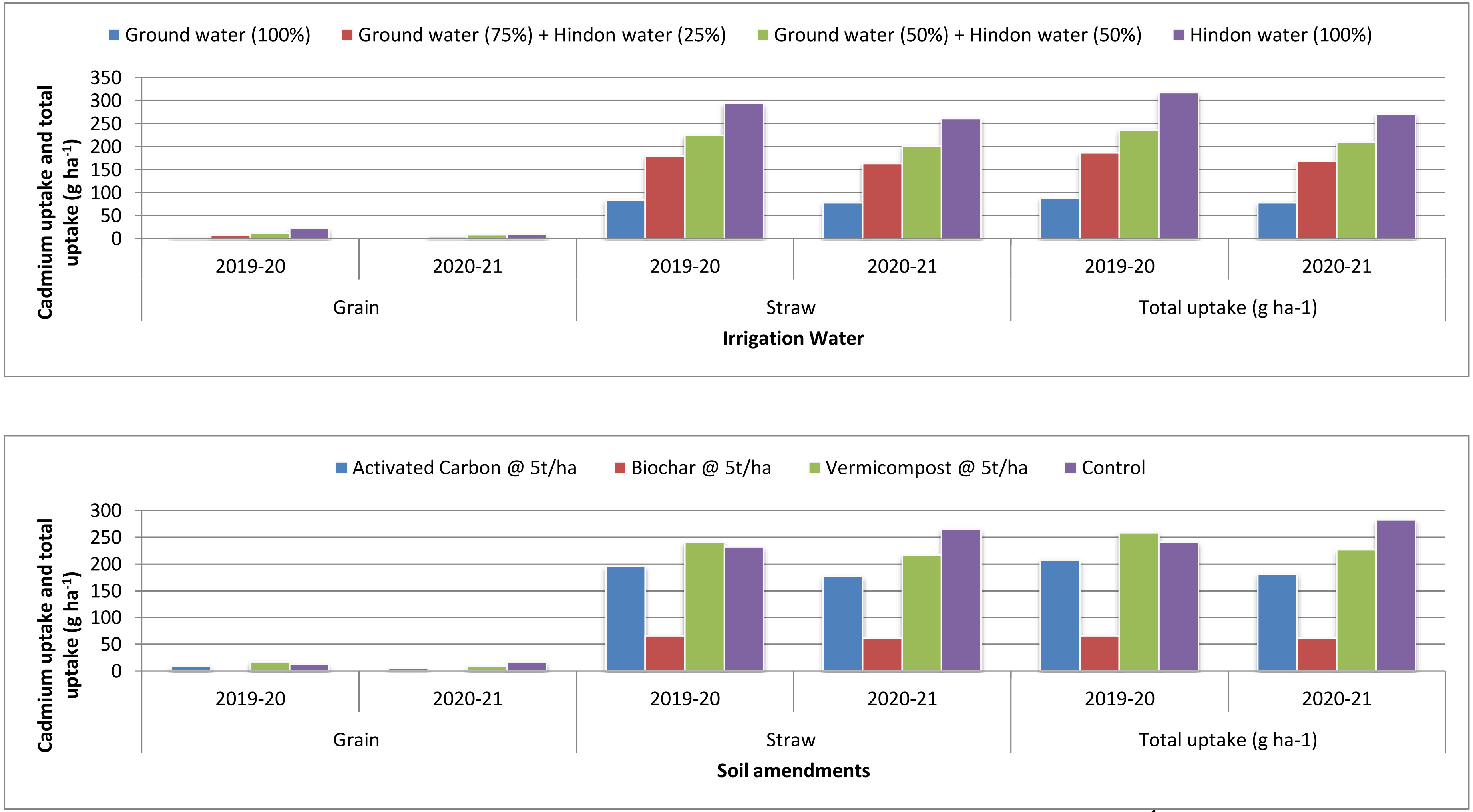


Fig. 4.29 Effect of irrigation treatments and soil amendments on Cadmium uptake and total uptake (g ha^{-1}) in wheat

Application of different soil amendments resulted in significantly lower cadmium uptake in grain and straw of wheat as compared to control during both the years. Maximum cadmium content in grain (0.04 and 0.04 ppm) and straw (0.338 and 0.401 ppm) was recorded in control followed by vermicompost @ 5t ha^{-1} (0.03 & 0.02 and 0.360 & 0.270) and activated carbon (0.02 & 0.01 and 0.310 and 0.270) during both years while lowest cadmium content in grain (0.000 and 0.000 ppm) and straw (0.149 and 0.134 ppm) was noted in Biochar treatment for both the years. The cadmium concentration in wheat grain under different irrigation treatments comprising Hindon water alone or in mixture was found to be above permissible limit of 0.20 mg kg^{-1}.

4.14.4 Cadmium uptake (g ha^{-1})

Significant variation was observed in cadmium uptake in grain and straw of wheat under different irrigation water and soil amendments **(Appendix-XXXVII)**. However, interaction between irrigation treatments and soil amendments was non-significant.

Perusal of data given in Table 4.29 and illustrated in Fig. 4.29 reveals that irrigation treatments comprising of Hindon water alone or in proportion with ground water resulted in significantly higher uptake of cadmium in grain and straw compared to 100% ground water. Highest cadmium uptake in grain (23.04 and 9.68 g ha^{-1}) and straw (293.99 and 261.20 g ha^{-1}) was recorded with 100% Hindon water which was significantly higher than dilution of raw Hindon water with 50% ground water (12.09 & 8.47 and 224.58 & 201.9) followed by irrigation with Hindon & ground water in 1:3 ratio (7.81 & 4.10 and 178.91 & 163.80) while lowest cadmium uptake in grain (3.52 and 0.00 g ha^{-1}) and straw (84.11 and 78.42 g ha^{-1}) was recorded with 100% ground water during both the years.

Among soil amendments, significantly lower cadmium uptake by grain and straw of wheat was recorded with the application of soil amendments in comparison to control during both the years. Maximum cadmium uptake in grain (9.04 and 17.22 g ha^{-1}) and straw (232.27 and 264.98 g ha^{-1}) was recorded in control followed by application of vermicompost @ 5t ha^{-1} (17.21 & 9.04 and 241.16 & 217.37) and activated carbon (12.20 & 4.27 and 195.58 & 177.17) while lowest cadmium uptake by grain (0.00 and 0.00 g ha^{-1}) and straw (65.92 and 61.71g ha^{-1}) was recorded in Biochar treatment (5t ha^{-1}) for both the years.

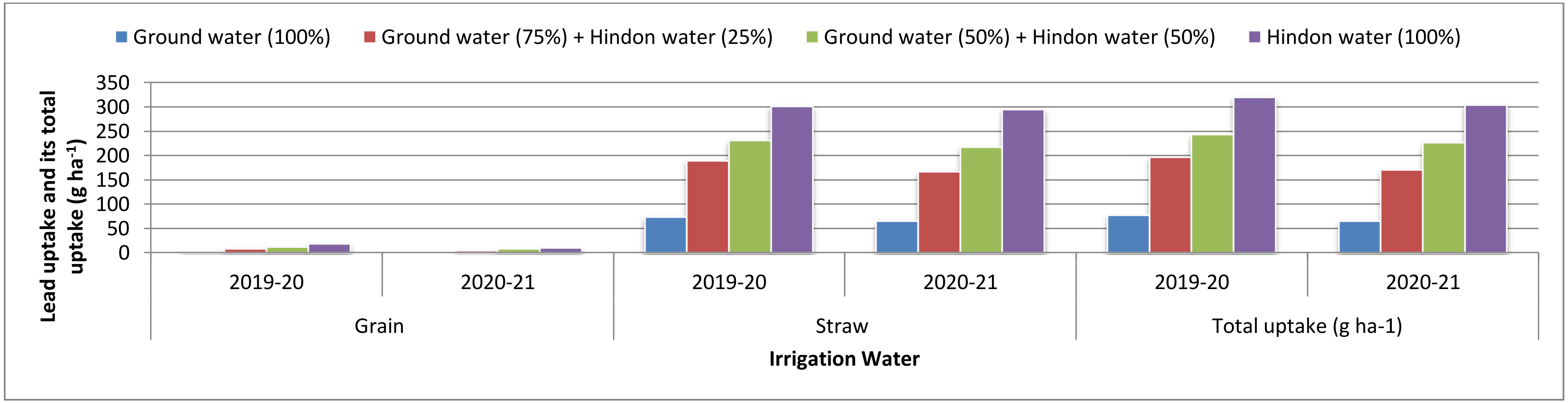
4.14.5 Lead content (ppm)

Different irrigation treatments and soil amendments significantly influenced the lead content in grain and straw of wheat during both the years **(Appendix-XXXVIII)**. However, the interaction between irrigation water and soil amendments was non-significant.

The data on lead content in grain and straw of wheat is given in Table 4.30 and illustrated in Fig. 4.30 reveals that irrigation treatments comprising of Hindon water alone or in proportion with ground water, resulted in significantly higher lead content in grain & straw compared to 100% ground water. Maximum lead content in grain (0.04 and 0.02 ppm) and straw (0.415 and 0.390) was recorded with 100% Hindon water followed by Hindon & ground water in 1:1 ratio (0.03 & 0.02 and 0.365 & 0.330) and irrigation with Hindon & ground water in 1:3 ratio (0.02 & 0.01 and 0.127 & 0.108) during both the years. Lowest lead content in grain (0.001 and 0.000) and straw (0.127 and 0.108) was noted with 100% ground water during both the years. The lead content in wheat grain was found below the permissible limit of 0.30 mg kg^{-1} for both years except for 100 % Hindon water (0.03ppm) and 50 % Hindon + 50% ground water (0.04 ppm) for first year of experiment

Table 4.30 Effect of irrigation treatments and soil amendments on lead content (ppm), uptake and its total uptake (g ha^{-1}) of wheat

Treatments	Lead content (ppm)				Lead uptake (g ha^{-1})				Total uptake (g ha^{-1})	
	Grain		Straw		Grain		Straw			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water										
Ground water (100%)	0.01	0.00	0.127	0.108	0.035	0.000	0.74	0.65	0.77	0.65
Ground water (75%) + Hindon water (25%)	0.02	0.01	0.318	0.270	0.078	0.041	1.89	1.67	1.97	1.71
Ground water (50%) + Hindon water (50%)	0.03	0.02	0.365	0.330	0.121	0.085	2.31	2.17	2.44	2.26
Hindon water (100%)	0.04	0.02	0.415	0.390	0.172	0.090	2.74	2.68	2.92	2.77
SE(m)±	**0.001**	**0.002**	**0.004**	**0.005**	**0.002**	**0.001**	**0.02**	**0.01**	**0.02**	**0.03**
C.D (P=0.05)	**0.003**	**0.006**	**0.012**	**0.015**	**0.006**	**0.003**	**0.05**	**0.03**	**0.06**	**0.08**
B. Soil amendments										
Activated Carbon @ 5t/ha	0.02	0.01	0.325	0.278	0.081	0.043	2.05	1.82	2.13	1.87
Biochar @ 5t/ha	0.00	0.00	0.125	0.105	0.000	0.000	0.91	0.79	0.91	0.79
Vermicompost @ 5t/ha	0.03	0.02	0.380	0.336	0.129	0.090	2.53	2.34	2.66	2.43
Control	0.02	0.04	0.384	0.410	0.055	0.117	1.70	1.89	1.75	2.00
SE(m)±	**0.001**	**0.002**	**0.003**	**0.004**	**0.003**	**0.002**	**0.03**	**0.02**	**0.03**	**0.04**
C.D (P=0.05)	**0.002**	**0.005**	**0.009**	**0.012**	**0.009**	**0.006**	**0.09**	**0.06**	**0.09**	**0.13**



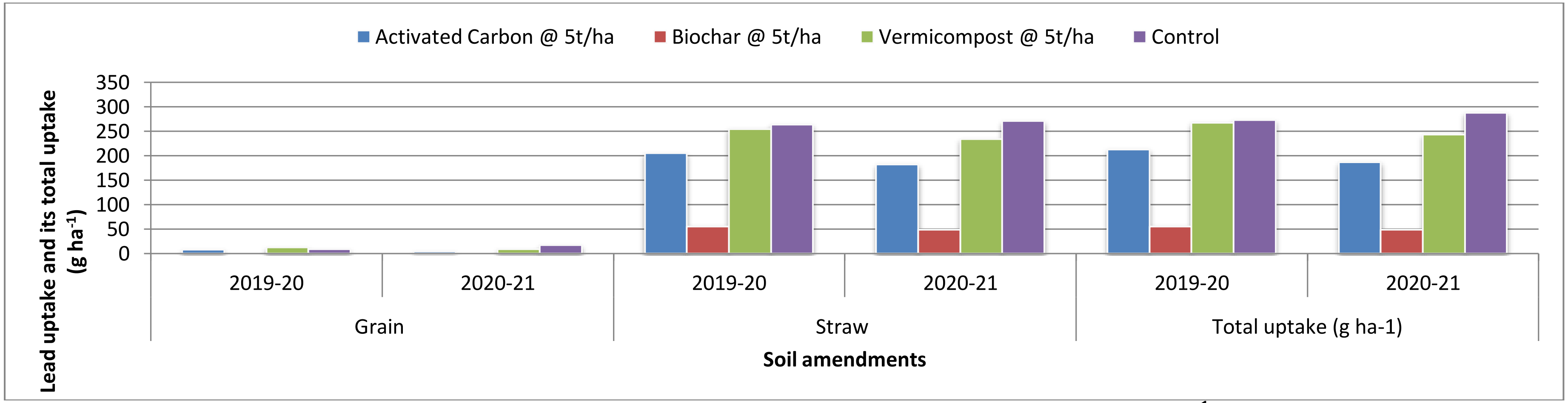


Fig. 4.30 Effect of irrigation treatments and soil amendments on Lead uptake and its total uptake (g ha^{-1}) of wheat

Application of soil amendments resulted in significantly lower lead content in grain and straw of wheat compared to control. Maximum lead content in grain (0.02 and 0.04 ppm) and straw (0.384 and 0.410 ppm) was recorded in control followed by vermicompost @ 5t ha^{-1} (0.03 & 0.02 and 0.38 & 0.33) during both years while lowest lead content in grain (0.00 and 0.00 ppm) and straw (0.105 and 0.125 ppm) was recorded in biochar treatment @ 5t ha^{-1} during both the years. The lead content in wheat grain was found below the permissible limit of 0.30 mg kg $^{-1}$ for both years except in control plots for both the years of experiment.

4.14.6 Lead uptake (g ha^{-1})

Significant variation was observed under different irrigation treatments and soil amendments on lead uptake in grain and straw of wheat **(Appendix-XXXVII)**. However, the interaction between irrigation water and soil amendments was non-significant.

The data pertaining to lead uptake in grain and straw of wheat is presented in Table 4.30 and depicted in Fig 4.30 reveals that irrigation treatments comprising of Hindon water alone or in proportion with ground water resulted in significantly higher uptake of lead in grain and straw compared to 100% ground water. Highest lead uptake in grain (18.43 and 9.68 g ha^{-1}) and straw (301.25 and 294.41 g ha^{-1}) of wheat was recorded with 100% Hindon water which was significantly higher than irrigation with 50 % Hindon + 50% ground water (12.09 & 8.47 and 231.56 & 217.73) followed by irrigation with 75% ground & 25 % Hindon water (7.81 & 4.10 and 189.02 & 166.89) while lowest lead uptake in grain (3.5 and 0.00 g ha^{-1}) and straw (73.6 and 65.1 g ha^{-1}) was recorded with 100% ground water during both years respectively.

Application of different soil amendments resulted in lower lead uptake in grain and straw of wheat as compared to control during both the years. Maximum lead uptake in grain (9.02 and 17.22 g ha^{-1}) and straw (263.88 and 270.93 g ha^{-1}) of wheat was recorded in control followed by vermicompost @ 5t ha^{-1} (12.91 & 9.04 and 254.56 & 234.09) and activated carbon @ 5t ha^{-1} (8.14 & 4.27 and 205.04 & 182.42) while lowest lead uptake in grain (0.00 and 0.00 g ha^{-1}) and straw (55.30 and 48.35 g ha^{-1}) of wheat was noted in biochar treatment (5t ha^{-1}).

4.14.7 Nickel content (ppm)

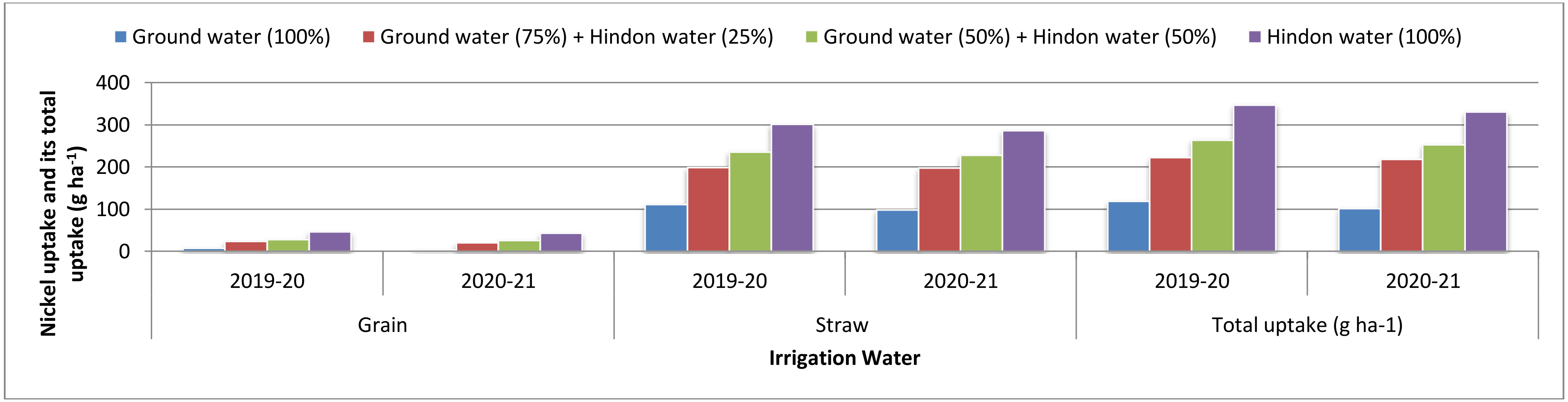
Irrigation water and soil amendments exhibited significant influence on nickel content in grain and straw of wheat during both years **(Appendix-XXXIX).** However, the interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in Table 4.31 and illustrated in Fig. 4.31 reveals that nickel concentration in wheat crop increased significantly with increased proportion of Hindon water in applied irrigation. Highest nickel content in grain (0.10 and 0.09 ppm) and straw (0.415 and 0.380) was recorded with irrigation treatment of 100% Hindon water which was significantly higher than dilution of raw Hindon water with 50% ground water (0.07 & 0.06 and 0.372 & 0.345) and irrigation with 75% ground & 25 % Hindon water (0.06 & 0.05 and 0.335 & 0.320) during both the years. Lowest nickel content in grain (0.02 and 0.01) and straw (0.192 and 0.163) was noted with 100% ground water during both years of experiment. Regardless of irrigation treatment, the nickel concentration in wheat grain was within the permissible limit of 67.90 mg kg^{-1} for both years of experiment.

Application of different soil amendments resulted in lower nickel content in grain and straw of wheat in comparison to control. Maximum nickel content in grain (0.08 and 0.09 ppm) and straw (0.373 and 0.410 ppm) was recorded in control followed by vermicompost @ 5t ha^{-1} (0.08 & 0.05 and 0.378 & 0.351) and activated carbon @ 5t ha^{-1} (0.07& 0.06 and 0.341 & 0.326) while minimum nickel content in grain (0.02 and 0.02 ppm) and straw (0.195 and 0.160 ppm) was observed with application of biochar @ 5t ha^{-1} during both years of experiment.

Table 4.31 Effect of irrigation treatments and soil amendments on nickel content (ppm), uptake and its total uptake (g ha^{-1}) of wheat

Treatments	Nickel content (ppm)				Nickel uptake (g ha^{-1})				Total uptake (g ha^{-1})	
	Grain		Straw		Grain		Straw			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water										
Ground water (100%)	0.02	0.01	0.192	0.163	0.070	0.037	1.11	0.98	1.18	1.02
Ground water (75%) + Hindon water (25%)	0.06	0.05	0.335	0.320	0.234	0.205	1.99	1.98	2.22	2.18
Ground water (50%) + Hindon water (50%)	0.07	0.06	0.372	0.345	0.282	0.254	2.36	2.27	2.64	2.53
Hindon water (100%)	0.10	0.09	0.415	0.380	0.430	0.407	2.74	2.61	3.17	3.02
SE(m)±	**0.002**	**0.003**	**0.006**	**0.007**	**0.002**	**0.001**	**0.02**	**0.01**	**0.03**	**0.04**
C.D (P=0.05)	**0.006**	**0.009**	**0.018**	**0.021**	**0.006**	**0.003**	**0.05**	**0.03**	**0.09**	**0.12**
B. Soil amendments										
Activated Carbon @ 5t/ha	0.07	0.06	0.341	0.326	0.285	0.256	2.15	2.14	2.44	2.39
Biochar @ 5t/ha	0.02	0.02	0.195	0.160	0.092	0.097	1.42	1.21	1.51	1.30
Vermicompost @ 5t/ha	0.08	0.05	0.378	0.351	0.344	0.226	2.52	2.44	2.87	2.67
Control	0.08	0.09	0.373	0.410	0.222	0.263	1.65	1.89	1.87	2.15
SE(m)±	**0.003**	**0.004**	**0.005**	**0.006**	**0.003**	**0.002**	**0.03**	**0.02**	**0.04**	**0.05**
C.D (P=0.05)	**0.008**	**0.011**	**0.013**	**0.016**	**0.009**	**0.006**	**0.09**	**0.06**	**0.12**	**0.14**



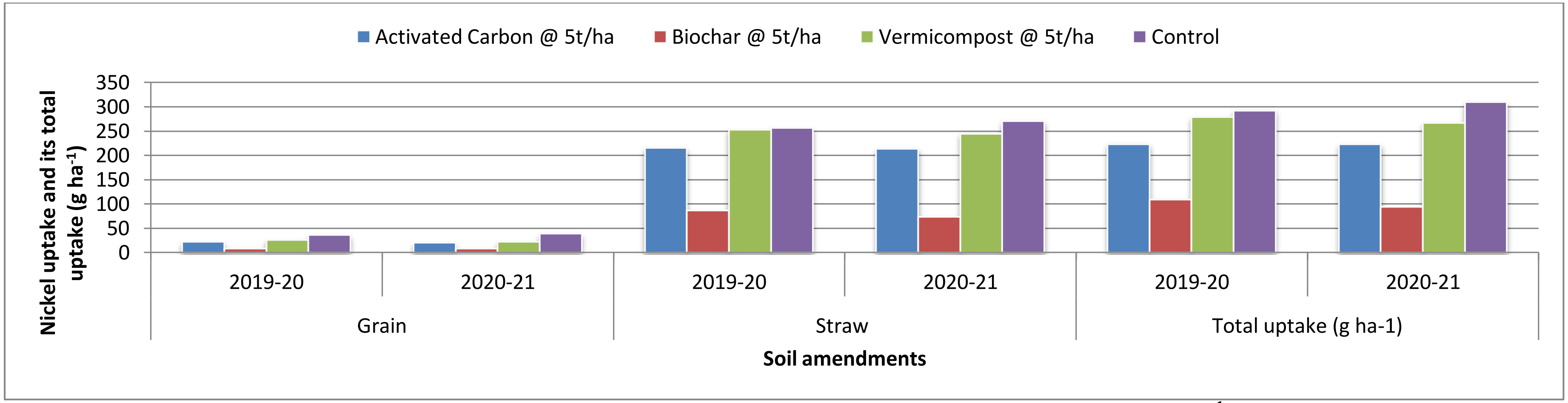


Fig. 4.31 Effect of irrigation treatments and soil amendments on Nickel uptake and its total uptake (g ha^{-1}) of wheat

4.14.8 Nickel uptake (g ha^{-1})

The data pertaining to nickel uptake in grain and straw of wheat is presented in Table 4.31 and depicted in Fig 4.31 for both the years respectively. Maximum nickel uptake in grain (46.08 and 43.54 g ha^{-1}) and straw (301.25 and 286.86 g ha^{-1}) was recorded with 100% Hindon water which was significantly higher than Hindon & ground water in 1:1 ratio (28.22 & 25.40 and 236 & 227.63) and irrigation with Hindon & ground water in 1:3 ratio (23.44 & 20.52 and 199.12 & 197.79) while lowest nickel uptake in grain (7.04 and 3.70 g ha^{-1}) and straw (111.38 and 98.32 g ha^{-1}) was with 100% ground water during both the years.

Different soil amendments resulted in lower nickel uptake in grain and straw of wheat compared to control during both the years. Highest nickel uptake in grain (36.16 and 38.74 g ha^{-1}) and straw (256.33 and 270.93 g ha^{-1}) was recorded in control followed by vermicompost @ 5t ha^{-1} (25.82 & 22.59 and 253.22 & 244.54) and activated carbon @ 5t ha^{-1} (22.26 & 20.45 and 215.14 & 213.92) while lowest nickel uptake in grain (8.54 and 8.14 g ha^{-1}) and straw (86.27 and 73.68 g ha^{-1}) was observed with application of Biochar @ 5t ha^{-1} during both the years.

4.14.9 Iron content (ppm)

Significant variation was observed under different irrigation treatments and soil amendments on iron content in grain and straw of wheat **(Appendix-XXXX)**. However, the interaction between irrigation water and soil amendments was non-significant.

The data on iron content in grain and straw of wheat is given in Table 4.32 and depicted in Fig. 4.32 during both the years respectively. Irrigation treatments comprising of Hindon water alone or in proportion with ground water resulted in significantly higher content of iron in grain and straw of wheat. In this study, the concentration of Fe was present within the safe limit of 425.5 mg kg^{-1} in all the irrigation treatments for both the years. Application of 100% Hindon water resulted in maximum iron content in grain (280.48 and 260.84 ppm) and straw (145.74 and 140.85 ppm) which was statistically superior to dilution of raw Hindon water with 50% ground water (258.10 & 260.84 and 127.49 & 122.85) followed by dilution of raw Hindon water with 75% ground water (236.60 & 207.54 and 115.41 & 106.39) during both the years. Lowest iron content in grain (138.30 and 126.85) and straw (93.65 and 88.69) was noted in wheat plots irrigated with 100% ground water.

Application of different soil amendments resulted in lower iron concentration in grain and straw of wheat over control. Maximum iron content in grain (257.34 and 275.40) and straw (138.65 and 142.36) was recorded in control followed by vermicompost @ 5t ha^{-1} (262.22 & 238.21 and 142.36 & 138.65) and activated carbon @ 5t ha^{-1} (240.71 & 212.33 and 117.36 & 110.36) while lowest iron content in grain (140.10 and 128.63) and straw (92.56 and 89.26) was noted in Biochar treatment during both the years.

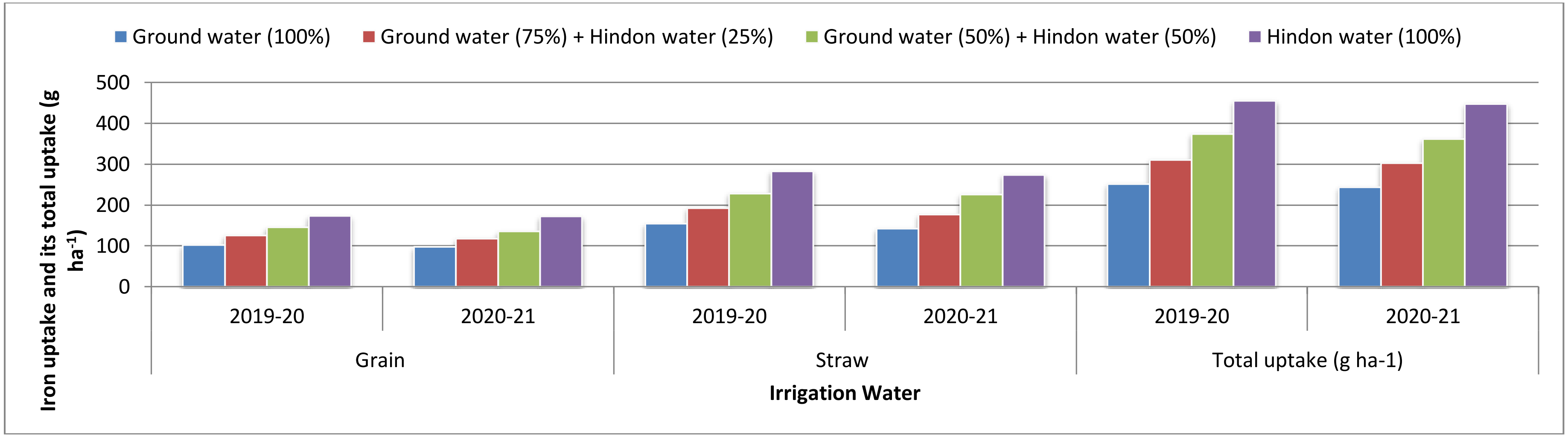
4.14.10 Iron uptake (g ha^{-1})

Iron uptake in wheat grain & straw differed significantly under different irrigation treatments and soil amendments **(Appendix-XXXX)**. However, their interaction was non significant.

Perusal of data given in Table 4.32 and illustrated in Fig. 4.32 reveals that irrigating wheat plots with Hindon water alone or in proportion with ground water resulted in significantly higher uptake of iron in grain and straw of wheat as compared to 100% ground water.

Table 4.33 Effect of irrigation treatments and soil amendments on iron content (ppm), uptake and its total uptake (g ha^{-1}) of wheat

Treatments	Iron content (ppm)				Iron uptake (g ha^{-1})				Total uptake (g ha^{-1})	
	Grain		Straw		Grain		Straw			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water										
Ground water (100%)	27.81	27.66	26.56	23.55	102.07	97.61	154.05	142.01	251.66	244.07
Ground water (75%) + Hindon water (25%)	30.57	30.26	32.45	28.63	125.34	118.01	192.75	176.93	310.77	302.27
Ground water (50%) + Hindon water (50%)	34.45	33.52	35.67	34.67	145.72	135.09	228.48	226.15	374.20	361.23
Hindon water (100%)	40.11	38.37	42.74	39.87	173.43	172.47	282.51	273.91	454.98	447.34
SE(m)±	**2.56**	**2.61**	**3.21**	**3.10**	**9.52**	**7.56**	**14.23**	**12.56**	**21.57**	**20.69**
C.D (P=0.05)	**7.65**	**7.80**	**9.61**	**9.28**	**28.52**	**22.62**	**42.65**	**37.62**	**64.68**	**62.02**
B. Soil amendments										
Activated Carbon @ 5t/ha	32.72	31.88	34.65	30.89	131.20	126.32	191.77	178.31	309.51	306.71
Biochar @ 5t/ha	28.46	26.10	24.56	22.45	114.93	105.39	169.99	169.12	295.82	275.38
Vermicompost @ 5t/ha	36.41	35.58	37.59	36.54	136.13	133.17	218.64	202.64	351.81	338.77
Control	37.91	39.36	38.46	41.69	156.56	160.82	250.73	254.32	407.29	415.14
SE(m)±	**3.06**	**3.06**	**3.68**	**3.52**	**8.25**	**10.85**	**15.79**	**14.59**	**24.67**	**22.56**
C.D (P=0.05)	**9.16**	**9.20**	**11.07**	**10.58**	**24.71**	**32.52**	**47.33**	**43.74**	**74.01**	**67.63**



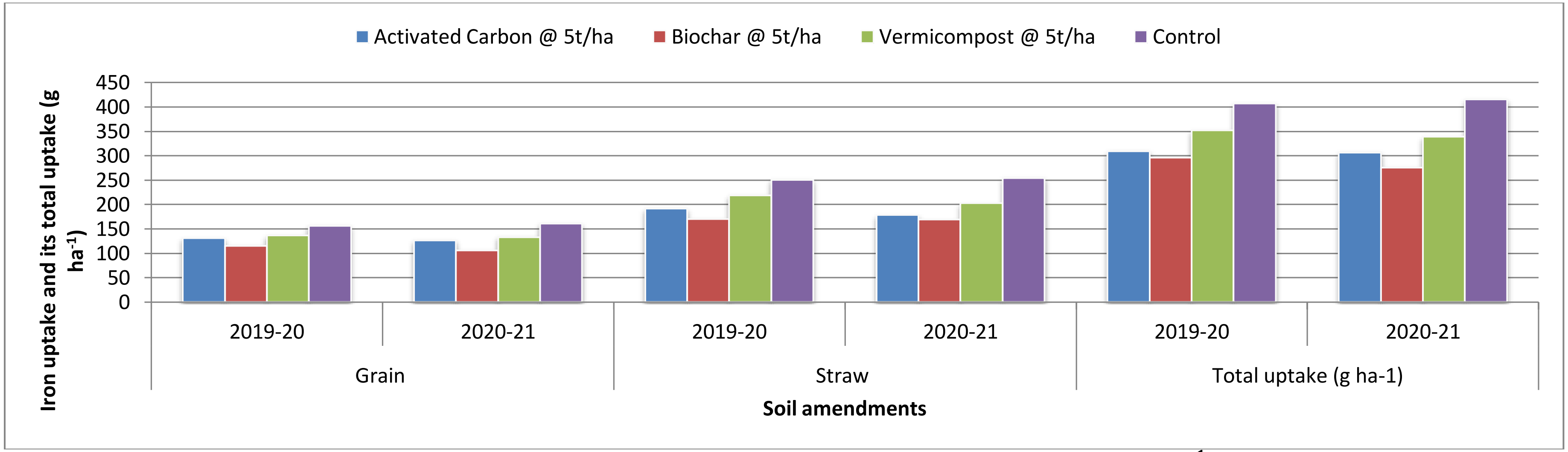


Fig. 4.33 Effect of irrigation treatments and soil amendments on Iron uptake and its total uptake (g ha^{-1}) of wheat

Maximum iron uptake in grain and straw (129245 & 126194 and 105792 & 106327g ha^{-1}) was recorded with 100% Hindon water and was significantly superior to irrigation at all stages with 50% ground water and 50% Hindon river water (104040 & 98912 and 80879 & 81056) followed by irrigation with 75% ground water and 25% hindon water (92439 & 85153 and 68559 & 65759) during both years. Lowest iron uptake in grain (48667 and 46871 g ha^{-1}) and straw (54326 and 53498 g ha^{-1}) was noted in 100% ground water treatment.

Application of different soil amendments resulted in significantly lower uptake of iron by wheat as compared to control during both the years. Maximum iron uptake in grain (116292 and 118532g ha^{-1}) and straw (95280 and 94071g ha^{-1}) was noted in control followed by vermicompost @ 5t ha^{-1} (112833 & 107623 and 88178 & 87568) and activated carbon @ 5t/ha (97920 & 90686 and 74042 & 72418) while lowest iron uptake by grain (38990 and 37586 g ha^{-1}) and straw (40949 and 41104 g ha^{-1}) was recorded with incorporation of biochar @ 5t ha^{-1} during both the years respectively.

4.14.11 Manganese content (ppm)

Irrigation water and soil amendments exhibited significant influence on manganese content in grain and straw of wheat **(Appendix-XXXXI)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in Table 4.33 and illustrated in Fig. 4.33 reveals that irrigation treatments comprising of Hindon water alone or in water mixtures resulted in significantly higher manganese content in grain and straw of wheat in comparison to 100% ground water. Highest manganese content in grain (40.11 and 38.37 ppm) and straw (42.74 and 39.87 ppm) was recorded with 100% Hindon water which was statistically at par to dilution of raw Hindon water with 50% ground water (33.52 & 34.45 and 35.67 & 34.67) and statistically superior to dilution of raw Hindon water with 75% ground water (30.26 & 30.57 and 32.45 & 28.63) during both the years.

Table 4.34 Effect of irrigation treatments and soil amendments on manganese content (ppm), uptake and its total uptake (g ha^{-1}) of wheat

Treatments	Manganese content (ppm)				Manganese uptake (g ha^{-1})				Total uptake (g ha^{-1})	
	Grain		Straw		Grain		Straw			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Underground + Hindon Mixtures										
Ground water (100%)	11.74	10.23	6.71	6.45	43.32	35.91	38.92	38.89	82.21	74.83
Ground water (75%) + Hindon water (25%)	15.29	14.32	9.72	8.52	62.69	55.85	57.74	52.65	115.34	113.59
Ground water (50%) + Hindon water (50%)	17.63	16.50	11.10	10.58	74.57	66.50	70.37	69.72	144.29	136.87
Hindon water (100%)	20.57	19.58	13.48	12.18	92.98	84.19	89.10	83.68	176.66	173.29
SE(m)±	**3.65**	**2.41**	**1.24**	**1.10**	**8.59**	**6.63**	**7.59**	**6.48**	**12.56**	**14.85**
C.D (P=0.05)	**10.92**	**7.20**	**3.70**	**3.28**	**25.74**	**19.85**	**22.74**	**19.40**	**37.64**	**44.52**
B. Soil amendments										
Activated Carbon @ 5t/ha	16.95	15.69	9.85	8.63	72.38	63.86	62.15	56.61	128.99	126.01
Biochar @ 5t/ha	11.85	10.28	6.87	6.58	57.35	47.39	49.88	49.68	107.03	97.27
Vermicompost @ 5t/ha	19.38	18.47	11.36	10.74	87.60	79.42	75.77	74.75	162.35	155.19
Control	20.36	21.57	12.07	13.20	56.60	62.98	53.35	60.72	109.95	123.7
SE(m)±	**4.67**	**3.85**	**1.80**	**1.68**	**9.85**	**7.69**	**9.58**	**8.46**	**14.10**	**16.32**
C.D (P=0.05)	**14.01**	**11.52**	**5.42**	**5.07**	**29.52**	**23.04**	**28.72**	**25.34**	**42.28**	**48.93**

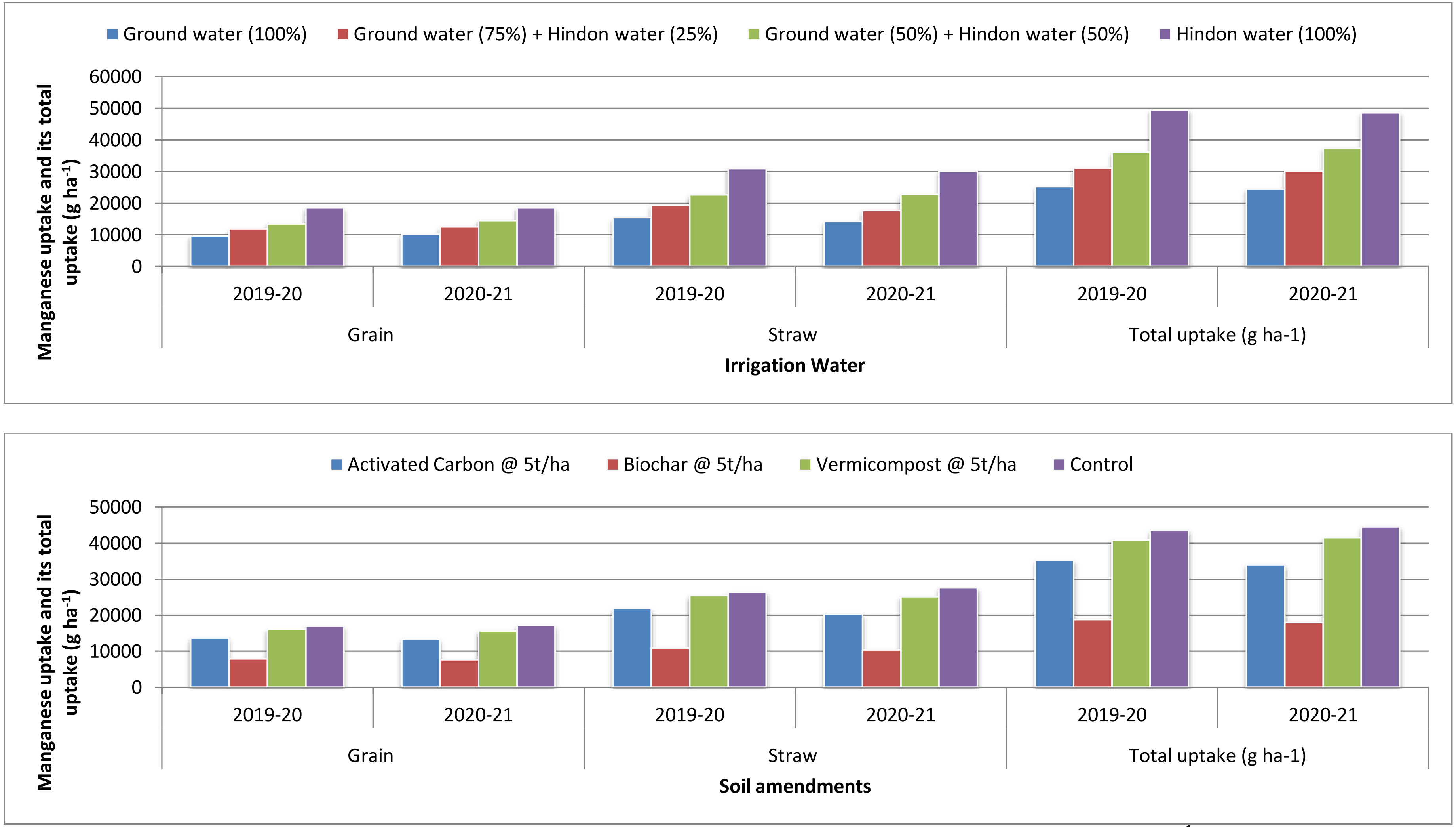


Fig. 4.34 Effect of irrigation treatments and soil amendments on Manganese uptake and its total uptake (g ha^{-1}) of wheat

Lowest manganese content in grain (27.81 and 27.66 ppm) and straw (26.56 and 23.55 ppm) was noted with 100% ground water during both the years.

Maximum manganese content in grain (37.91 and 39.36 ppm) and straw (38.46 and 41.69 ppm) was recorded in control followed by vermicompost @ 5t ha^{-1} (36.41 & 35.58 and 37.59 & 36.54) and activated carbon @ 5t ha^{-1} (32.72 & 31.88 and 34.65 & 30.89) during both the years while least value of manganese content in grain (28.46 and 26.10 ppm) and straw (24.56 and 22.45 ppm) was recorded in Biochar @ 5t ha^{-1} treatment for both the years respectively.

4.14.12 Manganese uptake (g ha^{-1})

Significant variation was observed in manganese uptake by grain and straw of wheat under different irrigation treatments and soil amendments **(Appendix-XXXXI)**. However, their interaction was non- significant.

Perusal of data given in Table 4.33 and illustrated in Fig. 4.33 reveals that manganese uptake by wheat crop increased significantly with increased proportion of Hindon water in applied irrigation when compared to irrigation with 100% ground water. Maximum uptake of manganese in grain (18482 and 18563 g ha^{-1}) and straw (31025 and 30098 g ha^{-1}) was observed with 100% Hindon water which was significantly superior to irrigation with 50 % Hindon + 50% ground water (13511 & 14582 and 22629 & 22875) followed by irrigation with 75% ground & 25 % Hindon water (11822 & 12542 and 19288 & 17696) during both the years. Lowest manganese uptake by grain (9786 and 10220 g ha^{-1}) and straw (15407 and 14205 g ha^{-1}) was noted with 100% ground water during both the years.

Application of different soil amendments resulted in significantly lower manganese uptake in wheat in comparison to control during both the years. Maximum uptake of manganese in grain (16941 and 17132 g ha^{-1}) and straw (26430 and 27549g ha^{-1}) was recorded in control followed by vermicompost @ 5t ha^{-1} (16075 &15667 and 25457 & 25181) and activated carbon @ 5t ha^{-1} (13615 & 13310 and 21860 & 20270) while lowest manganese uptake in grain (7920 and 7626 g ha^{-1}) and straw (10865 and 10338 g ha^{-1}) was noted in Biochar treatment during both the years.

4.14.13 Zinc content (ppm)

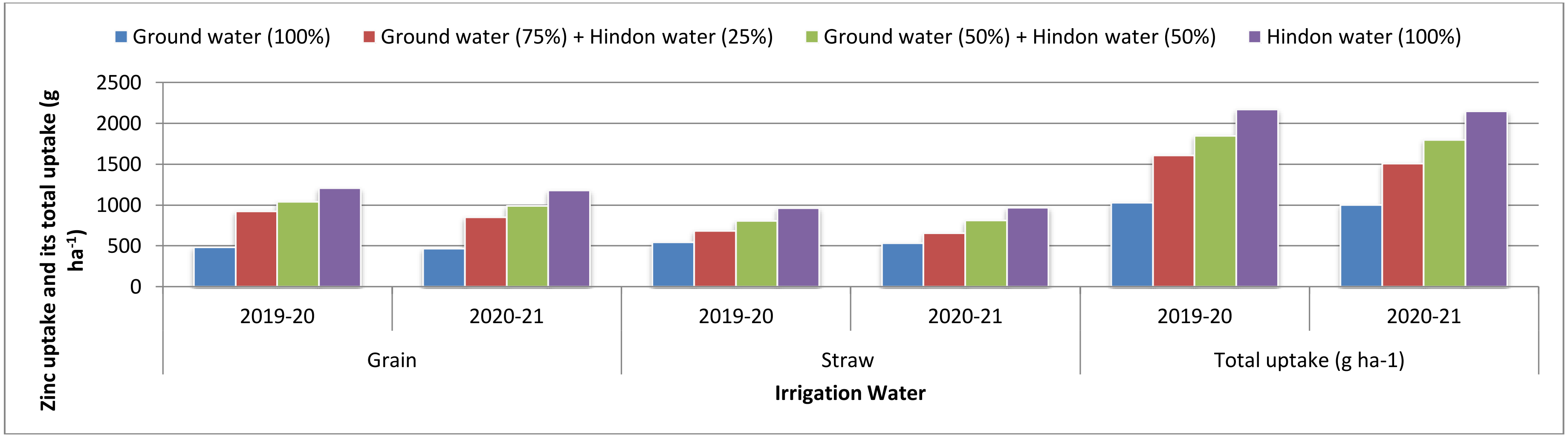
Zinc content in wheat was significantly influenced by different irrigation treatments and soil amendments **(Appendix-XXXXIII)**. However, the interaction between irrigation water and soil amendments was non-significant.

Perusal of data given in Table 4.34 and illustrated in Fig. 4.34 reveals that plots irrigated with mixture of Hindon & ground water or Hindon water alone resulted in significantly higher zinc content in grain and straw of wheat as compared to 100% ground water during both the years. Maximum zinc content in grain (1240.28 and 1228.40 ppm) and straw (13.4 & 12.1) was recorded with 100% Hindon water which was significantly superior to Hindon & ground water in 1:1 ratio (1173.2 & 1167.3 and 11.1 & 12.5) followed by irrigation with Hindon & ground water in 1:3 ratio (1148.8 & 1138.6 and 9.7 & 8.5) during both years while lowest zinc content in grain (1118.30 and 1101.56 ppm) and straw (6.7 & 6.4) was observed with 100% ground water. Regardless of irrigation treatment, the zinc concentration in wheat grain was much higher than the permissible limit of 50 mg kg^{-1} for both years of experiment.

Application of soil amendments resulted in significantly lower zinc content in grain and straw of wheat compared to control during both the years. Maximum zinc content in grain (1224.7 and 1232.5 ppm) and straw (12.07 and 13.20 ppm) was recorded in control which was significantly higher than vermicompost @ 5t ha^{-1} and activated carbon @ 5t ha^{-1} while lowest zinc content in grain (1120.37 and 1104.23 ppm) and straw (6.87 and 6.58 ppm) was noted with the application of Biochar@5t ha^{-1} during both the years.

Table 4.32 Effect of irrigation treatments and soil amendments on zinc content (ppm), uptake and its total uptake (g ha^{-1}) of wheat

Treatments	Zinc content (ppm)				Zinc uptake (g ha^{-1})				Total uptake (g ha^{-1})	
	Grain		Straw		Grain		Straw			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
A. Irrigation water										
Ground water (100%)	138.30	126.85	93.65	88.69	485.43	468.08	543.17	534.80	1028.60	1002.88
Ground water (75%) + Hindon water (25%)	236.60	207.54	115.41	106.39	922.74	850.91	685.54	657.49	1608.28	1508.40
Ground water (50%) + Hindon water (50%)	258.10	233.67	127.49	122.85	1040.14	988.42	808.29	809.58	1848.43	1798.01
Hindon water (100%)	280.48	260.84	145.74	140.85	1206.06	1179.00	963.34	967.64	2169.41	2146.64
SE(m)±	**4.42**	**4.35**	**3.74**	**3.64**	**25.62**	**23.58**	**16.35**	**15.38**	**35.85**	**32.69**
C.D (P=0.05)	**13.21**	**13.02**	**11.20**	**10.90**	**76.82**	**70.71**	**49.01**	**46.10**	**107.50**	**98.02**
B. Soil amendments										
Activated Carbon @ 5t/ha	240.71	212.33	117.36	110.36	979.69	906.65	673.91	671.99	1459.02	1328.24
Biochar @ 5t/ha	140.10	128.63	92.56	89.26	645.86	622.57	654.86	612.83	1317.85	1296.48
Vermicompost @ 5t/ha	257.34	238.21	131.63	125.69	804.17	715.41	740.54	723.96	1720.23	1630.61
Control	262.22	275.40	138.65	142.36	1076.71	1127.55	874.80	877.97	1951.51	2005.52
SE(m)±	**4.86**	**4.78**	**3.89**	**3.95**	**26.58**	**25.69**	**18.52**	**17.59**	**37.58**	**34.23**
C.D (P=0.05)	**14.60**	**14.36**	**11.70**	**11.88**	**79.75**	**77.10**	**55.58**	**52.80**	**112.76**	**102.71**



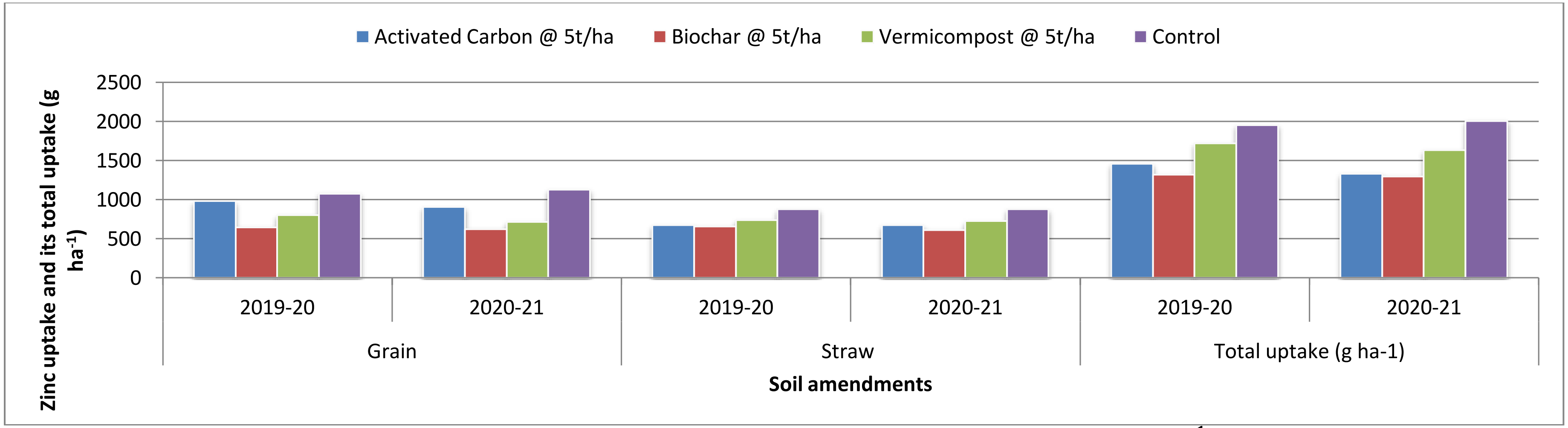


Fig. 4.32 Effect of irrigation treatments and soil amendments on Zinc uptake and its total uptake (g ha^{-1}) of wheat

4.14.14 Zinc uptake (g ha^{-1})

Zinc uptake in grain and straw of wheat was significantly influenced by different irrigation treatments and soil amendments **(Appendix-XXXXIII)**. However, the interaction between irrigation water and soil amendments was non-significant.

The data on zinc uptake by grain and straw of wheat is given in Table 4.34 and illustrated in Fig 4.34 for both the years respectively. Maximum uptake of zinc in grain (594300 and 571521 g ha^{-1}) and straw (9785 and 9195 g ha^{-1}) was recorded with the 100% Hindon water which was significantly superior irrigation with 50% Hindon + 50% ground water (494118 & 472916and 7041.8 & 6980.6) followed by irrigation with Hindon & ground water in 1:3 ratio (467175 & 448855and 5777 & 5266) during both the years while lowest zinc uptake in grain (407026 and 393530g ha^{-1}) and straw (3892 and 3891 g ha^{-1}) was noted with 100% ground water during both the years.

Application of different soil amendments resulted in significantly lower zinc uptake in wheat as compared to control during both the years. Highest zinc uptake in grain (530494 and 553460 g ha^{-1}) and straw (82.95 and 87.23 g ha^{-1}) was recorded in control which was statistically higher than vermicompost @ 5t ha^{-1} (508838 & 528935 and 7610 & 7482) and activated carbon @ 5t ha^{-1} (489204 & 469439and 6214 & 5663) while lowest zinc uptake in grain (322656 and 311799g ha^{-1}) and straw (3039 and 3030 g ha^{-1}) was in biochar treatment during both the years.

4.15.1 Bioconcentration Factor Arsenic

Irrigation water and soil amendments caused significant variation in bio-concentration of arsenic in root, shoot and grain of wheat **(Appendix- XXXXIII)**. However, the interaction between irrigation treatments and soil amendments was non-significant.

Bio-concentration factors (BCFs) are used to indicate the transfer ability of heavy metals from soils to plant grains. The bio-concentration factor of arsenic in roots, straw and grain of wheat under various treatments is shown in Table 4.19 and illustrated in figure 4.19 for both the years. The BCF values of arsenic in grains were significantly lower than those of straws which indicates lower translocation of arsenic from wheat straw to grains. Moreover, the BCFs of arsenic showed significant increase with increased proportion of Hindon water in applied irrigation. The order of arsenic accumulation in wheat was in order of shoot > roots > grain. The bio-concentration factor of arsenic in roots, shoot and grain of wheat ranged from 0.026- 0.007 & 0.003-0.006, 0.002- 0.008 & 0.001-0.007, 0.003- 0.006 and 0.002-0.006, 0.003- 0.007 & 0.003- 0.006, 0.001- 0.0008 & 0.001- 0.007 for both years, 2019-20 & 2020-21 respectively. Irrigation treatment of 100% Hindon water resulted in maximum transfer of arsenic from soil to roots, shoot and grain of wheat which was statistically superior to dilution of raw Hindon water with 50% ground water, dilution of raw Hindon water with 75% ground water while lowest bio-concentration of arsenic was noted with 100% ground water irrigation respectively.

The BCFs of arsenic in wheat crop showed an increase in control plots while the BCFs of arsenic decreased in soil amendment treatments. Application of different soil amendments resulted in lower bio-concentration of arsenic in stem, root, leaves and grain of wheat in comparison to control. Highest bio-concentration of arsenic in roots, straw and grain of wheat was in control as 0.008 & 0.007, 0.009 & 0.008, 0.007 & 0.006, 0.008 & 0.007, 0.001 & 0.001 while lowest bio-concentration of arsenic was with the application of biochar as 0.003 & 0.002, 0.001 & 0.001, 0.003 & 0.002, 0.003

& 0.003, 0.0001 & 0.0001 followed by activated carbon and vermicompost during both years of experiment.

4.15.2 Transfer Factor Arsenic

Irrigation water and soil amendments significantly influenced the transfer factor of arsenic in shoot and grain of wheat during both the years **(Appendix- XXXXIV)**. However, the interaction between irrigation treatments and soil amendments was non-significant.

Perusal of data given in table 4.36 and illustrated in Fig. reveals that irrigation treatment of 100% Hindon water recorded maximum transfer of arsenic from root to shoot (2.0 & 1.9) and grain (0.16 & 0.15) of wheat which was statistically higher than Hindon & ground water in 1:1 ratio (1.68 & 1.61 and 0.145 & 0.141) followed by Hindon & ground water in 1:3 ratio (1.48 & 1.37 and 0.128 & 0.124) while lowest transfer factor of arsenic in shoot and grain of wheat was noted with 100% ground water (0.930 & 0.748 and 0.105 & 0.096) during both the years of experiment.

Use of different soil amendments resulted in lower transfer factor of arsenic in shoot and grain of wheat in comparison to control. Highest transfer factor of arsenic in shoot and grain of wheat was in control (1.83 & 1.9) which was statistically superior to activated carbon (1.660 & 1.572, 0.132 & 0.130) and vermicompost (1.83 & 1.90 and 0.15 & 0.16) while lowest was with application of Biochar (0.90 & 0.76, 0.10 & 0.09) for both the years of experiment.

4.15.3 Bioconcentration Factor Cadmium

Irrigation water and soil amendments significantly influenced the bio-concentration of cadmium from soil to different plant parts *viz.*, root, shoot and grain of wheat **(Appendix- XXXXV)**. The interaction between irrigation treatments and soil amendments was non- significant.

The data on bio- concentration factor of cadmium is given in **Table 4.19** and illustrated in Fig. 4.19 for both the years. The BCF values of cadmium in grains were significantly lower than those of straw which indicates lower translocation of cadmium from wheat straw to grains. The BCFs of cadmium showed significant increase with increased proportion of Hindon water in applied irrigation. The order of cadmium accumulation in wheat was in order of root >straw > grain. The bio- concentration factor of cadmium in root, shoot and grain of wheat ranged from 0.026-0.375 & 0.021-0.449, 0.126- 0.337 & 0.153- 0.378 and 0.012- 0.041 & 0.001- 0.022 during both the years of experiment. Irrigation treatment of 100% Hindon water recorded maximum bio- concentration of cadmium in root (0.449 & 0.375), shoot (0.387 & 0.337) and grain (0.041 & 0.022) of wheat which was significantly higher than 50% ground and 50% Hindon water (0.412 & 0.315, 0.324 & 0.312 and 0.028 & 0.014) followed by 75% ground and 25% Hindon water (0.325 & 0.268, 0.272 & 0.264 and 0.018 & 0.010) while lowest bio- concentration factor in root, shoot and grain of wheat was recorded with 100% ground (0.026 & 0.021, 0.153 & 0.126 and 0.012 & 0.001) water during both the years.

Application of different soil amendments resulted in lower bio- concentration of cadmium in root, shoot and grain of wheat as compared to control during both the years. Highest bio- concentration factor of cadmium in root, shoot and grain of wheat was found in control (0.436 & 0.370, 0.387 & 0.337, 0.041 & 0.022) which was statistically higher to vermicompost @ 5 tonnes ha^{-1} (0.410 & 0.325, 0.333 & 0.318 and 0.032 & 0.016) and activated carbon @ 5 tonnes ha^{-1} (0.332 & 0.258, 0.282 & 0.273 and 0.022 & 0.011) while lowest bio- concentration factor of cadmium in root, shoot and grain was in biochar treatment @ 5 tonnes ha^{-1} (0.021 & 0.013, 0.146 & 0.120 and 0.010 & 0.001)

4.15.4 Bioconcentration Factor Lead

Irrigation water and soil amendments caused significant variation in bio concentration of lead from soil to roots, shoot and grain of wheat **(Appendix-XXXXVII)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

The distribution of lead accumulated in wheat crop under various treatments is shown in Table 4.21 and illustrated in figure 4.21 for both the years. The BCF values of lead in grains were significantly lower than those of straws which indicated less translocation of lead from wheat straw to grains. The Bio-concentration factors of lead in wheat crop increased significantly with increased proportion of Hindon water in applied irrigation. The lead accumulation in wheat was in order of straw > root > grain. Irrigation treatment of 100% Hindon water recorded maximum bio-concentration of lead in root (0.018 & 0.016), shoot (0.039 & 0.019) and grain (0.003 & 0.002) of wheat which was statistically higher than Hindon & ground water in 1:1 ratio (0.015 & 0.013, 0.030 & 0.016 and 0.002 & 0.002) followed by Hindon & ground water in 1:3 ratio (0.012 & 0.011, 0.020 & 0.014 and 0.001 & 0.001) while least bio concentration of lead in roots, shoot and grain of wheat was recorded with 100 % ground water (0.008 & 0.005, 0.011 & 0.010 and 0.00 & 0.00) during both the years of experiment.

Incorporation of different soil amendments resulted in lower bio-concentration of lead in roots, straw and grain of wheat as compared to control. Lowest bio-concentration of lead in roots, shoot and grain of wheat was noted with the application biochar @ 5 tonnes ha^{-1} (0.007 & 0.006, 0.010 & 0.009, 0.00 & 0.00) while highest was found in control (0.017 &0.015, 0.037 & 0.018 and 0.00 & 0.00) during both the years.

4.15.5 Transfer Factor Lead

Irrigation treatments and soil amendments exhibited significant influence on transfer factor of lead in shoot and grain of wheat **(Appendix -XXXXVIII)**. However, the interaction between irrigation water and soil amendments was non- significant.

Perusal of data given in **Table 4.21** and illustrated in **Fig. 4.21** reveals that irrigation with 100% Hindon water recorded highest transfer factor of lead in shoot (2.118 & 2.075) and grain (0.11 & 0.05) of wheat which was significantly higher than dilution of raw Hindon water with 50% ground water (2.025 & 1.910 and 0.08 & 0.03) followed by dilution of raw Hindon water with 75% ground water (1.855 & 1.77 and 0.05 & 0.02) while lowest transfer factor of lead in shoot and grain of wheat was recorded with 100% ground water(1.576 & 1.520 and 0.01 & 0.00) during both the years of experiment.

Application of different soil amendments resulted in lower transfer factor of lead from root to shoot and grain of wheat in comparison to control. Highest transfer factor of lead in shoot and grain of wheat was in control (2.032 & 2.102 and 0.04 & 0.10) followed by vermicompost (2.070 & 1.964 and 0.09 & 0.03) and activated carbon (1.876 & 1.785, 0.06 & 0.02) while lowest was with the application of biochar @ 5 tonnes ha^{-1} (1.582 & 1.560 and 0.01 & 0.00) for both the years of experiment.

4.15.6 Bio-concentration Factor Nickel

Irrigation water and soil amendments influenced the bio-concentration of nickel in roots, shoot and grain of wheat significantly for both the years **(Appendix-XXXXIX)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

The bio-concentration factor of nickel in roots, shoot and grain of wheat under various treatments is shown in Table 4.23 and illustrated in figure 4.23 for both the years. The BCF values of nickel in grains were significantly lower than those of straws which indicated lower translocation of nickel from wheat straw to grains. Moreover, the BCFs of nickel showed significant increase with increased proportion of Hindon water in applied irrigation. The nickel accumulation in wheat was in order of root > straw > grain. Irrigation treatment of 100% Hindon water recorded maximum bio-concentration of nickel in root (0.035 & 0.022), shoot (0.020 & 0.019) and grain (0.009 & 0.004) of wheat which was statistically superior to dilution of raw Hindon water with 50% ground water (0.026 & 0.017, 0.017 & 0.016 and 0.006 & 0.003) followed by dilution of raw Hindon water with ground water in 1:3 ratio (0.020 & 0.014, 0.015 & 0.014 and 0.005 & 0.002) while lowest bio-concentration of nickel in roots, straw and grain of wheat was recorded with 100% ground water (0.011 & 0.008, 0.009 & 0.008 and 0.004 & 0.001) during both the years of experiment.

The BCFs of nickel in wheat crop showed an increase in control plots while the BCFs of nickel decreased in soil amendment treatments during both the years. Lowest bio-concentration of nickel in roots, straw and grain of wheat was found in Biochar treatment @ 5 tonnes ha^{-1} (0.010 & 0.009, 0.009 & 0.008 and 0.004 & 0.001) while highest was noted in control (0.021 & 0.034, 0.018 & 0.019 and 0.004 & 0.008) followed by vermicompost @ 5 tonnes ha^{-1} (0.028 & 0.018, 0.018 & 0.017 and 0.007 & 0.003) and activated carbon @ 5 tonnes ha^{-1} (0.021 & 0.015, 0.016 & 0.015 and 0.006 & 0.002) for both the years.

4.15.7 Transfer Factor Nickel

Irrigation water and soil amendments caused significant variation in transfer factor of nickel from root to shoot and grain of wheat **(Appendix- XXXXX)**. The interaction between irrigation treatments and soil amendments was non- significant.

The transfer factor of nickel in shoot and grain of wheat under various treatments is shown in Table 4.24 and illustrated in figure 4.24 for both the years. The transfer factor in wheat was in order of shoot > grain. Irrigation with 100% Hindon water resulted in highest transfer factor of nickel from root to shoot (0.988 & 0.926) and grain (0.23 & 0.22) of wheat which was statistically higher to Hindon & ground water in 1:1 ratio (0.963 & 0.898, 0.16 & 0.15) followed by Hindon & ground water in 1:3 ratio (0.945 & 0.867 and 0.14 & 0.13) while lowest transfer factor of nickel in shoot and grain of wheat was recorded with application of 100% ground water (0.930 & 0.844, 0.10 & 0.09) during both the years of experiment.

Various soil amendments resulted in lower transfer factor of nickel in shoot and grain of wheat compared to control for both the years. Highest transfer factor of nickel in shoot and grain of wheat was noted in control (0.0985 & 0.921 and 0.21 & 0.20) followed by vermicompost (0.968 & 0.904 and 0.18 & 0.17) and activated carbon @ 5 tonnes ha^{-1} (0.949 & 0.871 and 0.15 & 0.14) while lowest was with the application of biochar @ 5 tonnes ha^{-1} (0.928 & 0.840 and 0.10 & 0.09) for both the years respectively.

4.15.8 Bio-concentration Factor Iron

Irrigation water and soil amendments significantly influenced the bio-concentration of iron in roots, shoot and grain of wheat **(Appendix- XXXXXI)**. However, the interaction between irrigation treatments and soil amendments was non-significant.

The bio-concentration factor of iron in roots, shoot and grain of wheat under various treatments is shown in Table 4.25 and illustrated in figure 4.25 for both the years (Appendix-). The BCF values of iron in grains were significantly lower than those of straws which indicated low translocation of iron from wheat straw to grains.

Furthermore, the BCFs of iron showed significant increase with increased proportion of Hindon water in applied irrigation. Irrigation treatment of applying raw Hindon water resulted in greatest bio-concentration factor of iron in roots (0.070 & 0.060), shoot (0.068 & 0.066) and grain (0.570 & 0.127) of wheat which was significantly higher than 50 % Hindon & 50% ground water (0.064 & 0.056, 0.060 & 0.057 and 0.400 & 0.111) followed by 75% ground + 25 % Hindon water (0.057 & 0.053, 0.054 & 0.052 and 0.081 & 0.300) while lowest bio-concentration factor of iron in wheat was recorded with 100 % ground water (0.052 & 0.051, 0.052 & 0.044 and 0.070 & 0.065) during both the years of experiment.

Application of various soil amendments resulted in lower bio-concentration of iron in roots, shoot and grain of wheat as compared to control during both the years. Lowest bio-concentration of iron was noted in biochar treatment @ 5 tonnes ha^{-1} (0.052 & 0.050, 0.045 & 0.042, 0.062 & 0.060) while highest bio-concentration of iron in root, shoot and grain of wheat was found in control (0.059 & 0.069, 0.065 & 0.067 and 0.125 & 0.550) during both the years.

4.15.9 Transfer Factor of Iron

Different irrigation treatments and soil amendments caused significant variation in transfer factor of iron in shoot and grain of wheat **(Appendix- XXXXXII)**. However, the interaction between irrigation water and soil amendments was non-significant.

Transfer factor was calculated to understand the extent of risk and associated hazard due to wastewater irrigation and consequent heavy metal accumulation in edible portion of wheat. The transfer factor of iron in shoot and grain of wheat under various treatments is shown in Table 4.26 and illustrated in figure 4.26 for both the years. The transfer of iron in wheat crop increased significantly with increased proportion of

Hindon water in applied irrigation. The transfer factor of iron in wheat was order of grain >shoot. The transfer factor values obtained for iron indicated that wheat grains had higher accumulation capacity with transfer factor more than 1 which means that wheat accumulated greater iron in shoot and grains with higher possibility of iron exposure to humans through intake of these grains. Application of 100% Hindon water recorded maximum transfer of iron from root to shoot (0.967 & 0.956) and grain (1.848 & 1.786) of wheat which was significantly higher than Hindon & ground water in 1:1 ratio (0.943 & 0.924, 1.720 & 1.658) followed by irrigation with Hindon & ground water in 1:3 ratio (0.883 & 0.867, 1.536 & 1.415) while lowest transfer factor of iron in shoot and grain of wheat was noted with application of 100% ground water (0.845 & 0.830 and 1.276 & 1.214) during both the years of experiment.

Different soil amendments resulted in lower transfer factor of iron in shoot and grain of wheat in comparison to control during both the years. Highest transfer factor of iron in shoot and grain of wheat was recorded in control (0.956 & 0.967 and 1.786 & 1.848) which was significantly higher than vermicompost @ 5 tonnes ha^{-1} (0.947 & 0.931, 1.740 & 1.676) and activated carbon (0.887 & 0.873 and 1.548 & 1.428) while lowest was with the application of biochar @ 5 tonnes ha^{-1} (0.842 & 0.828, 1.268 & 1.210) respectively.

4.15.10 Bio-concentration Factor Manganese

Irrigation water and soil amendments significantly influenced the bio-concentration factor of manganese in roots, shoot and grain of wheat **(Appendix-XXXXXIII)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

The bio-concentration factor of manganese in roots, shoot and grain of wheat under various treatments is shown in Table 4.27 and illustrated in figure 4.27 for both the years. The BCF values of manganese in grains were lower than those of straw which indicates lower translocation of manganese from wheat straw to grains. Moreover, the BCFs of arsenic showed significant increase with increased proportion of Hindon water in applied irrigation. The order of manganese accumulation in wheat crop was in order of shoot > root > grain. Irrigation treatment of 100% Hindon water resulted in greatest bio- concentration factor of manganese from soil to root (0.089 & 0.080), shoot (0.082 & 0.080) and grain (0.078 & 0.070) of wheat in comparison to different irrigation treatments during both the years and was significantly higher than Hindon & ground water in 1:1 ratio (0.074 & 0.080, 0.074 & 0.071 and 0.070 & 0.060) followed by Hindon & ground water in 1:3 ratio (0.056 & 0.048, 0.064 & 0.062 and 0.060 & 0.052) while lowest bio- concentration of manganese in roots, shoot and grain of wheat was noted with 100% ground water (0.044 & 0.041, 0.048 & 0.047 and 0.055 & 0.049) during both the years of experiment.

Soil amendments resulted in lower bio- concentration of manganese in roots, shoot and grain of wheat as compared to control during both the years. Lowest bio-concentration of manganese in roots, shoot and grain of wheat was with the application of biochar @ 5 tonnes ha^{-1} (0.042 & 0.040, 0.047 & 0.046 and 0.054 & 0.050) while highest was found in control (0.078 & 0.087, 0.079 & 0.081 and 0.068 & 0.077) followed by vermicompost @ 5 tonnes ha^{-1} (0.076 & 0.068, 0.077 & 0.046 and 0.054 & 0.050) and activated carbon @ 5 tonnes ha^{-1} (0.058 & 0.050, 0.065 & 0.063 and 0.061 & 0.056) during both the years.

4.15.11 Transfer Factor Manganese

Irrigation water and soil amendments exhibited significant influence on transfer factor of manganese in shoot and grain of wheat **(Appendix- XXXXXIV)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

The transfer factor of manganese in shoot and grain of wheat under various treatments is shown in Table 4.28 and illustrated in figure 4.28 for both the years. The transfer of manganese in wheat crop increased significantly with increased proportion of Hindon water in applied irrigation. The transfer factor of manganese in wheat was of order grain >shoot. The transfer factor values obtained for manganese indicated that wheat grains had higher accumulation capacity with transfer factor more than 1 which means that wheat accumulated greater manganese in shoot and grains with higher possibility of manganese exposure to humans through intake of these grains.

Irrigation treatment of 100% Hindon water resulted in maximum transfer factor of manganese from root to shoot (1.093 & 1.074) and grain (1.274 & 1.228) of wheat in comparison to rest of the irrigation treatments and was significantly superior to dilution of raw Hindon water with 50% ground water (1.036 & 1.014 and 1.124 & 1.10) followed by dilution of raw Hindon water with ground water in 1:3 ratio (0.972 & 0.960 and 0.968 & 0.960) while lowest transfer factor of manganese in shoot and grain of wheat was recorded with application of 100% ground water (0.938 & 0.884 and 0.883 & 0.862) during both the years of experiment.

Application of soil amendments resulted in lower transfer factor of manganese in shoot and grain of wheat in comparison to control during both the years. Highest transfer factor of manganese in shoot and grain of wheat was found in control (1.068 & 1.085 and 1.221 & 1.263) which was significantly higher than vermicompost (1.042 & 1.020 and 1.130 & 1.110) and activated carbon @ 5 tonnes ha^{-1} (0.978 & 0.966, 0.965

& 0.975) while lowest transfer factor of manganese in shoot and grain was in biochar treatment @ 5 tonnes ha^{-1} (0.933 & 0.891, 0.880 & 0.867) during both the years respectively.

4.15.12 Bioconcentration Factor Zinc

Irrigation water and soil amendments significantly influenced the bio-concentration of zinc in roots, shoot and grain of wheat during both the years **(Appendix- XXXXXV)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

The bio-concentration factor of zinc in roots, shoot and grain of wheat under various treatments is shown in Table 4.29 and illustrated in figure 4.29 for both the years. The BCF values of zinc in grains were significantly higher than those of straws which indicated higher translocation of zinc from wheat straw to grains. Furthermore, the bio- concentration of zinc in wheat crop showed significant increase with increased proportion of Hindon water in applied irrigation. The order of zinc accumulation in wheat was in order of grain > roots > shoot. Irrigation with 100% Hindon water recorded maximum bio- concentration of zinc in roots (0.258 & 0.246), shoot (0.235 & 0.228) and grain (24.10 & 21.52) of wheat in comparison to different irrigation treatments and was significantly higher than Hindon & ground water in 1:1 ratio (0.232 & 0.226, 0.214 & 0.183 and 23.48 & 20.28) followed by Hindon & ground water in 1:3 ratio (0.173 & 0.168, 0.174 & 0.144 and 22.82 & 19.90) while lowest bio-concentration of zinc in roots, shoot and grain was recorded with 100 % ground water (0.145 & 0.142, 0.128 & 0.120 and 21.65 & 19.64) during both the years.

The BCFs of zinc in wheat crop showed an increase in control plots while the BCFs of zinc decreased in soil amendment treatments. Soil amendments resulted in lower bio- concentration of zinc in roots, shoot and grain of wheat as compared to control during both the years. Lowest bio- concentration of zinc from soil to roots, shoot and grain of wheat was in biochar treatment @ 5 tonnes ha^{-1} (0.142 & 0.140, 0.126 & 0.117, 21.68 & 19.62) while highest bio- concentration of zinc in roots, shoot and grain was found in control (0.246 & 0.258, 0.228 & 0.235 and 21.52 & 24.10) followed by vermicompost @ 5 tonnes ha^{-1} (0.235 & 0.230, 0.216 & 0.188 and 23.51 & 20.31) and activated carbon @ 5 tonnes ha^{-1} (0.175 & 0.171, 0.178 & 0.148 and 22.86 & 19.93) during both the years of experiment.

4.15.13 Transfer Factor Zinc

Irrigation water and soil amendments exhibited significant influence on transfer factor of zinc in shoot and grain of wheat **(Appendix- XXXXXVI)**. However, the interaction between irrigation treatments and soil amendments was non- significant.

The transfer factor of zinc in shoot and grain of wheat under various treatments is shown in Table 4.30 and illustrated in figure 4.30 for both the years. The transfer of zinc in wheat crop increased significantly with increased proportion of Hindon water in applied irrigation. The transfer factor of zinc in wheat was of order grain >shoot. The transfer factor values obtained for zinc indicated that wheat grains had higher accumulation capacity with transfer factor more than 1 which means that wheat accumulated greater zinc in shoot and grains with higher possibility of zinc exposure to humans through intake of these grains.

Irrigation treatment of 100% Hindon water recorded maximum transfer factor of zinc from in shoot (0.924 & 0.916) and grain (155.02 & 139.12) of wheat followed by dilution of raw Hindon water with 50% ground water (0.912 & 0.885 and 134.85 & 122.46) and dilution of raw Hindon water with 75% ground water (0.906 & 0.862 and 116.28 & 95.89) while lowest transfer factor of zinc in shoot and grain of wheat was recorded with 100% ground water (0.903 & 0.844 and 94.67 & 84.51) during both the years of experiment.

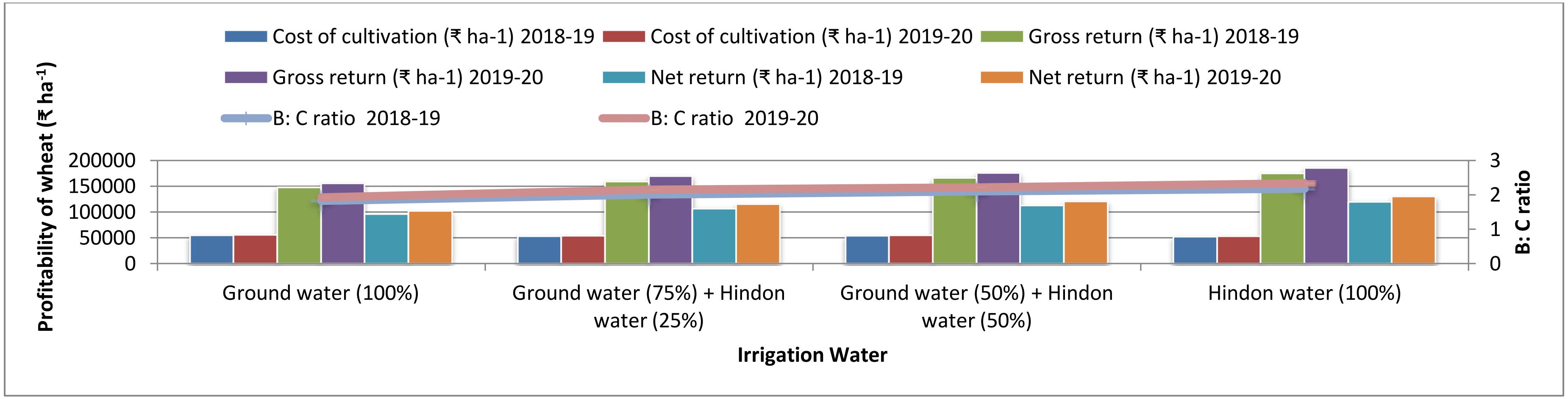
Different soil amendments resulted in lower transfer factor of zinc in shoot and grain of wheat as compared to control during both the years. Lowest transfer factor of zinc in shoot and grain of wheat was with the application of biochar @ 5 tonnes ha^{-1} (0.902 & 0.841, 82.72 & 92.67) while highest was in control (0.915 & 0.921 and 137.56 & 153.64) followed by vermicompost (0.913 & 0.889 and 136.46 &124.36) and activated carbon (0.908 & 0.865 and 118.69 & 96.78) for both the years of experiment.

4.16 Economics

4.16.1 Cost of cultivation (₹ ha^{-1})

Perusal of data given in table 4.48 reveals that highest cost of cultivation for both crops was incurred with 100 % ground water (54,914 & 55813 Rs.) which was significantly higher than 75% ground water and 25% Hindon water (53,015 & 53,830 Rs.) followed by 50% ground water and 50% Hindon water (53,610 & 54546 Rs.) while lowest cost of cultivation was noted with 100 % Hindon water (52,457 & 53,043 Rs.).

Application of different soil amendments resulted in higher cost of cultivation in comparison to control during both the years. Perusal of data revealed that cost of cultivation was more in Biochar treatment (58,120 & 59,300 Rs.) followed by vermicompost (57,500 & 58630 Rs.) and activated carbon (54,142 & 55,678 Rs.) for both the years.



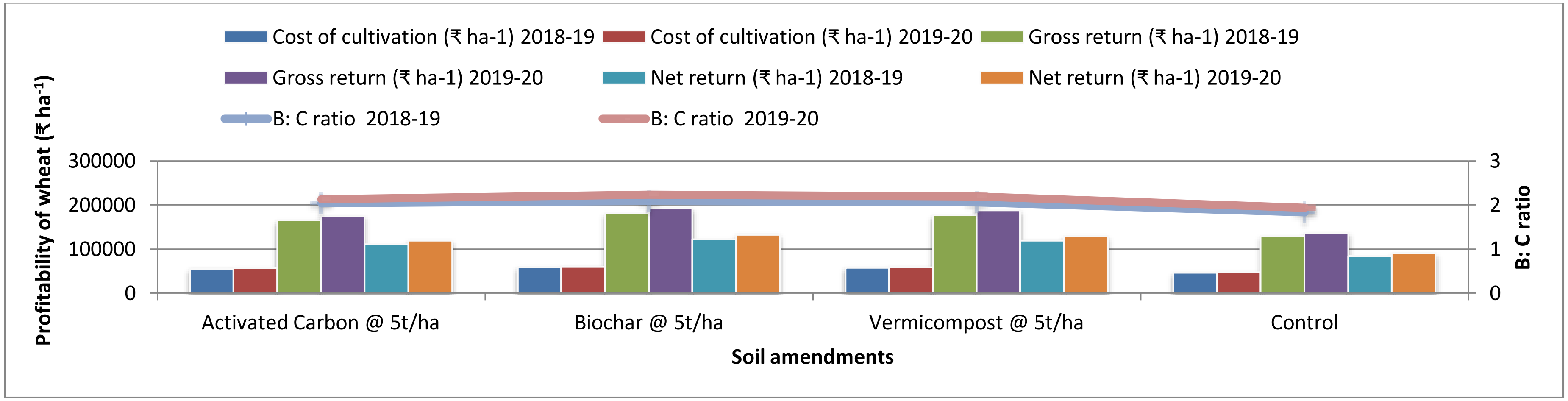


Fig. 4.49 Effect of irrigation treatments and soil amendments on economics of fodder sorghum and wheat

4.16.2 Gross returns (₹ ha^{-1})

The data presented in table 4.48 revealed that highest gross returns were obtained in irrigation treatment of 100 % Hindon water (1,48,123 & 1,55,216 Rs.) followed by 50% ground water and 50% Hindon water (1,66,137 & 1,75,227 Rs.) and 75% ground water and 25% Hindon water (1,59,430 & 1,69,507 Rs.) while lowest was with 100 % ground water (1,48,123 & 1,55,216 Rs.).

Application of different soil amendments resulted in higher gross returns in comparison to control for both the years. Perusal of data revealed that highest gross returns were obtained in biochar treatment (1,79,752 & 1,91,503 Rs.) followed by vermicompost (1,75,820 & 1,87,208 Rs.) and activated carbon (1,66,442 & 1,74,457 Rs.) while lowest was obtained in control (1,29,113 & 1,36,582 Rs.) during both the years.

4.16.3 Net returns (₹ ha^{-1})

Perusal of data presented in table 4.48 revealed that maximum value of net returns was obtained in irrigation treatment of 100 % Hindon water (1,19,938 & 1,29,777 Rs.) followed by irrigation with 50% ground water and 50 % Hindon river water (1,12,527 & 1,20,731 Rs.) and 75% ground water and 25% Hindon water (1,06,415 & 1,15,677 Rs.) while lowest was with 100 % ground water (95,666 & 1,02,173 Rs.).

Application of different soil amendments resulted in higher net returns in comparison to control for both the years. Perusal of data revealed that highest net returns were obtained in biochar treatment (1,21,632 & 1,32,203) followed by vermicompost (1,18,320 & 1,28,578) and activated carbon (1,10,280 & 1,18,779) while lowest was obtained in control (83,513 & 90,005) during both the years.

4.16.4 B: C ratio

Perusal of data presented in table 4.48 revealed that maximum value of B:C ratio was obtained in irrigation treatment of 100 % Hindon water (2.18 & 2.13) followed by irrigation with 50% ground water and 50 % Hindon water (2.10 & 2.21) and 75% ground water and 25% Hindon water (2.01 & 2.15) while lowest was with 100 % ground water (1.82 & 1.93) for both the years.

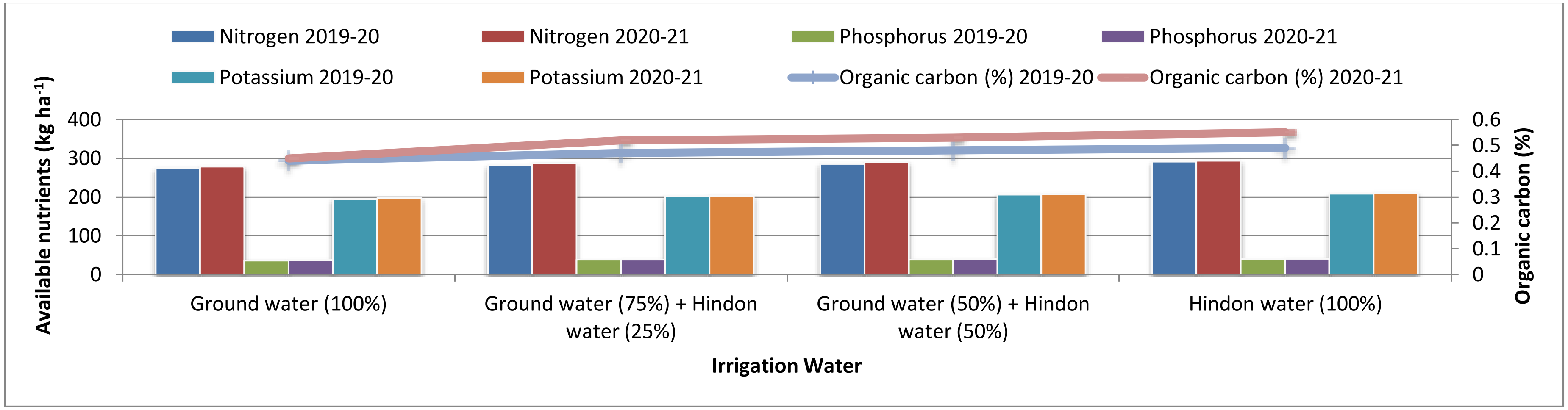
Application of different soil amendments resulted in higher B:C ratio in comparison to control for both the years. Perusal of data revealed that highest B:C ratio was obtained in biochar treatment (2.09 & 2.23) followed by vermicompost (2.06 & 2.19) and activated carbon (2.04 & 2.13) while lowest was obtained in control (1.83 & 1.94) during both the years.

4.17.1 Available nitrogen

Available nitrogen in soil varied significantly among different irrigation treatments and soil amendments. However, the interaction between irrigation water and soil amendments was non-significant.

The data on available nitrogen is given in table 4.49 and illustrated in fig. 4.49 during years, 2019-20 and 2020-21. Irrigation treatment of 100% Hindon water (290.7 & 293.5) resulted in highest available nitrogen and was statistically superior to Hindon & ground water in 1:1 ratio (285.4 & 290.4) followed by dilution of raw Hindon water with ground water in 1:3 ratio (281.4 & 286.3) while lowest available nitrogen was recorded with 100% ground water (274.1 & 278.2) during both the years of experiment.

Among different soil amendments, highest available nitrogen was noted with Biochar @ 5t ha^{-1} (293.5 & 295.3) which was statistically superior to vermicompost (287.2 & 291.4) followed by activated Carbon @ 5t ha^{-1} (283.5 & 287.5) while lowest available nitrogen was recorded in control (275.6 & 280.6) during both the years.



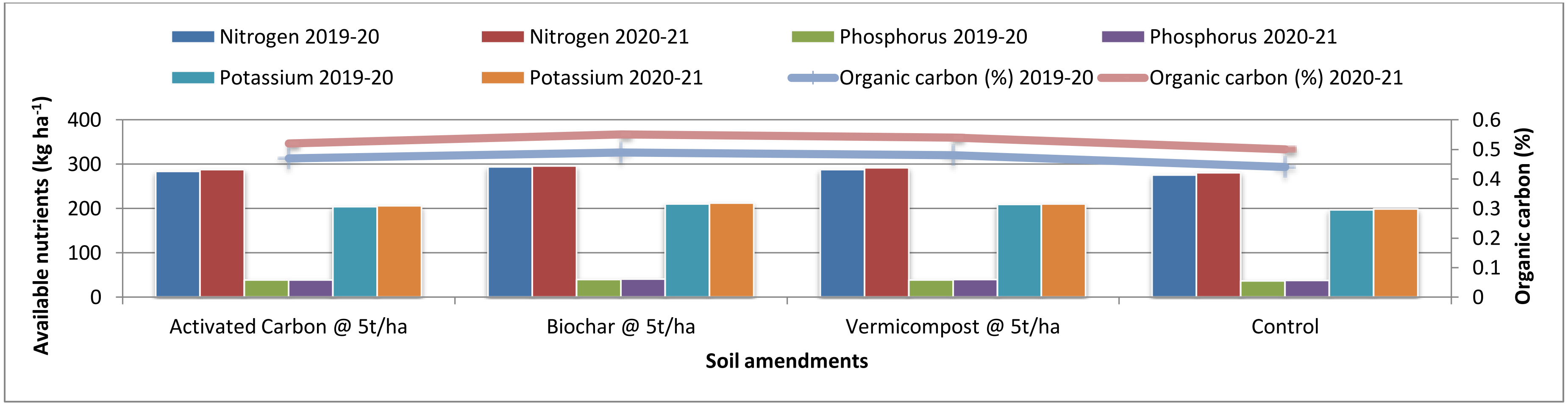


Fig. 4.50 Effect of irrigation treatments and soil amendments on available N, P, K (kg ha^{-1}) and organic carbon (%) in soil

4.5.2 Available Phosphorous

Available phosphorus in soil varied significantly among different irrigation treatments and soil amendments. However, the interaction between irrigation water and soil amendments was non-significant.

The data on available phosphorus is given in table 4.49 and illustrated in fig. 4.49 during years, 2019-20 and 2020-21. Irrigation treatment of 100% Hindon water (39.4 & 40.3) resulted in highest available phosphorus and was statistically superior to Hindon & ground water in 1:1 ratio (38.6 & 39.2) followed by dilution of raw Hindon water with ground water in 1:3 ratio (38.1 & 38.2) while lowest phosphorus was recorded with 100% ground water (35.9 & 36.9) during both the years of experiment.

Among different soil amendments, highest phosphorus was noted with Biochar @ 5t ha^{-1} (39.6 & 40.8) which was statistically superior to vermicompost (38.5 & 39.5) followed by activated Carbon @ 5t ha^{-1} (38.4 & 38.5) while lowest available phosphorus was recorded in control (36.5 & 37.2) during both the years.

4.5.3 Available Potassium

Available potassium in soil varied significantly among different irrigation treatments and soil amendments. However, the interaction between irrigation water and soil amendments was non-significant.

The data on available potassium is given in table 4.49 and illustrated in fig. 4.49 during years, 2019-20 and 2020-21. Irrigation treatment of 100% Hindon water (208.5 & 210.6) resulted in highest available potassium and was statistically superior to Hindon & ground water in 1:1 ratio (206.3 & 207.6) followed by dilution of raw Hindon water with ground water in 1:3 ratio (202.9 & 203.2) while lowest potassium was recorded with 100% ground water (194.6 & 196.8) during both the years of experiment.

Among different soil amendments, highest potassium was noted with Biochar @ 5t ha^{-1} (210.3 & 212.3) which was statistically superior to vermicompost (208.7 & 209.7) followed by activated carbon @ 5t ha^{-1} (203.5 & 205.6) while lowest available potassium was recorded in control (196.3 & 196.2) during both the years.

4.6.1 Available arsenic

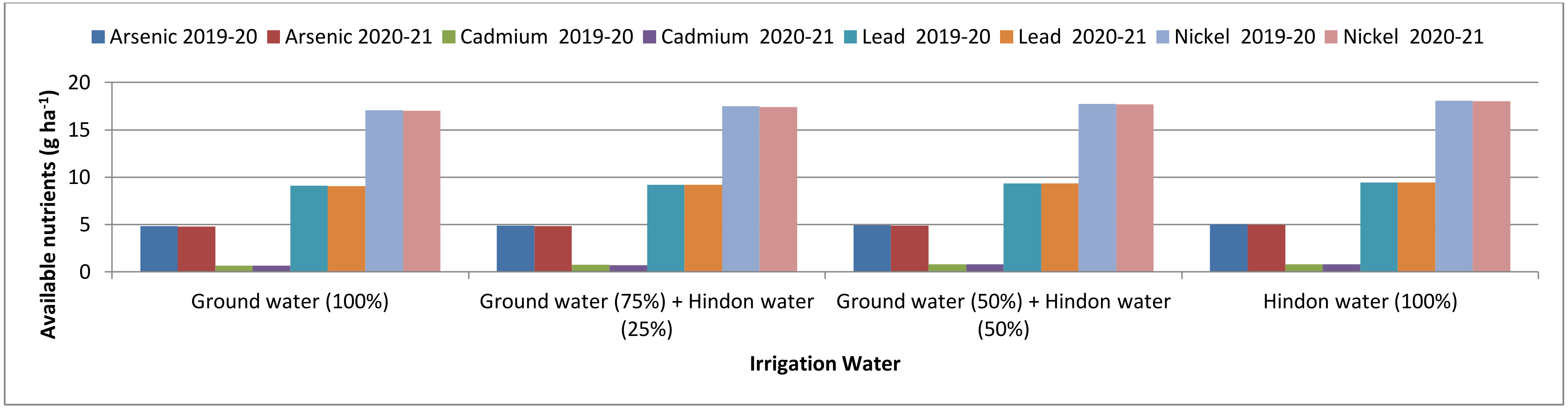
Irrigation water and soil amendments exhibited significant influence on available arsenic during both the years. However, the interaction between irrigation treatments and soil amendments was non- significant.

The data pertaining to available arsenic is presented in Table 4.50 and depicted in Fig 4.50, which reveals that available arsenic increased significantly with increased proportion of Hindon water in applied irrigation. Highest arsenic content in soil was recorded with 100% Hindon water (5.02 & 4.96) which was significantly higher than dilution of raw Hindon water with 50% ground water (4.93 & 4.90) followed by dilution of raw Hindon water with 75% ground water (4.89 & 4.85) during both the years while lowest arsenic content (4.84 & 4.80) was recorded with 100% ground water during both the years.

Among soil amendments**,** lowest arsenic in soil was found with the application of biochar @ 5t ha^{-1} during both the years. Maximum available arsenic was recorded in control (4.98 & 5.05) which was significantly higher than vermicompost @ 5t ha^{-1} (4.90 & 4.87) followed by activated carbon (4.90 & 4.87) while lowest was found in biochar treatment (4.85 & 4.81) during both the years. Incorporation of biochar resulted in 45 % reduction of arsenic in fodder for both the years

4.6.2 Available Cadmium

Irrigation water and soil amendments exhibited significant influence on available cadmium for both the years. However, the interaction between irrigation treatments and soil amendments was non- significant.



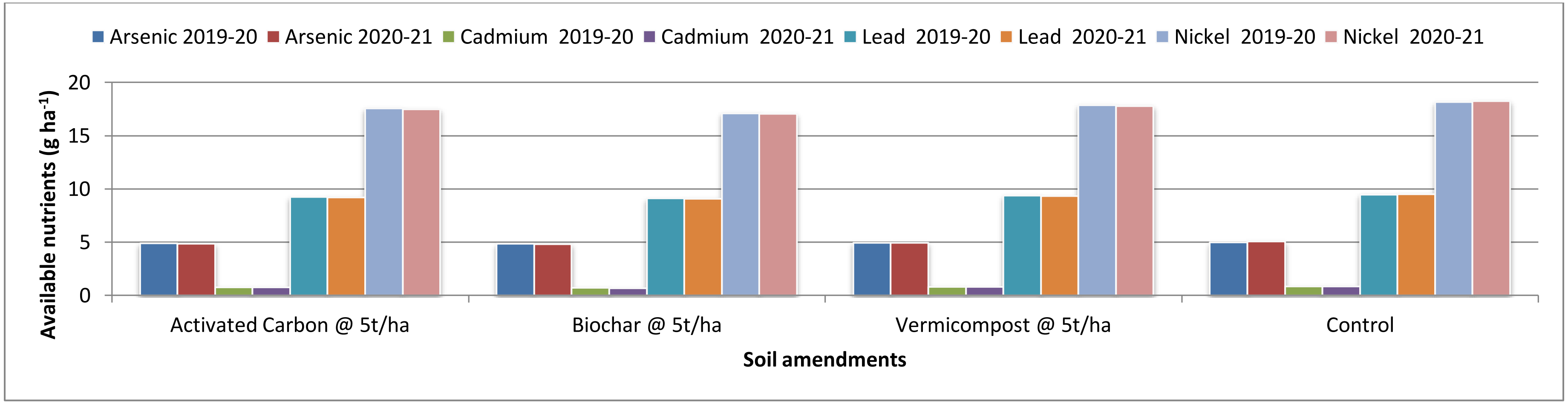


Fig. 4.51 Effect of irrigation treatments and soil amendments on available arsenic, cadmium, lead and nickel (g ha^{-1}) in soil

The data on available cadmium is given in table 4.50 and depicted in fig. 4.50 reveals that available cadmium increased significantly with increased proportion of Hindon water in applied irrigation. Irrigation with raw Hindon water resulted in highest cadmium content in soil (0.82 & 0.80) which was significantly higher than 50 % Hindon + 50% ground water (0.79 & 0.78) followed by 75% ground water and 25% hindon water (0.74 & 0.72) while lowest (0.68 & 0.65) was recorded with 100% ground water during both the years of experiment.

Application of various soil amendments resulted in lower cadmium content in soil as compared to control during both years. Among the soil amendments, lowest available cadmium was noted with the application of biochar @ 5 tonnes ha^{-1} (0.70 & 0.67) followed by activated carbon (0.76 & 0.74) and vermicompost (0.80 & 0.78) while highest was found in control (0.82 & 0.84) during both the years.

4.6.3 Available Lead

Irrigation treatments and soil amendments caused significant variation in lead content in soil for both the years. However, the interaction between irrigation water and soil amendments was non- significant.

The data on available lead is given in table 4.50 and illustrated in fig. 4.50 reveals that irrigation treatments comprising of Hindon water alone or in mixture resulted in significantly higher lead content in soil as compared to 100% ground water. Irrigation treatment of 100% Hindon water resulted in maximum available lead (9.45 & 9.42) which was significantly higher than Hindon & ground water in 1:1 ratio (9.35 & 9.32) followed by Hindon & ground water in 1:3 ratio (9.22 & 9.18) while lowest lead content & uptake was found with 100% ground water (9.08 & 9.04) during both the years of experiment.

Incorporation of different soil amendments resulted in lower lead content in soil as compared to control during both the years. Lowest available lead was observed with the application of biochar @ 5 tonnes ha^{-1} (9.10 & 9.07) followed by activated carbon (9.24 & 9.21) and vermicompost (9.37 & 9.32) while highest was noted in control (9.47 & 9.52) during both the years.

4.6.4 Available Nickel

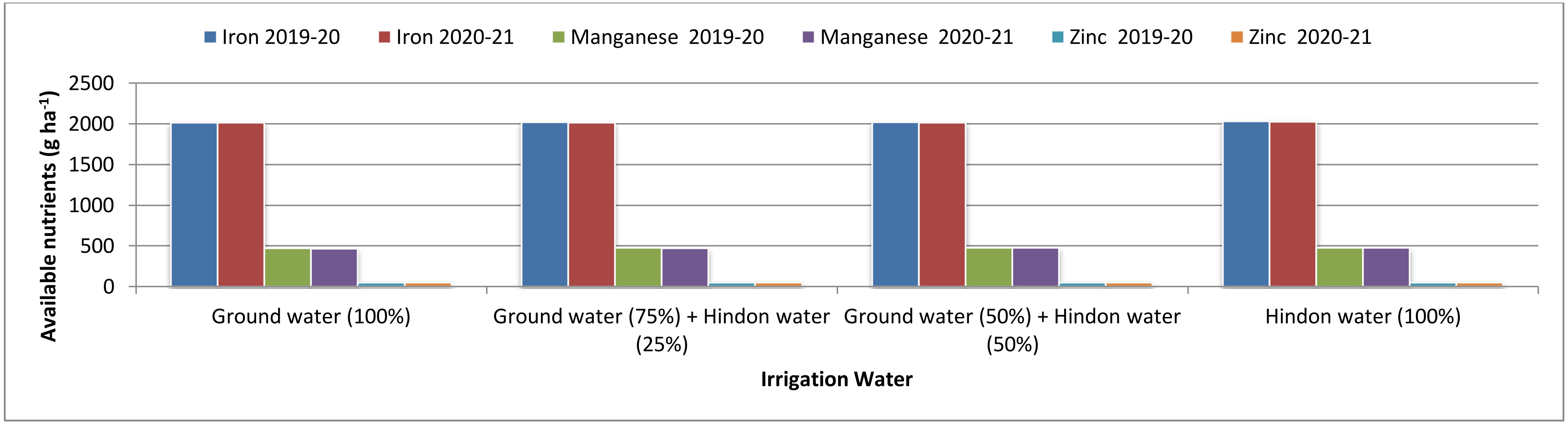
Different irrigation treatments and soil amendments exhibited significant influence on available nickel for both the years. However, the interaction between irrigation water and soil amendments was non- significant.

Perusal of data given in Table 4.50 and illustrated in Fig. 4.50 reveals that nickel concentration in soil increased significantly with increased proportion of Hindon water in applied irrigation. Irrigation treatment of 100% Hindon water resulted in highest value of available nickel (18.10 & 18.02) which was significantly higher than dilution of raw Hindon water with ground water in 1:1 ratio (17.75 & 17.68) followed by dilution of raw Hindon water with ground water in 1:3 ratio (17.51 & 17.42) while lowest available nickel (17.07 & 17.02) was recorded with 100% ground water for both the years.

Different soil amendments resulted in lower available nickel as compared to control during both the years. Lowest nickel content in soil was recorded with the application of biochar (17.10 & 17.05) followed by activated carbon (17.56 & 17.46) and vermicompost @ 5 tonnes ha^{-1} (17.85 & 17.78) while highest was recorded in control (18.15 & 18.23) for both the years.

4.6.6 Available Iron

Iron content in soil was significantly influenced under different irrigation treatments and soil amendments. However, the interaction between irrigation water and soil amendments was non- significant.



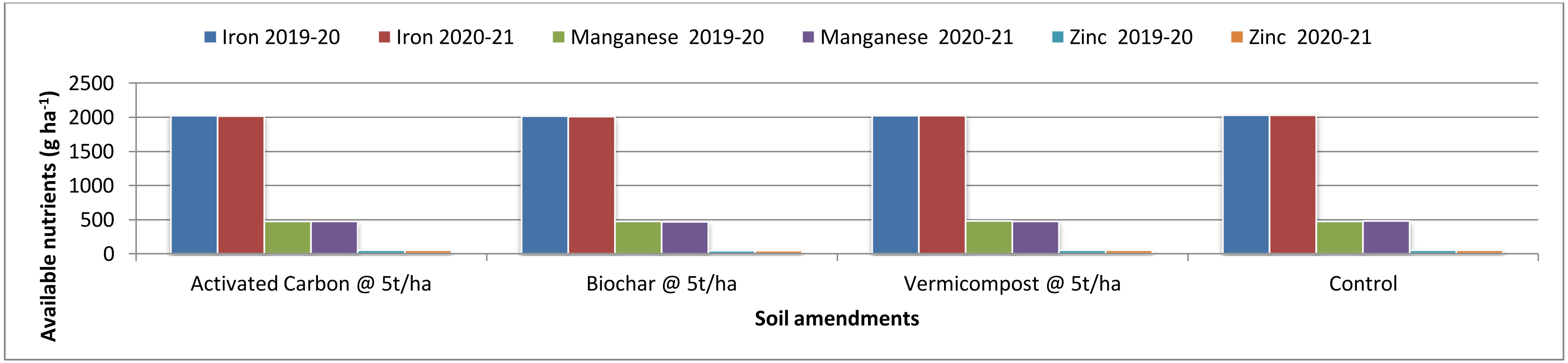


Fig. 4.52 Effect of irrigation treatments and soil amendments on available iron, manganese and zinc (g ha^{-1}) in soil

The data on iron content in soil is given in table 4.51 and depicted in Fig. 4.51 reveals that maximum available iron was recorded with 100% Hindon water (2030.25 & 2027.3) which was significantly superior to dilution of raw Hindon water with 50% ground water (2022.45 & 2017.59) followed by dilution of raw Hindon water with 75% ground water (2018.67 & 2015.58) while lowest iron content in soil was noted with 100 % ground water (2015.68 & 2012.54) during both the years of experiment.

Incorporation of different soil amendments resulted in lower available iron as compared to control for both the years. Lowest available iron was recorded in biochar treatment @ 5 tonnes ha^{-1} (2016.65 & 2011.68) followed by vermicompost (2024.57 & 2020.69) and activated carbon (2020.57 & 2017.50) while highest was found in control (2028.52 & 2032.57) for both the years.

4.6.7 Available Manganese

Irrigation water and soil amendments exhibited significant influence on manganese content in soil for both the years. However, the interaction between irrigation treatments and soil amendments was non- significant.

Perusal of data given in table 4.51 and illustrated in Fig. 4.51 reveals that irrigation treatments comprising of Hindon water alone or in proportion with ground water resulted in significantly higher available manganese in comparison to 100% ground water. Greatest value of manganese content in soil (478.69 & 475.35) was with 100% Hindon water which was significantly superior to dilution of raw Hindon water with 50% ground water (477.20 & 474.48) followed by dilution of raw Hindon water with 75% ground water (475.10 & 472.35) while lowest available manganese (471.62 & 467.29) was recorded with 100% ground water during both the years of experiment.

Incorporation of various soil amendments resulted in lower manganese content in soil as compared to control. Lowest available manganese content in soil was recorded with the application of biochar @ 5 tonnes ha^{-1} (473.68 & 470.54) followed by activated carbon (476.98 & 473.24) and vermicompost (478.52 & 475.20) while highest was found in control (477.29 & 480.29) for both the years.

4.6.8 Available Zinc

Significant variation was observed in available zinc under different irrigation treatments and soil amendments. However, the interaction between irrigation water and soil amendments was non-significant.

Perusal of data given in table 4.51 and illustrated in Fig. 4.51 reveals that zinc concentration in soil increased significantly with increased proportion of Hindon water in applied irrigation. Maximum available zinc was with 100% Hindon water (49.82 & 49.76) which was significantly superior to Hindon & ground water in 1:1 ratio (49.58 & 49.54) followed by Hindon & ground water in 1:3 ratio (49.30 & 49.25) while lowest zinc content and uptake in sorghum (47.98 & 47.94) was recorded with of 100% ground water during both the years of experiment.

Application of soil amendments resulted in lower available zinc as compared to control during both the years. Maximum zinc content in soil was noted in control (49.80 & 49.85) followed by vermicompost (49.32 & 49.27) and activated carbon (49.62 & 49.57) while lowest was with application of biochar @ 5 tonnes ha^{-1} (48.02 & 47.96) during both the years.

5.7 Effect of irrigation water on Sorghum

5.7.1 Growth attributes

Irrigation treatments had pronounced effect on plant height of sorghum at all the stages of crop growth during both the years. Taller plants of sorghum were measured in irrigation treatment of 100% Hindon water as compared to rest of the irrigation treatments. This could be possibly due to presence of higher concentration of macro (nitrogen, phosphorus and potassium) and micro nutrients (zinc, iron and manganese) along with organic matter in Hindon water. Continuous use of Hindon water for irrigation purpose made essential nutrients available to the plants for uptake that might have contributed to enhanced plant height of fodder sorghum. Also, due to repeated use of Hindon water in experimental field, the soil accumulated greater concentration of essential nutrients which could have attributed to taller plants of sorghum. Similar findings were given by Harati *et al.,* they observed that irrigation with urban wastewater on fodder corn in southeren Tehran increased the plant height in comparison to control and stated that irrigation with sewage provides nutritional elements and therefore the plant growth characteristics improved. Similarly, in a field experiment by Gupta *et al.,* (2015) to examine the effects of urban waste water irrigation on the growth & yield on forage sorghum revealed that irrigation with waste water increased plant height, number of leaves per plant and green forage yield.

Accumulation of dry matter showed significant variation under different irrigation treatments. Maximum accumulation of dry matter was recorded in sorghum crop given 100% Hindon water as compared to rest of the irrigation treatments. This might be due to the presence of excessive nutrients present in Hindon water which have manurial potential needed for high fodder growth and development and hence higher accumulation of dry matter was noted in sorghum. In similar studies, Gupta *et al.,* (2015) reported that irrigation with sewage water and scheduling at 1.2 ID/CPE ratio led to significant increase in plant height, number of leaves per plant, leaf area index, dry matter content and green fodder yield in comparison to ground water respectively. Similar results were obtained by Hamza *et al.,* (2002), they conducted a study in Khartoum State comparing the effect of fresh water versus domestic sewage water on the growth of different forage sorghum cultivars and concluded that there was an increase in vegetative growth of sorghum with sewage water irrigation.

5.7.2 Yields

Similar to growth attributes, green and dry fodder yield showed improvement with application of 100% Hindon water. Fodder yield increased with the increased proportion of Hindon water in the applied irrigation. The nutrient content of Hindon water (N, P, K) could have caused superior growth of fodder sorghum which consequently resulted in achieving maximum green fodder yield. Irrigation with 100 % Hindon water accelerated the growth and yield that resulted in highest green fodder yield. It could be attributed to greater content of inorganic nutrients present in raw Hindon water along with application of recommended doses of fertilizer which yielded greater fodder yield. The trend of increase in yield with application of 100 % waste water treatment is in conformity with study conducted by Nadia (2005), who recorded increased sorghum yield with the use of wastewater for irrigation rather than tube well-water and observed that it might be due to higher amount of nitrate in municipal treated wastewater which had led to a significant increase in the yield. Similarly, in a field experiment by Gupta *et al.,* (2015) examined the effects of irrigation with urban waste water on the growth & yield of forage and revealed that irrigation with waste water increased green forage yield. Also, Mandi and Abissy (2000) working on sorghum, Kouraa, *et al.,* (2002) on potato, Munir and Mohammad (2004) on lettuce, Lopez *et al.,* (2006) on alfalfa, observed that irrigation of these crops with treated sewage water resulted in significant increase in yield as compared to normal water.

Improved growth attributes contributed to better dry fodder yield in Hindon water-irrigated plots compared to 100 % ground water for both the years. Maximum dry fodder yield was recorded with 100% Hindon water in comparison to rest of the irrigation treatments which could be possibly due to presence of higher concentration of essential nutrients present in Hindon water *viz.,* N, P, K, Ca, Mg, Zn, Fe and Mn which could have enhanced the dry fodder yield for both the years. The results are in conformity with Bashey *et al.,* (2007), they conducted a experiment to study the effect of wastewater in alfalfa and observed that highest fodder yield was obtained from the first cutting by using 100% treated sewage water which dominated all other water mixtures giving the highest alfalfa fodder yield.

5.8 Nutrient content

Irrigation with 100% Hindon water recorded maximum nitrogen content and uptake in fodder sorghum as compared to rest of the irrigation treatments. The nitrogen content increased with the enhanced proportion of Hindon water in the applied irrigation. As the amount of Hindon water in irrigation treatment increased, the quantity of N, P and K in the irrigated plots also increased which might have led to greater availability of inorganic nitrogen in soil and in turn improved nitrogen uptake by sorghum. The nutrients (N, P, K) in Hindon water facilitated their better uptake in fodder sorghum resulting in higher nitrogen content and uptake in fodder for both the years. In similar studies conducted by Bernala *et al.,* 2006, they observed that soil nitrogen uptake increased by waste water irrigation because of plentiful nitrogen present in urban wastewater. Also, availability of adequate number of micronutrients in rhizosphere caused more nitrogen uptake and eventually enhanced protein synthesis.

Highest value of phosphorus content in sorghum was found with the application of 100% Hindon water against rest of the irrigation treatments. This could be possibly because Hindon water is rich in phosphorous, required for better growth and development of plants. Phosphorus content & uptake increased with the increasing proportion of Hindon water in the applied irrigation. Therefore, irrigation with 100 % Hindon water led to higher concentration of phosphorous in soil which caused higher phosphorous uptake by sorghum for both the years. In a similar experiment conducted in heavy metals spill area to study the accumulation of chemical elements in soil and two crops viz., sunflower and sorghum by Murillo *et al.*, (1999), they reported that the leaves of sorghum crop had higher nutrient concentrations (N, P and K for sorghum) than control, indicating a 'fertilizing' effect caused by the sludge. Also in a study by Rusan et al., (2007) they revealed that in some cases wastewater application provides N, P and K up to 4, 8 and 10 times more than the need of forage plants.

Potassium content and uptake in fodder sorghum was maximum with 100% Hindon water against rest of the irrigation treatments. It was noted that the potassium content & uptake increased with the increased proportion of Hindon water in applied irrigation. As the concentration of potassium was higher in Hindon water which might have led to greater availability of potassium in soil and hence increased its uptake by sorghum plants for both the years. These findings are consistent with the study conducted by Amir *et al.*, (2011), they revealed that irrigation with wastewater significantly increased the macro nutrient content (N, P and K) in corn forage by irrigation with wastewater. This increase could be related to the amount of sufficient nutrients elements present in wastewater. In similar studies conducted by Murillo *et* *al.,* (1999), they reported that leaves of spill affected sorghum plants had higher potassium concentration than controls, indicating a 'fertilizing' effect caused by the sludge. In similar studies by Rusan *et al.,* (2007) they revealed that in some cases wastewater application provides N, P and K up to 4, 8 and 10 times more than the need of forage plants.

Irrigation with 100% Hindon water resulted in highest value of arsenic content and uptake in fodder against rest of the irrigation treatments. It was noted that arsenic content & uptake in fodder was higher in treatments comprising of Hindon water in applied irrigation. Arsenic was present in Hindon water in low amounts, however continuous application of Hindon water for irrigating field crops had caused considerable accumulation of arsenic in soil of experimental field which might have increased its availability in soil over the period of time resulting in higher value of arsenic content & uptake in fodder sorghum. Similarly, in an experiment conducted in heavy metals spill area to study the accumulation of chemical elements in soil and two crops viz., sunflower and sorghum - affected by Murillo *et al.,* (1999), they reported that seeds of spill-affected sunflower plants did accumulate more As, Cd, Cu and Zn than control, however their values were below the toxic levels. They revealed that the leaves of sorghum plants accumulated more As, Bi, Cd, Mn, Pb and Zn than controls, however these values were also below toxic levels for livestock consumption.

Irrigation with 100% Hindon water resulted in highest value of cadmium content and uptake in fodder against rest of the irrigation treatments. Cadmium content & uptake was enhanced with the increase in quantity of Hindon water in the applied irrigation. Cadmium was present in Hindon water in low amounts, however continuous application of Hindon water for irrigating field crops had caused considerable accumulation of cadmium in soil of experimental field which might have increased its availability in soil over the period of time resulting in higher value of cadmium content & uptake in fodder sorghum. Similarly, in an experiment conducted in a heavy metal spill area to study the accumulation of chemical elements in soil and plants (sorghum) by Murillo *et al.,* (1999), they reported that leaves of sorghum plants accumulated more cadmium than control, however their values were also below toxic levels for livestock consumption.

Irrigation treatment of 100% Hindon water in comparison to rest of the irrigation treatments showed maximum value of lead content and uptake in sorghum plants. This could be possibly due to presence of lead in considerable in Hindon water which might have caused higher availability of lead in soils irrigated with raw Hindon water and in turn enhanced lead content & uptake in fodder sorghum. In an experiment conducted in heavy metals spill area to study the accumulation of chemical elements in soil and two crops viz., sunflower and sorghum - affected by Murillo *et al.,* (1999), they reported that seeds of spill-affected sunflower plants did accumulate more As, Cd, Cu and Zn than controls, but values were below toxic levels. Leaves of sorghum plants accumulated more As, Bi, Cd, Mn, Pb and Zn than controls, however these values were also below toxic levels for livestock consumption.

Nickel content and uptake in fodder sorghum was higher with 100% Hindon water as compared to rest of the irrigation treatments. Nickel content & uptake in fodder increased with the increasing proportion of Hindon water in the applied irrigation. Continuous application of Hindon water for irrigation might have caused considerable accumulation of nickel in soil of the experimental field that might have increased nickel availability in soil over the period of time. As the quantity of Hindon water increased in the irrigation mixture, content of nickel also increased with more availability for sorghum plants uptake.

Iron content and uptake in fodder sorghum was maximum in irrigation treatment of 100% Hindon water against rest of the irrigation treatments. This could be possibly due to presence of higher iron content in Hindon water coupled with its greater concentration in soil of field trial which increased iron availability in soil for plant uptake. Further, as the quantity of Hindon water increased in the irrigation mixtures, content of iron also increased proportionately with more availability for wheat plants uptake. Similarly, in a research conducted by Rajabisorkhani and Ghaemi, 2012 at Bajaga Research station, Shiraz University, they concluded that irrigation treatments with wastewater increased the plant yield and concentration of potassium, calcium, phosphorus, iron, manganese and zinc as compared to well water & there was a significant difference at the level of 5%.Also, in a study conducted by Ratan *et al.*, (2005), they reported that the waste water irrigation increased iron concentration in corn. They further concluded that this element was mainly accumulated in root of corn plant and was less transmitted to the plants shoot.

Irrigation with 100% Hindon water in comparison to rest of the irrigation treatments showed maximum value of manganese content and uptake in sorghum plants. This could be possibly because of the continued application of Hindon water in soil of field experimental that might have caused considerable accumulation of manganese over the period of time. Also, as the quantity of Hindon water increased in the irrigation mixture, content of manganese also increased with more availability for sorghum plants uptake. Similarly, in a research conducted by Rajabisorkhani and Ghaemi, (2012) at Bajaga Research station, Shiraz University, it was concluded that irrigation treatments with wastewater resulted in highest plant yield and manganese content in sorghum compared to well water. Also, in a study by Ratan *et al.*, (2005), they reported that the use of effluent water, increased the concentration of manganese in corn and showed that this element was mainly accumulated in root of corn plant and was less transmitted to the plants shoot. They also reported that zinc content in corn was also increased was effluent application.

Application of 100% Hindon water resulted in highest value of zinc content and uptake in fodder sorghum against all the irrigation treatments. Zinc content & uptake in fodder increased with the increasing proportion of Hindon water in the applied irrigation. Since, zinc was present in greater concentration in Hindon water, therefore it might be readily available to plants through irrigation that might have resulted in higher content & uptake of zinc in sorghum plants. In similar studies by Boll *et al.,* (1986), they reported that irrigation using wastewater increased the concentration of zinc to toxic levels in the soil and increased zinc uptake by plants. In similar studies Munir *et al.,* (2007), they reported that irrigation of forage plants with urban waste water for 2 to 10 years increased zinc, copper, iron and manganese concentrations in the soil. In similar studies by Singh *et al.,* 2010, they revealed that the long-term use of industrial or municipal waste water in irrigation can lead to the accumulation of heavy metals in soil and agricultural plants. Similarly, in a research conducted by Rajabisorkhani and Ghaemi, 2012 at Bajaga Research station, Shiraz University, they concluded that irrigation treatments with wastewater increased the plant yield and concentration of potassium, calcium, phosphorus, iron, manganese and zinc as compared to well water & there was a significant difference at the level of 5%.

5.9 Bioaccumulation Factor and Transfer factor of Arsenic

Different irrigation treatments exhibited significant influence on bioaccumulation of arsenic in stem & roots of sorghum plants**.** Irrigation with 100% Hindon water recorded maximum bioaccumulation of arsenic in stem & roots of sorghum in comparison to different irrigation treatments. Irrigation with 100% Hindon water not only readily provided macro & micro nutrients but also accumulated heavy metals in soil for plant uptake. Also as the amount of irrigation by Hindon water increased, the bioaccumulation of arsenic in stem & roots of fodder also increased for both the years.

5.9.1 Bioaccumulation Factor and Transfer factor of Cadmium

Bioaccumulation of cadmium in stem & roots of sorghum was maximum with 100% Hindon water. Irrigation with 100% Hindon water recorded maximum bioaccumulation of cadmium in stem & roots of sorghum in comparison to different irrigation treatments. Hindon water not only readily provided essential nutrients but was also loaded with heavy metals for plant uptake. As the amount of irrigation by Hindon water increased, the bioaccumulation of cadmium in stem & roots of fodder also increased for both the years.

5.9.2 Bioaccumulation Factor and Transfer factor of Lead

Different irrigation treatments exhibited significant influence on bioaccumulation of lead in stem and roots of sorghum**.** Irrigation with 100% Hindon water recorded maximum BAF value of lead in stem & roots of sorghum in comparison to different irrigation treatments. Irrigation with 100% Hindon water not only enriched soil with essential nutrients but also incorporated heavy metals in soil. As the proportion of Hindon water increased in the applied irrigation, the availability of lead also increased in irrigated plots for uptake by sorghum for both the years.

5.9.3 Bioaccumulation Factor and Transfer factor of Nickel

Irrigation treatments exhibited significant influence on bioaccumulation of arsenic in stem & roots of sorghum**.** Irrigation with 100% Hindon water recorded maximum BAF value of nickel in stem & roots of sorghum in comparison to different irrigation treatments. This could be possibly due to presence of higher nickel content in

Hindon water coupled with its greater concentration in soil of experiment field which increased nickel availability in soil for plant uptake. Further, as the quantity of Hindon water increased in the irrigation mixtures, content of nickel also increased simultaneously with more availability & uptake of nickel by fodder for both the years.

5.9.4 Bioaccumulation Factor and Transfer factor of Iron

Irrigation in the form of water mixtures exhibited significant influence on the bioaccumulation factor of iron in stem & roots of fodder sorghum**.** Application of 100% Hindon water noted maximum value of BAF iron in stem & roots of of sorghum in comparison to different irrigation treatments. This could be possibly due to presence of higher iron content in Hindon water coupled with its greater concentration in soil of field trial which increased iron availability in soil for plant uptake. Further, as the quantity of Hindon water increased in the irrigation mixture, content of iron also increased with more availability for plants uptake during both the years.

5.9.5 Bioaccumulation Factor and Transfer factor of Manganese

Application of various irrigation strategies significantly influenced the bioaccumulation factor of manganese in stem & roots of sorghum**.** Irrigation with 100% Hindon water recorded maximum BAF value of manganese in stem & roots of sorghum in comparison to different irrigation treatments. This might be due to presence of greater concentration of manganese in Hindon water along with its higher concentration in soil of experiment field which made manganese readily available in soil for plant uptake. Also, as the proportion of Hindon water increased in irrigation mixture, manganese content also increased with more availability for sorghum plants uptake.

5.9.6 Bioaccumulation Factor and Transfer factor of Zinc

Different irrigation strategies exhibited significant influence on bioaccumulation of arsenic in stem & roots of sorghum**.** Irrigation with 100% Hindon water recorded maximum BAF value of arsenic in stem & roots of sorghum in comparison to different irrigation treatments. This was possibly due to higher concentration of zinc in Hindon water coupled with over accumulation of zinc in soil of research field which made zinc available for plant uptake. As the proportion of Hindon water increased in irrigation mixture, content of zinc also increased in fodder for both the years

5.10 Effect of soil amendments on fodder sorghum

5.10.1 Growth Parameters

Among the various soil amendments used, significant increase in plant height of sorghum during both the years of experiment was observed with the application of biochar @ 5 t ha^{-1} followed by incorporation of vermicompost @ 5 t ha^{-1} and activated carbon @ 5 t ha^{-1}. Lowest plant height was observed in control plots against all soil amendments. This could be possibly due to unique characteristics of biochar *viz.*, high porosity which enhances the water retention capacity, high cation exchange capacity which influence the retention of nutrients; direct supply of nutrients and increase of beneficial microorganisms which might promote the release and uptake of nutrients by plants resulting in higher photosynthetic rate leading to better plant growth and taller height of sorghum plants. The increase in the nutrient uptake with incorporation of biochar might be due to release of nutrients as a result of decomposition, which caused enhancement in growth characters, increasing rate of N, P, K and micronutrients availability for longer period from biochar, which met the crop demand. Similar findings were given by Elangovan (2014) who observed significantly higher N, P and K uptake by cotton crop with application of biochar @ 10 t + 100% NPK. Biochar had influenced the growth of the sorghum crop at all the stages and it increased with increasing levels of application might be due to the biochar's ability to reduce leaching of nutrients, increase water and nutrient retention, increase microbial activity and aeration in the sandy loam soil and there by slow, steady and balanced supply of nutrients. This is in confirmation with the findings of Laird *et al.,* (2009) and Van Zwieten *et al.,* (2010) who reported that plant growth and shoot biomass of oat and alder, respectively were significantly greater in biochar treatments compared with unamended soil (no biochar).

Dry matter accumulation in sorghum showed consistent variation under different soil amendments. Highest accumulation of dry matter was observed with the incorporation of Biochar @ 5t ha^{-1} followed by vermicompost and activated carbon. Incorporation of biochar improved the nutrient and carbon availability in soil that might have resulted in higher plant metabolic functions leading to better crop development and dry matter production. However, biochar had influenced the growth of the sorghum crop at all the stages and it increased with increasing levels of application might be due to the biochar's ability to reduce leaching of nutrients, increase water and nutrient retention, increase microbial activity and aeration in the sandy loam soil and there by slow, steady and balanced supply of nutrients. Similar findings were given by Laird et al., (2009) and Van Zwieten et al., (2010) who revealed that plant growth and shoot biomass of oat and alder, respectively were significantly higher in biochar treatments compared with unamended soil (no biochar).

5.10.2 Yield

Similar to growth attributes, green and dry fodder yield of sorghum showed improvement with the application of various soil amendments. The increase in sorghum yield was mainly related to greater nutrient retention, minimized nutrient losses; improved soil properties like increase in water-holding capacity, decrease in soil compaction and immobilization of contaminants and enhanced soil biological properties such as favourable root environment, greater microbial activity favouring nutrient availability resulting in higher yield of sorghum leading to greater green and dry fodder yield of sorghum in plots amended with biochar.

Maximum green fodder yield was obtained in treatments where sorghum plots were incorporated with biochar @ 5t ha^{-1} followed by vermicompost and activated carbon. This could be possibly due to presence of macro and micro nutrients that facilitated in achieving better growth of sorghum plants leading to enhanced green fodder yield. This could be attributed to greater nutrient availability and increased micro-organisms activity that led to higher green fodder yield for both the years. The increase in green forage yield of sorghum with application of biochar may be due the slow release and timely availability of nitrogen from organic sources which were less subjected to losses as compared to mineral N applied which losses from soil more rapidly. An increase of plant available nutrients after biochar application has been repeatedly shown in the field experiments by Farkas *et al.*, (2020), Rondon, *et al.*, (2010) and Quilliam *et al.*, (2012) observed that their was an increase in green forage yield of sorghum with application of biochar that might be due the slow release and timely availability of nitrogen from organic sources which were less subjected to losses as compared to mineral N applied which losses from soil more rapidly. Similar results were reported by Uzoma *et al.*, (2011)

Maximum dry fodder yield in sorghum was produced in plots receiving biochar @ 5 t ha^{-1} followed by vermicompost and activated carbon. This increase in dry fodder yield might be due to greater nutrient retention, higher cation exchange capacity and enhancement in soil biological properties which might have favoured greater nutrient availability that contributed in achieving maximum dry fodder in plots amended with biochar @5 t ha^{-1} for both the years

5.11 Nutrient content

Incorporation of soil with biochar @ 5 t ha^{-1} resulted in highest nitrogen content and uptake in sorghum as compared rest of the soil amendments and control for both the years. In similar study conducted by Steiner *et al.*, (2008), they reported that the increase in nitrogen retention by charcoal amendments was higher than compost. They observed that addition of biochar to soil significantly increased plant nitrogen concentrations and concluded that even at low biochar application rate (10 ton/ha), plant nitrogen uptake increased from 41 to 45%, compared to control and nitrogen uptake increased further with increase in biochar application rate. Similarly, Uzoma *et al.*, (2011), they revealed that the rate of biochar application improved the rate of nitrogen uptake in maize. Further, Smith and Tibbett (2004) used sewage sludge as a soil amendment and found that loss of nitrogen by ammonia volatilization or nitrate leaching may limit the benefits of sludge amendments and concluded that such nutrient losses could be mitigated by amending the soil with biochar which increases the nitrogen fertilizer use efficiency. In similar findings it was revealed that the application of biochar may increase nutrient retention in the soil by increasing soil pH (Hossain *et al.*, 2020) and CEC (Glaser *et al.*, 2002)) due to reduction in loss of nitrate nitrogen through leaching (Hagemann, Kammann, Schmidt, Kappler, & Behrens, 2017; Yao, Gao, Zhang, Inyang, & Zimmerman, 2012). Furthermore, microbial nitrogen fixation, which was shown to increase after biochar application (Rondon, Ramirez Orozco, Hurtado, & Lehmann, 2007), may contribute to higher plant available nitrogen concentrations in the biochar-amended plots and revealed that if this repeated input is provided as biochar, it would reduce the requirement for mineral fertilizers. They further concluded that the relatively low but repeated dose of biochar has a lower probability to negatively affect the availability of micronutrients and nitrogen, as has been observed at high (≥30 t ha−1) biochar application rates (Borchard *et al.,* 2014; & Kammann, 2017).

Maximum phosphorus content and uptake in fodder sorghum was with the application of biochar @ 5t ha^{-1} against rest of the soil amendments and control. Biochar seems to represent a significant source of available P for crops (Asai *et al.,* 2009; Lehmann *et al.,* 2003). In a similar study conducted by Atkinson *et al.,* (2010), they reviewed several mechanisms which can enhance availability and plant uptake of phosphorus after biochar addition to soil and revealed that biochar acts as a source of soluble phosphorus salts and exchangeable phosphorus forms, avoids phosphorus precipitation by modifying soil pH and enhances microbial activity leading to changes in phosphorus availability. In similar lines, Lehmann *et al.,* (2003a,b) observed that increasing biochar application rates also increased the phosphorus concentration and uptake in plants. In conformity to above results, Asai *et al.*. (2009), revealed that there was an increase in grain yield after addition of biochar to rice fields with low available phosphorus. Also, high microbial biomass carbon starts to get high amounts of ortho-P for its metabolic functions, leading to having high concentrations of bioavailable phosphorus in soil (Masto *et al.,* 2013). Similarly, previous researchers have revealed that biochar encourages mycorrhizal colonization of plant roots by facilitating habitats for them and thereby indirectly promote P solubility (Warnock *et al.,* 2007; Gul and Whalen 2016). Further, in a study conducted by Uzoma *et al.,* (2011), they revealed that enhanced phosphorus uptake by maize grain was with the application of cow manure biochar that attributed to increased phosphorus availability dynamics as a result of increased soil pH that may facilitate increased alkaline extracellular phosphatase activities.

Maximum potassium content and uptake in sorghum was with incorporation of Biochar @ 5t ha^{-1} against rest of the soil amendments and control. Biochar seems to represent a significant source of available potassium for crops. Biochar can increase soil CEC, thereby they can increase the ability of soil to hold potassium and store them in the soil for plant uptake. The increase in the nutrient uptake with biochar might be due to release of nutrients as a result of decomposition, which caused enhancement in growth characters, increasing rate of N, P, K and micronutrients availability for longer period from biochar, which met the crop demand. In addition, biochar may inherently contain exchangeable potassium for plant uptake. In similar studies by Cheng *et al.*, (2008), they revealed that with the application of biochar, there was greater availability of potassium in soil that caused higher concentration of potassium in plants. Further, potassium uptake in maize grain was significant after the application of cow manure biochar as given by Uzoma *et al.*, 2011. Similar findings were also observed by Elangovan (2014) who found that the significantly higher N, P and K uptake in cotton crop was registered by the application of biochar @ 10 t + 100% NPK.

Lowest value of cadmium content in fodder sorghum was with the application of biochar @ 5t ha^{-1} when compared to rest of the soil amendments and control. Incorporation of biochar to the soil not only reduced cadmium in the soil but also reduced its concentration in sorghum crop. Biochar addition has the ability to immobilize cadmium in the soil and thus reduced its concentration in shoot. Also, biochar amendment to heavy metal contaminated soils caused immobilization of cadmium in the soil thereby reducing the uptake of cadmium in sorghum. In similar findings by Qin *et al.*, they showed that the addition of pig manure biochar to the contaminated soil sorbed both cadmium and Lead reducing their leaching losses (i.e., bioavailable forms) by 38% and 71%, respectively in comparison to control, thus lowering cadmium uptake by plants.

Arsenic content in sorghum was found to be lowest with the application of Biochar @ 5t ha^{-1} in comparison to rest of the soil amendments and control. Reduced accumulation of arsenic in sorghum due to biochar addition not only reduced arsenic in soil but also its concentration in the shoot of sorghum plants. Incorporation of biochar has the ability to immobilize arsenic in soil and thus reduce its concentration in shoot. In similar studies, it was observed that the bioavailability of arsenic could be reduced with the application of biochar. Also, biochar addition to heavy metal contaminated soils cause immobilization of heavy metals in the soil and thereby reduce their uptake in field crops.

Lowest value of lead content and uptake in sorghum was with application of Biochar @ 5t ha^{-1} in comparison to rest of the soil amendments and control. It might be possibly because biochar application has the ability to immobilize lead in soil and thus reduce its uptake by plants resulting in lower concentration in straw of sorghum. Also, due to distinct characteristics of biochar like surface heterogeneity, presence of functional groups and a large surface area that adsorb the heavy metals on the soil surface resulted in lower lead content in sorghum. Further, biochar mechanism to adsorb heavy metals on the micro-porous structure and excess soluble salts enhanced the lead immobilization by precipitation and surface sorption and hence resulted in reduced uptake by sorghum.

Nickel content and uptake in sorghum was found to be lower with the application of Biochar @ 5t ha^{-1} in comparison to rest of the soil amendments and control. Since biochar affects the adsorption, deformation and availability of heavy metals due to their high specific surface, porous structure, and presence of oxygenated functional groups (e.g., carbonyl, carboxyl, and hydroxyl)15, 31, that might have resulted in complexation of nickel with functional groups on the biochar surface making reduced availability of nickel for uptake by sorghum plants.

Micronutrients such as iron, manganese, molybdenum, nickel, and zinc are vital for the normal healthy plant growth (Alloway 2008). Biochar addition in sorghum plots resulted in significant lower value of zinc content and uptake in sorghum against all the soil amendments and control. In similar study by Bradl (2004) they revealed that incorporation of biochar causes increase in soil pH that might increase the number of negatively charged surface sites in the soil and correspondingly increase the sorption capacity of soil for cationic metals such as zinc, thus reducing their availability for plant uptake. Similarly, Puga *et al.,* (2015), reported that application of biochar reduced the availability of zinc in mine-contaminated soils thereby decreasing the uptake rate of zinc in Jack bean (Canavalia ensiformis) and Mucuna aterrima plants.

Iron content and uptake was lowest in sorghum plants where soil was amended with biochar @ 5 t ha^{-1} in comparison to rest of the soil amendments and control. Similar results were given by Kloss *et al.,* (2012), they reported that iron uptake in sorghum decreased with the application of biochar amendment which could be possibly be due to the precipitation of iron thereby reducing its content and uptake by sorghum.

Incorporation of biochar @ 5t ha^{-1} in sorghum plots resulted in lowest value of manganese in comparison to rest of the soil amendments and control. Addition of biochar can stimulate or inhibit the activity of microorganisms which affect the availability of manganese by alteration in microorganism population and activity (Meek *et al.,* 1968; Abou-Shanab *et al.,* 2003). This can be attributed to the great retention of manganese resulting in lower uptake of manganese in sorghum (Novak *et al.,* 2009; Amonette and Joseph 2009).

5.12 Bioaccumulation Factor and Transfer factor of Arsenic

Different soil amendments exhibited significant influence on the bioaccumulation of arsenic in stem and rootsof sorghum**.** Application of biochar @ 5 t ha^{-1} recorded lowest BAF value of arsenic in stem & roots of sorghum in comparison to rest of the soil amendments and control. It could be possibly because biochar application has the ability to immobilize arsenic in soil and thus reduce its concentration in root and shoot of sorghum. Previous studies have demonstrated that the bioavailability of arsenic could be reduced with the application of biochar due to immobilization of heavy metals in soil thereby reducing its bioaccumulation and transfer factor in sorghum crop.

5.12.1 Bioaccumulation Factor and Transfer factor of Cadmium

Bioaccumulation of cadmium in stem and roots of sorghum was lowest with the application of biochar @ 5t ha^{-1}. Use of Biochar to ameliorate heavy metal contaminated soils might have caused immobilization of cadmium in soil thereby reducing its uptake in fodder sorghum. The application of biochar tends to reduce the availability of cadmium in mine-contaminated soils thereby decreasing uptake rate of cadmium in Jack bean (Canavalia ensiformis) and Mucuna aterrima plants as given by Puga *et al.,* 2015. In an experiment conducted by Quin *et al.,* they showed that the addition of pig manure biochar to contaminated soil adsorbed cadmium reducing its leaching losses (*i.e.*, bioavailable forms) by 38% and 71%, respectively, as compared to a control.

5.12.2 Bioaccumulation Factor and Transfer factor of Lead

Different soil amendments exhibited significant influence on bioaccumulation of lead in stem and roots of sorghum**.** Application of Biochar @ 5 t ha^{-1} in sorghum recorded lowest BAF of lead in stem and roots of sorghum in comparison to rest of the soil amendments and control. It might be possibly because biochar application has the ability to immobilize lead in soil and thus reduce its concentration in different parts of sorghum. Also, bioaccumulation of lead was reduced with the application of biochar due to stabilization of heavy metals in soil because of its distinct characteristics like surface heterogeneity, different functional groups and a large surface area that adsorb the heavy metals on the soil surface. Biochar mechanism to adsorb lead on the micro-porous structure enhanced the lead immobilization by precipitation and surface sorption resulting in lower bio accumulation of lead from soil to shoot and transfer factor from root to shoot in sorghum.

5.12.3 Bioaccumulation Factor and Transfer factor of Nickel

Different soil amendments exhibited significant influence on bioaccumulation of nickel in stem and roots of sorghum**.** Application of Biochar @ 5 t ha^{-1} recorded lowest BAF value of nickel in stem and roots of sorghum in comparison to rest of the soil amendments and control. This could be possibly because biochar acts as an ideal amendment for metal retention and it might impact nickel uptake due to high cation exchange capacity, acid neutralization in soil and high specific surface area. (Beesley *et al.,* 2010; Asai *et al.,* 2009). Also, enhanced soil pH due to biochar addition might cause lower bio accumulation of nickel from soil to shoot and transfer factor from root to shoot in foddersorghum.

5.12.4 Bioaccumulation Factor and Transfer factor of Iron

Application of different soil amendments exhibited significant influence on bioaccumulation of iron in stem and roots of fodder sorghum**.** Sorghum plots amended with Biochar @ 5 t ha^{-1} recorded lowest BAF and TF value of iron in stem and roots of sorghum in comparison to rest of the soil amendments and control. Uptake of iron decreased with biochar amendment might be due to the precipitation of iron thereby resulting in lower bio accumulation of iron from soil to shoot and transfer of iron from root to shoot.

5.12.5 Bioaccumulation Factor and Transfer factor of Manganese

Different soil amendments exhibited significant influence on bioaccumulation of manganese in shoot and roots of sorghum**.** Application of Biochar @ 5 t ha^{-1} in sorghum plots recorded lowest BAF and TF value of manganese in shoot and roots of sorghum in comparison to rest of the soil amendments and control. Biochar addition might have resulted in significant lower bio accumulation of manganese in fodder for both the years. Also, biochar might have bought increase in soil pH causing an increase of negatively charged surface sites in the soil and correspondingly increase the sorption capacity of soil for cationic metals such as manganese resulting in lower bio accumulation and transfer factor of manganese in sorghum.

5.12.6 Bioaccumulation Factor and Transfer factor of Zinc

Different soil amendments exhibited significant influence on bioaccumulation of zinc in stem and roots of fodder sorghum**.** Application of Biochar @ 5 t ha^{-1} recorded lowest BAF value of zinc in stem and roots of sorghum in comparison to rest of the soil amendments and control. Incorporation of biochar caused an increase in soil pH that might have increased the number of negatively charged surface sites in the soil and correspondingly increase the sorption capacity of soil for cationic metals such as zinc resulting in lower bio accumulation of zinc in shoot and roots of fodder sorghum for both the years.

5.1 Effect of irrigation water (pure/ mixture) on wheat

5.1.1 Growth attributes

Growth attributing characters of wheat *viz.*, plant height, dry matter accumulation and number of tillers m^{-2} were evaluated for their response under four different irrigation water treatments comprising Hindon or ground water alone or in mixtures. It is evident from the research findings that application of Hindon water alone or in mixture always resulted in enhanced value of growth attributes in wheat.

Irrigation treatments had pronounced effect on plant height of wheat at all the stages of crop growth during both the years. Taller plants of wheat were measured in irrigation treatment of 100% Hindon water as compared to rest of the irrigation treatments. This could be possibly due to presence of higher concentration of macro (nitrogen, phosphorus and potassium) and micro nutrients (zinc, iron and manganese) along with organic matter in Hindon water. Use of Hindon water for irrigation purpose made essential nutrients available to the plants for uptake that might have eventually enhanced the plant height of wheat. Also, due to continuous use of Hindon water in adjoining fields, the soil had greater concentration of macro and micro nutrients which might have attributed to greater height of wheat plants. These findings are similar to research conducted by Devi, (1991) and Srikanth and Rao, (1993). Similar findings were given by Ozyazici *et al.,* (2013), they revealed that the use of waste water increased the yield attributes and yield significantly in wheat. They further told that nitrogen was present in plenty in waste water which is main component of the formation of chlorophyll and in general it will increase photosynthesis and thus increase plant height and growth. In a similar study by Harari *et al.,* they examined the effect of irrigation with urban waste water in southeren Tehran on corn fodder. Their research results showed that irrigation with waste water provides nutrients and thus improves plant growth characteristics.

Accumulation of dry matter showed consistent variation under different irrigation treatments. In general, dry matter of wheat increased with the crop age and the highest increment was between 60 to 90 days period. Maximum accumulation of dry matter was recorded in wheat crop given 100% Hindon water as compared to rest of the irrigation treatments. This might be due to the presence of excessive nutrients in Hindon water which has manurial potential due to presence of essential nutrients (N, P and K) needed for higher wheat growth and development and hence higher accumulation of dry matter. In a similar research conducted to study the effect of raw wastewater on growth of wheat by Chakrabarti (1995), revealed that there was paramount increase in growth attributes & dry matter of wheat in the plots irrigated with raw wastewater. The results are in conformity with Kumar *et al.,* (2014) who reported that there was an increase in dry matter of wheat due to presence of high levels of nitrogen, phosphorus and potassium in the waste water irrigation relative to well water.

Number of tillers per meter row length in wheat differed significantly under different irrigation water treatments at all the stages of crop growth. Wheat plants showed prolific growth with highest number of tillers in plots given raw Hindon water against plots irrigated with ground water alone or water mixtures. This might be possibly due to higher amount of mineral nutrients present in Hindon water which might have increased the available nutrients in soil resulting in greater uptake of nutrients by plants causing vigorous growth and greater number of tillers per meter in wheat. Also, it was observed that irrigation water treatments comprising of higher proportion of Hindon water in water mixtures showed improvement in growth attributes of wheat as compared to irrigation with ground water alone. The above results are in conformity with findings by Srikanth and Rao, 1993.

5.1.2 Yield attributes and Yield

Similar to growth attributes, yield attributes and yield of wheat showed improvement with 100% Hindon water. Also, the yield attributes & yield of wheat crop increased with the higher proportion of Hindon water in the applied water mixture. Maximum spike length was measured with 100% Hindon water in comparison to rest of the irrigation treatments. This might be due to greater concentration of essential nutrients *viz.,* nitrogen, phosphorus, potassium, calcium, magnesium, zinc and iron etc., present in 100% Hindon water which in combination with recommended dose of fertilizers led to longer spikes in wheat crop. The increased N, P and K eventually helped augmenting the growth attributes of wheat. The observed results are fully consistent with the findings of Ghanbari *et al.,* (2007).

Maximum number of spikelets spike^{-1} were noticed under irrigation treatment of 100% Hindon water in comparison to rest of the irrigation water. This could be possibly due to greater nutrient concentration present in Hindon water (N, P, K) which might have caused superior growth of the wheat plants and consequently contributed achieving highest number of spikelets spike^{-1} for both the years. Similar findings were given by Ozyazici *et al.,* (2013) on wheat and they revealed that use of waste water increased the yield attributes and yield significantly in wheat crop.

Improved growth attributes contributed to better yield attributes in Hindon water-irrigated plots compared to 100 % ground water. Maximum number of grains spike^{-1} was recorded with 100% Hindon water in comparison to rest of the irrigation treatments which could be possibly due to presence of higher concentration of essential nutrients in Hindon water *viz.,* N, P, K, Ca, Mg, Zn, Fe and Mn which might have led to enhanced number of grains per spike in wheat crop. Similar results were given by Feyzi and Rezvani (2008), they used urban wastewater for the irrigation of barley, wheat, and triticale and concluded that along with increasing wastewater amount up to 50%, the yield attributes *viz.,* number of grains per spike of wheat was enhanced achieving higher yields. Similarly, Lazarova and Bahri, (2005) mentioned that treated sewage water contains elements and metals which are useful to plants thus increasing crop yield.

Heavier grains were obtained in wheat plants irrigated with Hindon water alone or in proportion with ground water. Highest test weight in wheat was observed with 100 % Hindon water against rest of the irrigation treatments. This could be possibly due to macro and micro nutrients present in Hindon water contributed to better growth of wheat plants leading to enhanced growth and heavier grains in wheat. The increased N, P and K eventually helped augmenting the test weight in wheat plants irrigated with 100 % Hindon water. In a field experiment conducted by Kattimani *et al.,* (1989), they observed improved growth attributes that contributed to higher grain yield of wheat in wastewater-irrigated plots compared to the freshwater-irrigated plots containing greater number of relatively heavier grains in these treatments compared to the control, which contributed to the greater yields.

Cumulative effects of the yield attributes boosted up both grain and biological yields of wheat. The nutrient content present in Hindon water (N, P, K) might have caused superior growth of the wheat plants and consequently resulted in achieving maximum grain and biological yields. Irrigation with 100 % Hindon water accelerated the growth and yield attributing characters which resulted in highest grain and biological yields. It could be attributed to greater content of inorganic nutrients present in raw Hindon water along with application of recommended doses of fertilizer which yielded greater grain and biological yields. The trend of increase in grain and biological yields with application of 100 % waste water treatment is in conformity with study conducted by Choukr-Allah *et al.,* 2003 who reported that increasing amount of wastewater irrigation resulted in increased grain and biological yield in wheat. The observed results are fully in consistence with the findings of Ghanbari *et al.,* (2007) who reported that improved vegetative growth in terms of plant height and dry matter due to the contribution of wastewater elevated the biomass yield, which, in turn, together with yield attributes, boosted up the biological yield. These results are also in line with the findings of Mojid and Wyseure (2014), who, in a similar experiment with potato over three years, reported that irrigation by a mixture of fresh water and wastewater having 75 and 100% wastewater in combination with recommended fertilizer dose produced the maximum tuber yield. Similar results were given by Ozyazici *et al.,* (2013) on wheat planting patterns in India, they showed that the use of waste water increased the grain yield of wheat significantly.

Maximum harvest index was observed with 100% Hindon water against rest of the irrigation treatments. This might be possibly due to presence of essential nutrients in Hindon water *viz.,* N, P, K, Ca, Mg, Zn, Fe and Mn which resulted in higher grain yield and greater value of harvest index in wheat for both the years.

5.2 Nutrient content in grain and straw

Irrigation with 100% Hindon water recorded maximum nitrogen content and uptake in grain and straw of wheat in comparison to rest of the irrigation water treatments. Nitrogen uptake in wheat increased with the increasing proportion of Hindon water in the applied irrigation. As the amount of Hindon water in the irrigation treatment increased, the quantity of nitrogen, phosphorus and potassium in the irrigated wheat plots also increased proportionately which led to greater availability of inorganic nitrogen in soil and in turn improved nitrogen content and uptake in wheat grain and straw. The nutrients (nitrogen, phosphorus and potassium) in Hindon water facilitated their better uptake in wheat plants resulting in higher nitrogen content and uptake in wheat for both the years. In a field experiment conducted in Zabol city of Iran, they used five irrigation treatments including: using well water in all stages (t1),well water irrigation up to the flowering stage and then wastewater irrigation from the flowering stage up to the end of growth period (t2), well water irrigation to stem emergence stage and then wastewater irrigation from stem emergence to the end of growth period (t3), well water irrigation to tillering stage and thereafter, wastewater irrigation from tillering to the end of growth period (t4), and wastewater irrigation in all stages of plant growth (t5) and eventually reported that there was increased nitrogen content in wheat seeds with the application of waste water(Ghanbari *et al.*, 2007).

Greatest value of phosphorus content and uptake in grain and straw of wheat was found with 100% Hindon water against rest of the irrigation treatments. This could be possibly because Hindon water was rich in phosphorous content required for better growth and development of plants. Phosphorus content & uptake increased with the increasing proportion of Hindon water in the applied irrigation. Therefore, irrigation with Hindon water led to higher concentration of phosphorous in plots which caused higher phosphorous uptake in wheat grain and straw. This result is consistent with the study conducted by Amir *et al.*, (2011), they reported that wastewater significantly increased the macro elements (N, P and K) content in corn forage by with wastewater irrigation. This increase could be related to the amount of sufficient nutrient elements present in wastewater.

Potassium content and uptake in grain and straw of wheat was maximum under irrigation with 100% Hindon water against rest of the irrigation treatments for both the years. It was observed that potassium content & uptake increased with the increasing proportion of Hindon water in the applied irrigation. As the concentration of potassium was higher in Hindon water which led to greater availability of potassium in soil and hence increased its uptake by wheat plants resulting in greater potassium content. Similar findings were given by Amir *et al.*, (2011), they revealed that irrigation with wastewater significantly increased the macro elements (N, P and K) contents in corn in comparison to ground water. This increase could be related to the amount of sufficient nutrients elements present in wastewater.

Arsenic content and uptake in grain and straw of wheat was highest in wheat plants irrigated with 100% Hindon water in comparison to rest of the irrigation treatments during both the years. It was noted that arsenic content & uptake increased with the increasing proportion of Hindon water in applied irrigation. Since, arsenic was present in excessive concentration in Hindon water, henceforth there was greater availability of potassium in soil resulting in higher uptake by wheat plants.

Irrigation with 100% Hindon water resulted in highest value of cadmium content and uptake in grain and straw of wheat against rest of the irrigation treatments during both the years. It was observed that cadmium content & uptake was enhanced with the greater quantity of Hindon water mixed in the applied irrigation or when applied alone. Since, cadmium was present in Hindon water that resulted in its higher availability to plants and therefore plots irrigated with Hindon water showed higher value of content & uptake of cadmium in wheat plants. The results are in conformity with the research conducted by Singh *et al*., (2010), they studied the risk to human health by heavy metals uptake in rice and wheat (Cd, Cu, Pb, Zn, Ni and Cr) and suggested that waste water irrigation leads to accumulation of heavy metals in wheat causing potential health risks to consumer.

Irrigation strategy of 100% Hindon water showed maximum value of lead content and uptake in grain and straw in wheat plants. This could be possibly due to presence of lead in considerable amounts in Hindon water which might cause higher availability of lead in soils irrigated and in turn enhance content & uptake of lead in wheat. In a field experiment conducted by Singh *et al*., (2010), to study the effect of waste water irrigation on lead uptake by wheat revealed that waste water irrigation leads to accumulation of lead in wheat causing potential health risk to consumers.

Nickel content and uptake in grain and straw of wheat was higher in wheat plants under irrigation treatment of 100% Hindon water in comparison to rest of the irrigation treatments during both the years. The content & uptake of nickel increased with the increasing proportion of Hindon water in the applied irrigation. As the concentration of nickel was in considerable amount in Hindon water so irrigation with Hindon water resulted in its easy availability to plants which might have caused greater content & uptake of nickel in wheat plants.

Irrigation treatment of 100% Hindon resulted in highest value of zinc content and uptake in grain and straw of wheat against all the irrigation treatments during both the years. It was observed that the content & uptake of zinc in wheat plants increased with the increasing proportion of Hindon water in the applied irrigation. Since, zinc was present in greater amount in Hindon water, therefore it was readily available to plants through irrigation resulted in higher content & uptake of zinc in wheat plants. In a research conducted by Rajabisorkhani and Ghaemi, (2012), they concluded that irrigation treatments with waste water, concentration of iron, manganese and zinc increased significantly in wheat than by use of well water.

Iron content and uptake in grain and straw of wheat was maximum in wheat plants under irrigation strategy of 100% Hindon water against rest of the irrigation treatments during both the years. Iron content & uptake in wheat increased with the greater proportion of Hindon water in the applied irrigation. Since, iron concentration was higher in Hindon water so irrigation with Hindon water resulted in its easy availability to plants which might have caused greater content & uptake of iron in wheat plants. In a research conducted by Rajabisorkhani and Ghaemi, (2012), they concluded that irrigation treatments with waste water, concentration of iron, manganese and zinc increased significantly in wheat than by use of well water. Similarly, in a research conducted by Feizi (2001) on heavy metals accumulation in soil and corn irrigated by wastewater for 8 years reported that there was significant increase in concentration of iron content in maize.

In comparison to rest of the irrigation treatments, application of 100% Hindon water showed maximum value of manganese content and uptake in grain and straw in wheat plants. This could be possibly due to presence of manganese in greater amount in Hindon water which might have caused its higher availability in soils irrigated and in turn enhance content & uptake of manganese in wheat.

5.3 Bioaccumulation Factor and Transfer factor of Arsenic

Different irrigation treatments exhibited significant influence on bioaccumulation of arsenic in roots, shoot and grain of wheat**.** Irrigation with 100% Hindon water recorded maximum BAF value of arsenic in stem, root, leaves, shoot and grain of wheat in comparison to different irrigation treatments. Irrigation with 100% Hindon water not only readily provided macro & micro nutrients but also accumulated heavy metals in soil, available for plant uptake. As the amount of irrigation by Hindon water increased, the quantity of arsenic in the irrigated plots also increased proportionately. The results are in conformity with research conducted by Singh *et al*., (2010).

5.3.1 Bioaccumulation Factor and Transfer factor of Cadmium

Bioaccumulation of arsenic in roots, shoot and grain of wheat was maximum with irrigation strategy of 100% Hindon water. Irrigation with 100% Hindon water not only readily provided macro & micro nutrients but also accumulated heavy metals in soil that were available for plant uptake. As the amount of irrigation by Hindon water increased, the quantity of arsenic in the irrigated plots also increased proportionately.

5.3.2 Bioaccumulation Factor and Transfer factor of Lead

Different irrigation treatments exhibited significant influence on bioaccumulation of arsenic in roots, shoot and grain of wheat**.** Irrigation with 100% Hindon water recorded maximum BAF value of arsenic in roots, shoot and grain of wheat in comparison to different irrigation treatments. Irrigation with 100% Hindon water not only readily provided macro & micro nutrients but also accumulated heavy metals in soil that were available for plant uptake. As the amount of irrigation by Hindon water increased, the quantity of arsenic in the irrigated plots also increased proportionately.

5.3.3 Bioaccumulation Factor and Transfer factor of Nickel

Different irrigation strategies exhibited significant influence on bioaccumulation of nickel in roots, shoot and grain of wheat**.** Irrigation with 100% Hindon water recorded maximum BAF value of nickel in roots, shoot and grain of wheat in comparison to different irrigation treatments. Irrigation with 100% Hindon water not only readily provided macro & micro nutrients but also accumulated heavy metals in soil that were available for plant uptake. As the amount of irrigation by Hindon water increased, the quantity of arsenic in the irrigated plots also increased proportionately.

5.3.4 Bioaccumulation Factor and Transfer factor of Iron

Supplementation of irrigation in the form of different water mixtures exhibited significant influence on the bioaccumulation factor of iron roots, shoot and grain of wheat**.** Application of 100% Hindon water noted maximum value of BAF iron in roots, shoot and grain of wheat in comparison to different irrigation treatments. This could be possibly due to presence of higher iron content in Hindon water coupled with its greater concentration in soil of field trial which increased iron availability in soil for plant uptake. Further, as the quantity of Hindon water increased in the irrigation mixtures, content of iron also increased proportionately with more availability for wheat plants uptake.

5.3.5 Bioaccumulation Factor and Transfer factor of Manganese

Application of various irrigation strategies significantly influenced the bioaccumulation factor of manganese in roots, shoot and grain of wheat**.** Irrigation with 100% Hindon water recorded maximum BAF value of manganese in roots, shoot and grain of wheat in comparison to different irrigation treatments. This might be due to presence of greater concentration of manganese in Hindon water along with its higher concentration in soil of experiment field which made manganese readily available in soil for plant uptake. Also, as the proportion of Hindon water increased in irrigation mixtures, content of manganese also increased proportionately with more availability for wheat plants uptake.

5.3.6 Bioaccumulation Factor and Transfer factor of Zinc

Different irrigation strategies exhibited significant influence on bioaccumulation of zinc in roots, shoot and grain of wheat**.** Irrigation with 100% Hindon water recorded maximum BAF value of zinc in roots, shoot and grain of wheat in comparison to different irrigation treatments. This was possibly due to higher concentration of zinc in Hindon water coupled with over accumulation of zinc in soil of research field which made zinc available for plant uptake. As the proportion of Hindon water increased in irrigation mixtures, content of zinc also increased proportionately.

5.4 Effect of soil amendments on wheat

5.4.1 Growth Parameters

Among the various soil amendments used, significant increase in plant height of wheat during both the years of experiment was observed with the application of biochar @ 5 t ha^{-1} followed by incorporation of activated carbon @ 5 t ha^{-1} and vermicompost @ 5 t ha^{-1}. Lowest plant height was observed in control plots against all soil amendments used. This could be possibly attributed to the unique properties of biochar *viz.*, high porosity that enhances the water retention capacity; high cation exchange capacity, that favours the retention of nutrients and prevent their loss; direct nutrient supply and promotion of beneficial microorganisms which might promote the release and uptake of nutrients by plants, thus resulting in higher photosynthetic rate causing better plant growth and taller height of wheat plants (Atkinson *et al.,* 2010; Sohi *et al.,* 2010). Similar findings about the positive effects of biochar for plant height in maize crop have been reported by Manolikaki and Diamadopoulos, they reported that incorporation of biochar improved the uptake of nutrients, activity of soil microorganisms, photosynthetic rate causing increase in plant height. Addition of biochar enhanced the wheat growth and productivity by altering the organic matter mineralization which is associated with nutrients retention, especially nitrogen (Sarman *et al.* 2018; Olszyk *et al.* 2018; Minhas *et al.* 2020).

Accumulation of dry matter showed consistent variation under different soil amendment treatments. Dry matter in wheat increased with the crop age with highest increment between 60 to 90 days period. Maximum accumulation of dry matter was recorded with the incorporation of Biochar @ 5t ha^{-1} followed by activated Carbon and Vermicompost. Incorporation of biochar improved the nutrient and carbon availability in soil that might have resulted in higher plant metabolic functions leading to better crop development and dry matter production. Biochar also helps in reducing the uptake of Na^+ from the soil which improves the overall biomass production, growth and yield of wheat. In a study conducted by Van Zwieten *et al.,* (2010a), they tested the efficiency of two biochars produced from the slow pyrolysis of paper mill waste, at two different agricultural soils in a glasshouse and found that biochar amendment significantly increased biomass in wheat, soybean and radish. Also in a similar experiment conducted by Vaccari *et al.,* 2011, they revealed that application of biochar at 30 t ha^{-1} had significant effect in increasing grain yield, above ground biomass and dry matter in wheat.

Number of tillers per meter row length in wheat differed significantly under different soil amendments at all the stages of crop growth except 30 DAS. Wheat plants showed prolific growth with highest number of tillers in the plots receiving soil amendment- biochar @ 5 t ha^{-1}. Since, biochar has the potential to improve the soil water holding capacity, physiochemical properties, pH and cation exchange capacity that improves the water and nutrient availability in soils and hence improved the number of tillers per meter row length and yield of wheat crop. In a field experiment conducted by Liu *et al.,* (2007) to study the effect of biochar amendment on growth attributes of wheat, they revealed that there was improvement in number of tillers and concluded positive influence on plant growth and development of wheat. They further told that this improvement in growth might be attributed to positive impact of biochar which improves soil field capacity, fertilizer use efficiency, nutrients availability from soil to plants, pH, CEC, and biological properties of soil (Fornazier *et al,.* 2000) that improve soil health and nutrients retention, resultantly improving plant growth and increasing the tillers growth in wheat.

5.4.2 Yield attributes and Yield

Similar to growth attributes, yield attributes and yield of wheat showed improvement with application of various soil amendments. The noted increase in nutrient efficiency after amending soil with biochar were mainly related to a greater nutrient retention, minimized nutrient losses; improved soil properties like increase in water-holding capacity, decrease in soil compaction, and immobilization of contaminants and enhancement in soil biological properties such as more favourable root environment, microbial activities favouring nutrient availability resulting in higher yield attributes leading to greater grain and straw yield of wheat plots incorporated with biochar for both the years.

Maximum spike length in wheat plants was measured in plots incorporated with biochar @ 5 t ha^{-1} in comparison to rest of the soil treatments and control. This might be due to enriched nutrient content of biochar, improvements in soil properties like increase in water-holding capacity, decrease in soil compaction, and enhancement in soil biological properties such as more favorable root environment, microbial activities favoring nutrient availability, etc. leading to longer spikes in wheat plants.

Improved growth attributes contributed to better yield attributes in plots incorporated with soil amendment of biochar @ 5 t ha^{-1} in comparison to rest of the soil treatments and control. Maximum number of spikelets $spike^{-1}$ was noticed with biochar @ 5 t ha^{-1}. This increase in spikelets $spike^{-1}$ might be due to greater nutrient retention, higher cation exchange capacity and enhancement in soil biological properties which might have favoured greater nutrient availability that contributed in achieving maximum number of spikelets $spike^{-1}$ in wheat plots amended with biochar @5 t ha^{-1}.

Maximum number of grains $spike^{-1}$ was observed in plots incorporated with biochar @ 5 t ha^{-1} in comparison to rest of the soil treatments and control. This could be possibly due to enhanced availability of essential nutrients in wheat plots incorporated with biochar. Soil amended with biochar improves the nutrient and carbon availability that results in higher plant metabolic functions. It helps to reduce the uptake of Na^+ from the soil that improves biomass production, growth and yield of wheat.

Heavier grains were obtained in treatments where wheat plots were incorporated with biochar. Maximum value of test weight of wheat was observed in wheat plots receiving biochar @ 5 t ha^{-1} and control. The macro and micro nutrients facilitated achieving better growth of wheat plants leading to enhanced value of growth and yield attributes. This could be attributed to greater nutrient availability and increased micro-organisms activity that lead to higher test weight of grains in wheat.

The improved growth attributing characters in terms of plant height, dry matter accumulation and number of tillers due to application of biochar accelerated the yield attributing characters, and resulted in highest grain and biological yields. This was possibly due to greater content of inorganic nutrients present in Biochar which not only improved the ion transfer ability, soil structure and fertility but also increased the activity of microbes and nutrient holding and exchange capacity of soil. In a field experiment by Haefele *et al.*, (2011), Yang *et al.*, (2015), they observed an increase in yield of wheat in biochar amended soils and cocluded that there was an increase in nitrogen concentration through biochar application, as also found in several field experiments carried out on nutrient-poor tropical soils (Cornelissen *et al.*, 2018; Haefele *et al.*, 2011;Kätterer *et al.*, 2019; Major, Rondon, *et al.*, 2010). In a similar experiment conducted by Vaccari *et al.*, (2011), they revealed that biochar application at 30 t ha^{-1} had significant effect on increasing grain yield, above ground biomass and dry matter in durum wheat. Similarly, in an experiment by Laird *et al.*, (2010), they used biochar amendment in cadmium contaminated soil and recorded an enhancement in biological yield and economic yield of wheat. They concluded that this improvement in wheat yield was due to better soil properties like soil porosity, microbial activity and physical properties of soil that provided favourable environment to microorganism's (Lehmann and Joseph 2009).

Maximum value of harvest index was noted with the application of biochar against rest of the soil amendments and control. This might be possibly due to presence of essential nutrients in biochar which resulted in higher grain yields and greater value of harvest index for both the years. These findings are in conformity with findings given by Laird *et al.,* (2010), they used biochar amendment in heavy metal contaminated soil and recorded an enhancement in biological yield and economic yield and harvest index of wheat. They concluded that this improvement in wheat yield was due to better soil properties like soil porosity, microbial activity and physical properties of soil that provided favourable environment to microorganism.

5.5 Nutrient content in grain and straw

Incorporation of soil with biochar @ 5 t ha^{-1} resulted in maximum nitrogen content and uptake in grain and straw of wheat in comparison to rest of the soil amendments and control for both the years. Similarly, in a field experiment conducted by Steiner *et al.,* (2008), they reported that the increased nitrogen retention by charcoal amendments was more than compost. They further told that the addition of biochar amendment to soil significantly increased the plant nitrogen concentration and even at low biochar application rate (6t ha^{-1}), plant nitrogen uptake increased from 41 to 45%, compared to control and nitrogen uptake increased further with increasing biochar application rate. Also, in a field experiment carried out by Uzoma *et al.,* (2011) they revealed that the rate of biochar application improved the rate of nitrogen uptake in maize. In similar studies by Smith and Tibbett (2004), they used sewage sludge as a soil amendment and found that loss of nitrogen by ammonia volatilization or nitrate leaching may limit the benefits of sludge amendments. Such nutrient losses can be mitigated by amending the soil with biochar which increases the nitrogen fertilizer use efficiency. Also, in a field trial conducted by Rajkovich *et al.,* (2012) they observed that nitrogen uptake in corn plants was increased by 15% after biochar application with recommended fertilizers. Similarly, an increased uptake of nitrogen by several crops grown in soils amended with biochar and nitrogen fertilizer was reported by Van Zwieten *et al.,* (2010). In a study carried out by Van Zwieten *et al.,* (2010a) tested two biochars produced from the slow pyrolysis of paper mill waste in two agricultural soils in a glasshouse and found that they significantly increased nitrogen content &uptake in wheat and biomass in wheat, soybean and radish.

Maximum value of phosphorus content and uptake in grain and straw of wheat was with the application of Biochar @ 5t ha^{-1} against rest of the soil amendments and control. Biochar seems to represent a significant source of available phosphorus for crops (Asai *et al.,* 2009; Lehmann *et al.,* 2003). These findings are in conformity with results given by Atkinson *et al.,* (2010), they reviewed several mechanisms which can enhance availability and plant uptake of phosphorus after biochar addition to soil. It acts as source of soluble P salts and exchangeable phosphorus forms, avoids phosphorus precipitation by modifying soil pH and enhances microbial activity leading to changes in phosphorus availability. In soil, more than 80% of the phosphorus remains immobile and unavailable for plant uptake as a result of adsorption, precipitation, or conversion to the organic form. Application of biochar to the root zone of phosphorus deficient soil increased plant growth by 59% and phosphorus uptake by 73% as given by Shen *et al.,* 2016). In similar lines, Lehmann *et al.,* (2003a, b) revealed that increasing biochar application rates also increase the phosphorus concentration and uptake by plants. In addition, an increase in grain yield has been recorded from after addition of biochar to rice fields with low available phosphorus (Asai *et al.*. 2009). Similarly, previous researchers have revealed that biochar encourages mycorrhizal colonization of plant roots by facilitating habitats for them and thereby indirectly promote phosphorus solubility (Warnock *et al.,* 2007; Gul and Whalen 2016). Also, nutrients in biochar increase the production of phosphorus - solubilizing organic acids. Further, enhanced phosphorus uptake by maize grain with the application of cow manure biochar had been attributed to the increased phosphorus availability dynamics as a result of increased soil pH by biochar as given by Uzoma *et al.,* 92011).Further, it was revealed that in biochar production, most phosphorus fractions become stable during pyrolysis, and hence may provide a long lasting P source to crop fields as given by Dai *et al.,* (2015).

Highest value of potassium content and uptake in grain and straw of wheat was with application of Biochar @ 5t ha^{-1} against rest of the soil amendments and control. Biochar seems to represent a significant source of available potassium for crops. Biochar can increase soil CEC, thereby they can increase the ability of soil to hold potassium and store them in the soil for plant uptake. In addition, biochar may inherently contain exchangeable potassium for plant uptake. A great availability of potassium in soil, soon after biochar application, has been reported (Cheng *et al.,* 2008). In a field trial conducted by Lentz and Ippolito (2012), they revealed that biochar application increased potassium content in plant biomass by 57%, whereas manure application had increased 43% during the same period. Further, potassium uptake by maize grain was significant after the application of cow manure biochar (Uzoma *et al.,* 2011). Several researchers suggested that increased potassium availability in soil could be attributed to enhanced soil pH by biochar (Smider and

Singh 2014). In a field trial carried out by Oram et al. (2014), they revealed that enhanced concentration of potassium in legume biomass had been reported after addition of grass-derived biochar. They further told that available potassium in biochar applied treated soils was even exceeding concentrations in the treatments that received potassium fertilizer. Also, in a study by Karer *et al.,* (2013), they revealed that fresh biochar is considered to have available potassium that could be rapidly taken by plants. Further, addition of biochar to soil promoted the nutrients retention that mostly based on biochar properties such as porosity, surface area, pH and cation exchange capacity as given by Yuan *et al.,* (2011) & Farooq *et al.,* (2020b).

Reduced value of cadmium content and uptake in grain and straw of wheat was with the application of Biochar @ 5t ha^{-1} in comparison to rest of the soil amendments and control for both the years. Incorporation of biochar to the soil not only reduced cadmium in the soil but also reduced its concentration in shoot of maize plants. Biochar addition has the ability to immobilized cadmium in the soil and thus reduced its concentration in shoot. In the previous researchers it was demonstrated that the bioavailability of cadmium could be reduced with the application of biochar. Also, biochar amendment to heavy metal contaminated soils caused immobilization of heavy metals in the soil thereby reducing the uptake of heavy metals. In a study conducted by Puga *et al.,* (2015), they revealed that application of biochar reduced the availability of cadmium and zinc in mine-contaminated soils thereby decreasing the uptake rate of zinc in Jack bean (Canavalia ensiformis) and Mucuna aterrima plants. Similar findings were given by Qin *et al.,* revealed that addition of pig manure biochar to the contaminated soil adsorbed both cadmium and lead, reducing their leaching losses (*i.e.,* bioavailable forms) by 38% and 71%, respectively in comparison to control. Further, in a study given by Chen *et al.,* (2020), they revealed that the contaminated soil amended with biochar reduced the root-shoot translocation of toxic metals. Furthermore, Albert *et al.,* (2021) found that the concentration of toxic metals in roots and shoots were linearly and positively related, thus, cadmium concentration reduction in root could result in decrease of shoot cadmium concentration. In a study carried out by Lu *et al.,* (2014), they revealed that addition of biochar (poultry manure, FYM, and sugarcane press muds) reduced the cadmium uptake in wheat by inducing Cd immobilization in alkaline polluted soil. Soil amendment with various type of biochar slightly increased soil pH in cadmium polluted soil. Addition of biochar reduces the metal mobility by reducing metals phytotoxicities and translocation in plants grown in polluted soil as given by Hussain *et al.,* (2017). In a study by Lu *et al.,* (2017), they revealed that addition of rice straw and bamboo derived biochar induced the Cu, Zn, Pb and Cd immobilization in polluted soil by reducing heavy metals uptake in plants. Addition of biochar potentially reduces the cadmium bioavailability in wheat as compared to farmyard manure, compost and press mud as given by Yousaf *et al.,* (2016). Biochar has potential to reduce the hazards of cadmium toxicities in plants including rice (Bian et al. 2013), rapeseed (Brassica napus L.) (Shaheen and Rinklebe 2015), wheat (Yousaf *et al.,* 2016) and spinach (Spinacia oleracea L.) (Younis *et al.,* 2016).

Reduced value of arsenic content and uptake in grain and straw of wheat was with application of Biochar @ 5t ha^{-1} in comparison to rest of the soil amendments and control. Reduced accumulation of arsenic in grain and straw of wheat due to biochar addition not only reduced arsenic in soil but also reduced its concentration in the shoot of maize plants. Incorporation of biochar has the ability to immobilize arsenic in soil and thus reduce its concentration in shoot. In similar studies it was observed that the bioavailability of arsenic could be reduced with the application of biochar. Also, biochar application to heavy metal contaminated soils caused immobilization of heavy metals in the soil thereby reducing the uptake of heavy metals in field crops. In a field experiment conducted by Kumpiene *et al.,* (2008), they revealed that there was significant reduction in the concentration of arsenic, cadmium and copper in maize shoots at their highest application rate (50 mg/kg) in the biochar-amended soil can be attributed to 2 major mechanisms (i) formation of stable metal-organic complexes and (ii) adsorption of the trace elements to organic matter (Elliott et al. 1986). Similarly, in a study by Liang *et al.,* (2006), they reported that addition of biochar to soil can considerably increase both pH and CEC, which could also have led to the reduction in shoot concentration of arsenic.

Lowest value of lead content and uptake in grain and straw of wheat was with application of Biochar @ 5t ha^{-1} in comparison to rest of the soil amendments and control. It might be possibly because biochar application has the ability to immobilize lead in soil and thus reduced its concentration in shoot and grain of wheat. Also, bioavailability of arsenic could be reduced with the application of biochar due to stabilization of heavy metals content because of unique characteristics like surface heterogeneity, different functional groups, and a large surface area that adsorbed the heavy metals on the soil surface. Biochar mechanism to adsorb heavy metals on the micro-porous structure and excess soluble salts enhanced the lead immobilization by precipitation and surface sorption. In a study carried out by Hussain *et al.,* (2017), they revealed that addition of biochar reduces the metal mobility by reducing metals phytotoxicities and translocation in plants grown in polluted soil. In a study by Lu *et al.,* (2017), they revealed that the addition of rice straw and bamboo derived biochar induced the copper, zinc, lead and cadmium immobilization in polluted soil by reducing heavy metals uptake in plants.

Nickle content and uptake in grain and straw of wheat was found to be lower with application of Biochar @ 5t ha^{-1} in comparison to rest of the soil amendments and control. Since biochar affects the adsorption, deformation and availability of heavy metals due to their high specific surface, porous structure, and presence of oxygenated functional groups (e.g., carbonyl, carboxyl, and hydroxyl) which might have resulted in complexation of nickel with functional groups on the biochar surface making reduced availability of nickel for uptake by wheat plants. Similarly, in a field trial on maize by Rehman *et al.,* (2010), they showed that biochar increased pH and decreased bioavailable nickel in the soil.

Iron content and uptake in grain and straw of wheat was lowest in wheat plants with the application of biochar @ 5 t ha^{-1} in comparison to rest of the soil amendments and control. Micronutrients such as iron, manganese, molybdenum, nickel, and zinc are vital for the normal healthy plant growth (Alloway 2008). Since biochar is mentioned as an ideal amendment for metal retention, it might pose impact on such nutrient uptake. The mechanisms involved in metal retention can be attributed to biochar-induced soil cation exchange capacity, acid neutralization in soil and biochar's high specific surface area (Beesley et al. 2010; Asai et al. 2009). Also, enhanced soil pH due to biochar addition might cause micronutrient deficiencies which occur at high pH (>6). In a similar studies conducted by Kloss *et al.,* (2012), they revealed that uptake of iron decreased with biochar amendment that might be due to the precipitation of iron thereby reducing its mobility into phloem cells for long distance translocation and concluded that low uptake efficiency of the micronutrients after biochar addition suggests that they may prevent toxicity accumulations in plants.

Incorporation of biochar @ 5t ha^{-1} in wheat plots resulted in lowest value of manganese in comparison to rest of the soil amendments and control. Addition of biochar can stimulate or inhibit the activity of microorganisms which affect the availability of manganese by alteration in microorganism population and activity as given by Abou-Shanab *et al.,* (2003).

Biochar addition in wheat plots resulted in significant lower value of zinc content and uptake in grain and straw of wheat against all the soil amendments and control. Incorporation of biochar caused increase in soil pH that might have increased the number of negatively charged surface sites in the soil and correspondingly increase the sorption capacity of soil for cationic metals such as zinc (Bradl 2004). Phosphorus contained in the biochar might induce the formation of metal-phosphate precipitates with low solubility products that are responsible for soil zinc immobilization (McGowen *et al.,* 2001; Cao *et al.*,2003a). The application of biochar was reported to reduce the availability of cadmium and zinc in mine-contaminated soils thereby decreasing uptake rate of zinc in Jack bean (Canavalia ensiformis) and Mucuna aterrima plants (Puga *et al.*, 2015). Similarly, the exchangeable zinc concentrations decreased from 13 to 10 mg/kg with increasing biochar application rates indicating high zinc sorption capacity of biochar (Jayawardhana *et al.*, 2016a). Another study had shown that zinc content in wheat plant tissues decreased after biochar application which could be attributed to high adsorption capacity of biochar as well as enhanced soil pH leading to precipitation of zinc and make it less available (Kloss *et al.*, 2012). Also, compost amendments had contributed to decreasing zinc availability by improving the soil porosity, particle size distribution and cracking patterns allowing the formation of stable water aggregates and thereby limiting the dispersion as given by Park *et al.,* 2011.

5.6 Bioaccumulation Factor and Transfer factor of Arsenic

Different soil amendments exhibited significant influence on the bioaccumulation of arsenic in roots, shoot and grain of wheat**.** Application of biochar @ 5 t ha^{-1} recorded lowest BAF value of arsenic in roots, shoot and grain of wheat in comparison to rest of the soil amendments and control plots. It could be possibly because biochar application has the ability to immobilize arsenic in soil and thus reduce its concentration in root, shoot and grain of wheat. Previous studies have demonstrated that the bioavailability of arsenic could be reduced with the application of biochar due to immobilization of heavy metals in soil thereby reducing its bioaccumulation and transfer factor in wheat crop.

5.6.1 Bioaccumulation Factor and Transfer factor of Cadmium

Bioaccumulation of cadmium in roots, shoot and grain of wheat was lowest with the application of biochar @ 5 t ha^{-1}. Biochar amendment to ameliorate heavy metal contaminated soils caused immobilization of cadmium in the soil thereby reducing its uptake in wheat plants. The application of biochar was reported to reduce the availability of cadmium and zinc in mine-contaminated soils thereby decreasing uptake rate of cadmium in Jack bean (Canavalia ensiformis) and Mucuna aterrima plants (Puga *et al.*, 2015). Qin *et al.*, showed that the addition of pig manure biochar to contaminated soil adsorbed cadmium reducing its leaching losses (*i.e.*, bioavailable forms) by 38% and 71%, respectively, as compared to a control.

5.6.2 Bioaccumulation Factor and Transfer factor of Lead

Different soil amendments exhibited significant influence on bioaccumulation of lead in roots, shoot and grain of wheat**.** Application of Biochar @ 5 t ha^{-1} wheat plots recorded lowest BAF value of lead in roots, shoot and grain of wheat in comparison to rest of the soil amendments and control. It might be possibly because biochar application has the ability to immobilize lead in soil and thus reduced its concentration in shoot and grain of wheat. Also, bioaccumulation of arsenic reduced with the application of biochar due to stabilization of heavy metals in soil because of unique characteristics like surface heterogeneity, different functional groups, and a large surface area that adsorbed the heavy metals on the soil surface. Biochar mechanism to adsorb lead on the micro-porous structure enhanced the lead immobilization by precipitation and surface sorption resulting in lowering its bio accumulation from soil to shoot and transfer factor.

5.6.3 Bioaccumulation Factor and Transfer factor of Nickel

Different soil amendments exhibited significant influence on bioaccumulation of nickel in roots, shoot and grain of wheat**.** Application of Biochar @ 5 t ha^{-1} wheat plots recorded lowest BAF value of nickel in roots, shoot and grain of wheat in comparison to rest of the soil amendments and control. Since biochar is an ideal amendment for metal retention, it might pose impact on nickel uptake due to high cation exchange capacity, acid neutralization in soil and biochar's high specific surface area (Beesley et al. 2010; Asai et al. 2009). Also, enhanced soil pH due to biochar addition might cause lower bio accumulation of nickel from soil to shoot and grain of wheat.

5.6.4 Bioaccumulation Factor and Transfer factor of Iron

Different soil amendments exhibited significant influence on bioaccumulation of iron in roots, shoot and grain of wheat**.** Application of Biochar @ 5 t ha^{-1} wheat plots recorded lowest BAF value of iron in roots, shoot and grain of wheat in comparison to rest of the soil amendments and control. Uptake of iron decreased with biochar amendment that might be due to the precipitation of iron thereby reducing its mobility into phloem cells for long distance translocation (Kloss et al. 2012). However, the low uptake efficiency of the micronutrients after biochar addition suggests that they may prevent toxicity accumulations in plants.

5.6.5 Bioaccumulation Factor and Transfer factor of Manganese

Different soil amendments exhibited significant influence on bioaccumulation of manganese in roots, shoot and grain of wheat**.** Application of Biochar @ 5 t ha^{-1} wheat plots recorded lowest BAF value of manganese in roots, shoot and grain of wheat in comparison to rest of the soil amendments and control. Since biochar is an ideal amendment for metal retention, it might pose impact on manganese uptake due to high cation exchange capacity, acid neutralization in soil and biochar's high specific surface area (Beesley *et al.* 2010; Asai *et al.* 2009). Also, enhanced soil pH due to biochar addition might cause lower bio accumulation of manganese from soil to shoot and grain of wheat.

5.6.6 Bioaccumulation Factor and Transfer factor of Zinc

Different soil amendments exhibited significant influence on bioaccumulation of zinc in roots, shoot and grain of wheat**.** Application of Biochar @ 5 t ha^{-1} wheat plots recorded lowest BAF value of zinc in roots, shoot and grain of wheat in comparison to rest of the soil amendments and control.

5.7 Economics

5.7.1 Cost of cultivation (₹ ha^{-1})

Highest cost of cultivation for both crops sorghum and wheat was incurred with 100 % ground water while lowest cost of cultivation was noted with 100 % Hindon water. This was obvious because Hindon water served as a free and inexpensive source of irrigation while ground water irrigation incurred substantial cost to farmer. Application of different soil amendments resulted in higher cost of cultivation in comparison to control during both the years. This was possibly because of higher cost of soil amendments *viz.,* biochar, vermicompost and activated carbon while no cost of soil amendments was incurred in control.

5.7.2 Gross returns (₹ ha^{-1})

Highest gross returns were obtained in irrigation treatment of 100 % Hindon water while lowest was with 100 % ground water. It could be attributed to greater content of inorganic nutrients present in raw Hindon water along with application of recommended doses of fertilizer which yielded greater yield in both crops.This could be possibly because of the high nutrient content present in Hindon water (N, P, K) that could have caused superior growth of fodder sorghum and wheat which consequently resulted in producing maximum yield in both the crops. Irrigation with 100 % Hindon water accelerated the growth attributes that resulted in improved yield attributes and yields that led to greater fodder yield in sorghum and grain yield in wheat resulting in overall higher gross returns for both crops. Application of different soil amendments resulted in higher gross returns in comparison to control for both the years. Highest gross returns were obtained in biochar treatment followed by vermicompost and activated carbon while lowest was obtained in control during both the years. This could be possibly due to presence of macro and micro nutrients in biochar that facilitated in achieving better growth of sorghum and wheat plants leading to enhanced fodder yield in sorghum and grain yield in wheat resulting in higher gross returns. Application of biochar led to greater nutrient availability and increased micro-organisms activity that produced higher yield for both the crops. The increase in yield of sorghum and wheat with application of biochar may be due the slow release and timely availability of nitrogen from organic sources which were less subjected to losses as compared to mineral N applied which losses from soil more rapidly and therefore this enhanced yield and gross returns of both the crops.

5.7.3 Net returns (₹ ha^{-1})

Highest net returns were obtained in irrigation treatment of 100 % Hindon water while lowest was with 100 % ground water. It could be attributed to greater content of inorganic nutrients present in raw Hindon water along with application of recommended doses of fertilizer which yielded greater yield in both crops. This could be possibly because of the high nutrient content present in Hindon water (N, P, K) that could have caused superior growth of fodder sorghum and wheat plants which consequently resulted in producing maximum yield in both the crops. Irrigation with 100 % Hindon water accelerated the growth attributes that resulted in improved yield attributes and yields leading to greater fodder yield in sorghum and grain yield in wheat and thus resulting in overall higher gross returns for both crops. Application of different soil amendments resulted in higher gross returns in comparison to control for both the years. Highest gross returns were obtained in biochar treatment followed by vermicompost and activated carbon while lowest was obtained in control during both the years. This could be possibly due to presence of macro and micro nutrients in biochar that facilitated in achieving better growth of sorghum and wheat plants leading to enhanced fodder yield in sorghum and grain yield in wheat resulting in higher gross returns. Application of biochar led to greater nutrient availability and increased micro-organisms activity that produced higher yield for both the crops. The increase in yield of sorghum and wheat with application of biochar may be due the slow release and timely availability of nitrogen from organic sources which were less subjected to losses as compared to mineral N applied which losses from soil more rapidly and therefore this enhanced yield and gross returns of both the crops.

5.7.4 B: C ratio

Maximum value of B:C ratio was obtained in irrigation treatment of 100 % Hindon water while lowest was with 100 % ground water for both the years. It was obvious because of higher yields and returns of both the crops by use of raw Hindon water along with application of recommended doses of fertilizer which yielded greater yield in both crops. Irrigation with 100 % Hindon water accelerated the growth attributes that resulted in improved yield attributes and yields that led to greater fodder yield in sorghum and grain yield in wheat resulting in overall higher B:C ratio for both crops. Application of different soil amendments resulted in higher B:C ratio in comparison to control for both the years. Highest B:C ratio was obtained in biochar treatment followed by vermicompost and activated carbon while lowest was obtained in control during both the years. This could be possibly due to presence of macro and micro nutrients in biochar that facilitated in achieving better growth of sorghum and wheat plants leading to enhanced fodder yield in sorghum and grain yield in wheat resulting in higher B:C ratio. The increase in yield of sorghum and wheat with application of biochar may be due the slow release and timely availability of nitrogen from organic sources which were less subjected to losses as compared to mineral N applied which losses from soil more rapidly and therefore this enhanced yield and B:C ratio of both the crops.

6. SUMMARY AND CONCLUSION

The present investigation entitled **"Assessment of heavy metal content in Hindon water and an integrated approach for soil and crop management"** was conducted in field adjoining hindon river situated at Ator village, Ghaziabad during *kharif* & *rabi* season for two consecutive years from June 2019- April 2021 by cultivating fodder sorghum in *kharif* and wheat in *rabi* season respectively. The soil of the experimental field was well drained, sandy loam in texture and slightly alkaline in reaction. It was medium in organic carbon, available nitrogen and high in available phosphorus and potassium. Four irrigation water treatments and three soil amendments were tested in a split- plot design. The salient findings of investigation have been summarized in this chapter as following:

Sorghum

The salient findings of investigation have been summarized in this chapter as follows:

- The tallest height of sorghum plants was noted with 100% Hindon water which was statistically at par to dilution of raw Hindon water with ground water in 1:1 ratio and significantly superior to Hindon & ground water in 1:3 ratio respectively. Irrigation treatment of 100% Hindon water resulted in increase of 15.8 & 16.7, 7.25 & 7.01 and 1.8 & 2.2 (%) in plant height over 100% ground water at 30, 60 days after sowing and at harvest stage respectively. Among the soil amendments, biochar @ 5t ha^{-1} produced significantly taller plants of sorghum which was statistically superior to vermicompost @ 5t $ha\text{-}^{1}$ and activated carbon @ 5t ha^{-1} during both years of experiment. Lowest plant height was observed in control against all soil amendments during both the years. There was about 19.8 & 18.9, 10.5 & 10.3 and 2.6 & 2.7 (%) increase in plant height by application of biochar @ 5t ha^{-1} over control at 30, 60 days after sowing and at harvest respectively.

- Maximum concentration of dry matter was observed in sorghum plants irrigated with 100% Hindon water, being statistically at par to Hindon & ground water in 1:1 ratio and significantly superior to Hindon & ground water irrigation in 1:3 ratio while minimum concentration of dry matter was observed in plots irrigated with 100 % ground water during both the years of experiment. Among different soil amendments, maximum dry matter was produced in biochar treatment @ 5t ha^{-1} which was significantly superior to vermicompost @ 5t ha^{-1} and activated carbon @ 5t ha^{-1} while lowest dry matter was recorded in control during both the years. There was percent increase of 39.06 & 41.14, 7.97 & 8.65 and 4.06 & 4.13 (%) in dry matter in biochar treatment over control at 30, 60 days after sowing and at harvest respectively.
- Maximum yield *viz.* green and dry fodder yield was produced in sorghum plants with 100% Hindon water which was significantly superior to Hindon & ground water in 1:1 ratio followed by dilution of raw Hindon & ground water in 1:3 ratio while lowest green fodder yield was recorded with 100% ground water. Application of 100% Hindon water resulted in percent increase of 14.5 & 17.8 in green fodder yield over 100% ground water, respectively. With regard to soil amendments, application of Biochar @ @ 5t ha^{-1} produced highest green & dry fodder yield which was statistically at par to vermicompost @ 5t ha^{-1} and superior to activated carbon @ 5t ha^{-1} while lowest green fodder yield was noted in control for both the years.
- Highest protein content was noted with 100% Hindon water which was statistically at par to dilution of raw Hindon water with ground water in 1:1 ratio

and significantly superior to dilution of raw Hindon water with ground water in 1:3 ratio while lowest protein content was recorded with 100% ground water during both the years of experiment. Among the soil amendments, Application of biochar @ 5 tonnes ha^{-1} recorded maximum protein content which was statistically at par to vermicompost @ 5 tonnes ha^{-1} and significantly superior to activated carbon @ 5 tonnes ha^{-1} while lowest protein content was noted in control during both the years.

- Maximum nitrogen, phosphorus and potassium content & uptake in sorghum was recorded in irrigation treatment 100% Hindon water and was statistically superior to Hindon & ground water in 1:1 ratio followed by dilution of raw Hindon water with ground water in 1:3 ratio while lowest nitrogen, phosphorus and potassium content & uptake was recorded with 100% ground water. Among different soil amendments, maximum nitrogen, phosphorus and potassium content and uptake in fodder was recorded with Biochar @ 5t ha^{-1} (0.82 & 0.88) which was statistically superior to vermicompost followed by activated Carbon @ 5t ha^{-1} while lowest nitrogen, phosphorus and potassium content & uptake was recorded in control during both the years.
- Maximum content and uptake of arsenic, cadmium, lead, nickel, iron, manganese and zinc in fodder was recorded with 100% Hindon water which was significantly higher than dilution of raw Hindon water with 50% ground water followed by dilution of raw Hindon water with 75% ground water while lowest value of arsenic, cadmium, lead, nickel, iron, manganese and zinc content was observed with application of 100% ground water. Among the soil amendments, highest content and uptake of arsenic, cadmium, lead, nickel, iron, manganese and zinc in sorghum fodder was recorded in control which was

significantly higher than vermicompost @ 5t ha^{-1} followed by activated carbon while lowest was found in biochar treatment during both the years.

- Highest bio-accumulation and transfer factor of arsenic, cadmium, lead, nickel, iron, manganese and zinc in sorghum fodder was recorded with 100% Hindon river water while lowest bio-accumulation and transfer factor for arsenic, cadmium, lead, nickel, iron, manganese and zinc was found with the application of 100% ground water. In regard to soil amendments, lowest bio-accumulation and transfer factor for arsenic, cadmium, lead, nickel, iron, manganese and zinc in sorghum was recorded with the application of biohar @ 5t/ha while highest was found in control for both the years.

Conclusion

The following conclusions can be drawn on the basis of summary of present investigation:

- Irrigation with 100% Hindon water under irrigation treatments and Biochar @ 5t/ha under soil amendments exhibited significant influence on the growth, yield attributes and yields of fodder sorghum as compared to control during both the years.
- Significant improvement in plant height, dry matter accumulation, green and dry fodder yield, NPK content, protein content and yield were highest with the irrigation treatment of 100% Hindon water and Biochar @ 5t/ha under soil amendments.
- Heavy metals *viz.*, arsenic, cadmium, iron and manganese content in fodder sorghum was above the permissible limit which poses toxicity issues if such fodder is ingested by animals.

- Transfer factor shoot of arsenic, cadmium, lead, iron and manganese were more than one indicating that sorghum accumulated greater arsenic, cadmium, lead, iron and manganese in shoot and hence there could be possible exposure of these metals to animals by ingestion of this fodder.

Wheat

- Tallest wheat plants were measured in irrigation treatment of 100% Hindon water which was statistically at par to Hindon & ground water in 1:1 ratio and significantly superior to dilution of raw Hindon water with ground water in 1:3 ratio whereas the shortest wheat plants were noted with 100 % ground water during both the years of experiment. Among the soil amendments, biochar @ 5t ha^{-1} produced significantly taller wheat plants which were statistically at par to vermicompost @ 5t $ha^{-1}$and significantly superior to activated carbon @ 5t ha^{-1} while lowest plant height was observed in control during both the years of experiment.
- Among the various irrigation treatments, maximum number of tillers per meter row length was recorded with 100% Hindon water during both years and was significantly superior to rest of the irrigation treatments while least number of tillers per meter row length was recorded with 100% ground water during both the years of experiment. The maximum number of tillers in wheat plants was recorded at 60 days after sowing with 100% Hindon waterwhich was statistically superior to dilution of raw Hindon water with 50% ground water followed by irrigation with Hindon & ground water in 1:3 ratio and 100% ground water. Among various soil amendments, maximum number of tillers per meter row length was recorded with incorporation of biochar @ 5t ha^{-1} which was statistically superior to vermicompost @ 5t ha^{-1} and activated Carbon @ 5t

ha^{-1} during both the years while lowest number of tillers per meter row was recorded in control for both the years of experiment.

- Maximum concentration of dry matter was noted in raw Hindon water treatment being statistically at par to Hindon & ground water irrigation in 1:1 ratio and significantly superior to Hindon & ground water irrigation in 1:3 ratio while minimum concentration of dry matter was recorded in wheat plants receiving 100 % ground water during both the years of experiment. Among different soil amendments used, maximum dry matter accumulation was recorded with the application of Biochar @ 5t/ha, which was statistically at par to Vermicompost @ 5t/ha while lowest dry matter accumulation was found in control plots.
- The highest value of yield attributes *viz.* spike length, spikelets spike^{-1}, grains spike^{-1} and 1000 grain weight were maximum in wheat plots irrigated with 100% Hindon river water at all the stages while the minimum length, spikelets spike^{-1}, grains spike^{-1} and 1000 grain weight were recorded in wheat plots irrigated with 100% ground water whereas, spike length and 1000 grains weight were under Irrigation at all stages with 100% ground water, respectively. In regard to soil amendments, application of Biochar @ 5t/ha resulted in longest spike length (cm), highest number of spikelets spike^{-1}, maximum grains spike^{-1} and greatest 1000 grain weight and was statistically *at par* to application of Vermicompost @ 5t/ha. Minimum spike length (cm), spikelets spike^{-1}, grains spike^{-1} and 1000 grains weight were recorded in control plots during both the year of experiment.
- Maximum yield *viz.* grain, straw, biological yield and harvest index was produced in wheat plots irrigated with 100% Hindon river water at all stages which was significantly superior to rest of the irrigation strategies Lowest yield

and harvest index of wheat was recorded in wheat plots irrigated with 100% ground water at all the stages. Among different soil amendments, application of Biochar @ 5t/ha recorded maximum grain, straw and biological yield which was statistically at par to application of vermicompost @ 5t/ha, while lowest grain, straw, biological yield and harvest index was observed in control.

Maximum protein content & protein yield in wheat was recorded with 100% Hindon river water and lowest protein content & protein yield was recorded in wheat plots irrigated with 100% ground water at all the stages. Application of raw Hindon water resulted in highest protein content & yield which was statistically at par to dilution of raw Hindon water with ground water in 1:1 ratio and significantly superior to Hindon & ground water in 1:3 ratio while lowest protein content & yield in wheat was recorded in 100% ground water during both the years. Among the soil amendments, biochar @ 5 tonnes ha^{-1} recorded highest protein content & yield which was statistically at par to vermicompost @ 5 tonnes ha^{-1} and significantly superior to activated carbon @ 5 tonnes ha^{-1} while lowest protein content & yield was recorded in control for both the years of experiment.

- Maximum nitrogen, phosphorus and potassium content in grain was recorded in wheat plots applied with irrigation strategy of using 100% Hindon river water at all the stages while lowest nitrogen, phosphorus and potassium content was recorded in wheat plots irrigated with 100% ground water. Also, highest uptake of nitrogen, phosphorus and potassium was recorded in irrigation treatment comprising 100% Hindon water which was statistically superior to Hindon & ground water in 1:1 ratio followed by dilution of raw Hindon water with ground water in 1:3 ratio while lowest nitrogen content in grain and straw of wheat was recorded with 100% ground water during both the years of experiment. Application of raw Hindon water resulted in 2.4 & 3.1 and 27.4 & 44.4 (%) increase of nitrogen content in grain and straw of wheat as compared to 100% ground water during both the years. Among the soil amendments, maximum nitrogen, phosphorus and potassium content and uptake in grain was recorded with the application of biochar @ 5t/ha which was statistically at par to application of vermicompost @ 5t/ha and activated Carbon @ 5t/ha while minimum nitrogen, phosphorus and potassium uptake in wheat was found in control for both the years.

- Maximum nitrogen, phosphorus and potassium content in straw was recorded in wheat plots irrigated with 100% Hindon water while lowest nitrogen, phosphorus and potassium content in wheat straw was noted in wheat plots irrigated with 100% ground water. Highest uptake of nitrogen, phosphorus and potassium was recorded in wheat plots with 100% Hindon water, which was significantly superior to dilution of raw Hindon water with 50% ground water followed by dilution of raw Hindon water with 50% ground water while least value of phosphorous content in grain and straw of wheat was recorded with 100% ground water during both the years of experiment. Application of raw Hindon water resulted in 25.0 & 20.6 and 3.5 & 17.4 (%) increase in phosphorus content in grain and straw compared to 100% ground water. Among the soil amendments, maximum nutrient content and uptake of nitrogen, phosphorus and potassium in wheat was recorded with the application of biochar @ 5t/ha followed by vermicompost @ 5t/ha while lowest content and uptake was recorded in control for both the years.

Highest total nitrogen, phosphorus, potassium content and uptake was recorded with the application of 100% Hindon water which was statistically superior to dilution of raw Hindon water with 50% ground water followed by dilution of raw Hindon water with 50% ground water while least value of phosphorous content in grain and straw of wheat was recorded with 100% ground water during both the years of experiment. Among the soil amendments, maximum total content and uptake was recorded with the application of Biochar @ 5t/ha, which was statistically superior to vermicompost @ 5t/ha while lowest total content and uptake was recorded in control for both the years.

- Greatest value of arsenic, cadmium, lead, nickel, iron, manganese and zinc content in grain of wheat was recorded with 100% Hindon water followed by dilution of raw Hindon water with 50% ground water and dilution of raw Hindon water with 75% ground water during both the years while lowest arsenic, cadmium, lead, nickel, iron, manganese and zinc content was recorded with 100% ground water. Also, maximum uptake of arsenic, cadmium, lead, nickel, iron, manganese and zinc was recorded with 100% Hindon water followed by dilution of raw Hindon water with 50% ground water and dilution of raw Hindon water with 75% ground water while lowest was recorded with 100% ground water during both the years. during both the years. Among the soil amendments, maximum value of arsenic, cadmium, lead, nickel, iron, manganese and zinc content and uptake in grain was recorded in control followed by vermicompost @ 5t ha^{-1} during both years while lowest was noted with application of biochar @ 5t ha^{-1} for both the years.
- The maximum arsenic, cadmium, lead, nickel, iron, manganese and zinc content in straw was recorded with 100% Hindon water which was significantly higher

than dilution of raw Hindon water with 50% ground followed by irrigation with Hindon & ground water in 1:3 ratio while lowest arsenic, cadmium, lead, nickel, iron, manganese and zinc content in straw was recorded with 100% ground water. Also, maximum uptake of arsenic, cadmium, lead, nickel, iron, manganese and zinc was observed in wheat plots given 100% Hindon water which was significantly higher than dilution of raw Hindon water with 50% ground water followed by irrigation with Hindon & ground water in 1:3 ratio for both the years. With regard to soil amendments, lowest content and uptake of arsenic, cadmium, lead, nickel, iron, manganese and zinc was recorded in Biochar treatment @ 5 t ha^{-1} followed by activated carbon @ 5t/ha and vermicompost @ 5t/ha while highest content and uptake was recorded in control for both the years of experiment.

- The highest total arsenic, cadmium, lead, nickel, iron, manganese and zinc uptake was recorded with 100% Hindon water, which was significantly higher than dilution of raw Hindon water with 50% ground water followed by irrigation with Hindon & ground water in 1:3 ratio while lowest uptake of total arsenic, cadmium, lead, nickel, iron, manganese and zinc were recorded with 100% ground water. Among the soil amendments, minimum total uptake was recorded with the application of Biochar @ 5t/ha while highest total uptake was recorded in control for both the years.
- The maximum bio-accumulation and transfer factor of arsenic, cadmium, lead, nickel, iron, manganese and zinc was recorded in wheat plants irrigated ith 100% Hindon water followed by 50% ground water followed by irrigation with Hindon & ground water in 1:3 ratio while minimum bio-accumulation and transfer factor of arsenic, cadmium, lead, nickel, iron, manganese and zinc was

recorded with 100% ground water. Among the soil amendments, lowest bio-accumulation and transfer factor of arsenic, cadmium, lead, nickel, iron, manganese and zinc was recorded in Biochar treatment @ 5t/ha while highest was recorded in control plots during both the years of experiment.

- Among the different irrigation treatments, significantly higher available nitrogen, phosphorus, potassium and organic carbon (%) was with 100% Hindon water and was statistically superior to Hindon & ground water in 1:1 ratio followed by dilution of raw Hindon water with ground water in 1:3 ratio while lowest available nitrogen, phosphorus, potassium c were recorded with 100% ground water for both the years. Among different soil amendments, application of Biochar @ 5t/ha recorded significantly higher available nitrogen, phosphorus, potassium and organic carbon which was statistically superior to vermicompost followed by activated carbon @ 5t ha^{-1} while lowest available nitrogen, phosphorus, potassium and organic carbon (%) was recorded in control during both the years.

  Highest cost of cultivation for both crops was incurred with 100 % ground water which was significantly higher than 75% ground water and 25% Hindon water followed by 50% ground water and 50% Hindon water while lowest cost of cultivation was noted with 100 % Hindon water. Application of different soil amendments resulted in higher cost of cultivation in comparison to control during both the years. Cost of cultivation was more in Biochar treatment followed by vermicompost and activated carbon for both the years.

- Highest gross returns were obtained in irrigation treatment of 100 % Hindon water followed by 50% ground water and 50% Hindon water and 75% ground water and 25% Hindon water while lowest was with 100 % ground water.

Application of different soil amendments resulted in higher gross returns in comparison to control for both the years. Highest gross returns were obtained in biochar treatment followed by vermicompost and activated carbon while lowest was obtained in control during both the years.

- Maximum value of net returns was obtained in irrigation treatment of 100 % Hindon water followed by irrigation with 50% ground water and 50 % Hindon water and 75% ground water and 25% Hindon water while lowest was with 100 % ground water. Application of different soil amendments resulted in higher net returns in comparison to control for both the years. Highest net returns were obtained in biochar treatment followed by vermicompost and activated carbon while lowest was obtained in control (83,513 & 90,005) during both the years.
- Maximum B:C ratio was obtained in irrigation treatment of 100 % Hindon water followed by irrigation with 50% ground water and 50 % Hindon water and 75% ground water and 25% Hindon water while lowest was with 100 % ground water for both the years. Application of different soil amendments resulted in higher B:C ratio in comparison to control for both the years. Highest B:C ratio was obtained in biochar treatment followed by vermicompost and activated carbon while lowest was obtained in control during both the years.

Conclusion

The following conclusions can be drawn on the basis of summary of present investigation:

- Irrigation with 100% Hindon water under irrigation treatments and Biochar @ 5t/ha under soil amendments exhibited significant influence on the growth, yield attributes and yields of wheat during both the years.

- ❖ Significant improvement in growth parameters *viz.*, plant height, number of tillers, dry matter accumulation as well as yield attributes and yields was also recorded with the irrigation treatment of 100% Hindon water followed by irrigation with 50% ground water and 50% Hindon water and Biochar @ 5t/ha under soil amendments.
- ❖ The gross return, net return and B: C ratio was obtained maximum with the 100% Hindon water under irrigation treatments and Biochar @ 5t/ha among soil amendments.
- ❖ Heavy metals *viz.*, cadmium, iron, manganese and zinc content in edible part of wheat was above the permissible limit which poses toxicity issues if such grains are used for human intake.
- ❖ Transfer factor shoot of iron, manganese and zinc were more than one indicating that sorghum accumulated greater iron, manganese and zinc in shoot and hence there could be possible exposure of these metals to humans by intake.

Recommendation

On the basis of results obtained from two year studies it may be recommended that the application of Hindon water must be avoided by farmers for irrigation purpose. Moreover, since the soils adjoining Hindon river belt are contaminated with toxic heavy metals, so these soils should be reclaimed by using soil amendments like Biochar @ 5t/ha.

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Appendix-I: Mean weekly Agro-meteorological data during the *kharif* season, 2019-20

Standard weeks	Temperature (^{0}C)		Relative humidity (%)		BSS (hrs)	Total Rainfall (mm)
	Maximum	Minimum	Morning	Evening		
16	32.5	17.9	87.3	49.3	7.9	2.4
17	40.0	22.8	86.6	34.1	9.2	0.0
18	39.1	22.0	84.3	40.4	9.1	3.4
19	40.0	21.5	72.5	32.3	8.6	0.0
20	36.8	20.8	77.2	36.3	7.4	4.6
21	38.5	22.3	71.2	36.5	10.2	1.0
22	42.8	23.7	64.3	33.8	10.8	0.0
23	42.3	26.4	71.0	44.1	9.7	0.0
24	41.3	26.7	84.0	60.7	9.1	0.0
25	39.0	25.4	71.0	44.1	8.6	2.1
26	41.3	26.4	84.0	60.7	9.1	0.0
27	40.1	25.1	84.3	46.6	7.6	0
28	36.1	24.2	90.3	69.3	3.1	92.3
29	36.4	23.9	87.3	50.6	8.0	8.4
30	35.3	24.5	93.7	68.0	3.0	150
31	35.9	25.2	90.0	46.6	2.3	48
32	34.0	25.2	94.8	67.6	3.9	92
33	32.0	24.4	95.0	86.7	4.6	64
34	33.7	24.5	94.8	71.3	7.4	3.2
35	34.8	25.2	93.3	70.7	8.7	88
36	34.4	25.4	95.8	76.0	6.7	0

Appendix-II: Mean weekly Agro-meteorological data during the *kharif* season, 2020-21

Standard weeks	Temperature (^{o}C)		Relative humidity (%)		BSS (hrs)	Total Rainfall (mm)
	Maximum	Minimum	Morning	Evening		
16	36.3	17.9	46.6	27.1	9.6	6.1
17	35.6	22.8	57.1	36.9	8.4	1.4
18	35.3	22.0	53.0	38.8	9.9	6.9
19	36.8	21.5	54.7	35.6	8.4	24.4
20	36.8	20.8	77.2	36.3	7.4	0.1
21	38.5	22.3	71.2	36.5	10.2	0
22	38.5	21.4	70.9	41.7	11.0	42.1
23	34.6	24.2	70.7	52.9	8.6	7.9
24	38.1	27.0	69.3	50.7	9.7	0.2
25	35.4	26.6	79.0	55.6	8.8	1.1
26	36.1	27.3	73.9	60.3	8.2	7.2
27	35.4	26.1	78.7	66.1	7.1	30.3
28	32.5	24.6	88.1	73.7	2.7	150.4
29	33.5	25.9	82.9	71.4	7.1	23
30	33.5	25.9	86.3	72.6	5.7	19.1
31	34.9	26.4	82.7	72.1	3.9	12.1
32	32.2	24.7	93.3	84.0	1.7	61.5
33	32.1	25.0	81.6	69.1	6.6	55.3
34	33.4	25.0	83.9	72.3	7.1	0.2
35	34.3	26.3	77.3	61.7	7.6	4.3
36	35.6	26.6	78.0	59.0	7.4	5.1

Appendix-III: Mean weekly Agro-meteorological data during the *rabi* season, 2019-20

Standard weeks	Temperature (^{0}C)		Relative humidity (%)		BSS (hrs)	Total Rainfall (mm)
	Maximum	Minimum	Morning	Evening		
46	29.6	12	95.3	57.6	6.2	0
47	29.4	13.3	89.1	53.6	7.1	0
48	28.1	10.9	96.6	49	6	0
49	28.2	11.4	94.5	54.8	6.2	0
50	26.1	9.1	94.4	59.9	5.3	0
51	21.1	6.5	96	60.7	6	0
52	19.4	5	92	57.1	5.2	0
1	20.0	6.9	92.6	58.9	3.9	2.2
2	20.4	6.7	89.7	45.6	6.0	0
3	21.7	8.3	86.3	45.0	6.1	28.3
4	19.0	7.7	94.6	48.4	5.5	13.8
5	21.1	8.4	80.3	47.4	4.8	0
6	20.7	10.0	93.0	47.9	5.1	23.4
7	22.4	12.0	83.1	46.3	5.3	6.5
8	23.3	13.1	82.3	52.3	5.7	5.3
9	23.4	9.9	88.6	54.7	6.4	5.1
10	25.6	11.3	87.1	41.7	8.2	6
11	26.9	13.7	89.1	45.7	6.6	0.0
12	32.7	16.3	82.3	46.1	9.6	0.0
13	32.9	17.6	84.5	36.6	10.0	0.0
14	34.2	17.8	89.9	47.2	8.2	0.0
15	36.2	19.6	89.9	44.7	9.7	0.0
16	32.5	17.9	87.3	49.3	7.9	2.4

Appendix-IV Mean weekly Agro-meteorological data during the *rabi* season, 2020-21

Standard weeks	Temperature (^oC)		Relative humidity (%)		BSS (hrs)	Total Rainfall (mm)
	Maximum	Minimum	Morning	Evening		
46	29.6	12.0	95.3	57.6	6.2	0
47	29.4	13.3	89.1	53.6	7.2	0
48	25.6	11.1	96.5	51.5	6.0	30
49	23.4	8.1	91.8	52.3	6.3	0
50	19.2	8.2	93.3	69.0	6.0	42.8
51	14.8	7.9	93.9	76.2	6.1	0
52	12.9	5.0	91.6	75.9	5.9	0
1	19.3	8.9	89.7	69.6	3.8	1.0
2	17.3	7.9	95.1	76.7	3.8	15.0
3	17.0	8.8	95.5	86.6	1.8	16.7
4	18.3	8.6	94.8	61.2	5.6	6.8
5	18.9	8.4	93.2	61.0	6.6	4.5
6	20.6	7.6	93.6	46.8	8.3	0.0
7	24.5	11.0	92.3	46.6	10.1	0.0
8	24.9	12.2	94.8	47.1	6.7	19.8
9	25.2	11.3	95.3	59.9	7.1	7.8
10	24.9	11.3	94.2	58.3	6.3	31.4
11	25.2	13.7	94.0	60.6	8.1	7.1
12	30.3	16.3	90.7	41.0	7.8	0.2
13	30.7	17.6	89.2	34.5	7.7	6.8
14	32.5	17.8	79.6	24.0	10.1	0.0
15	35.6	19.6	50.7	22.0	9.5	0
16	36.3	17.9	46.6	27.1	9.6	6.1

Appendix- V

Analysis of variance for plant population at 30 DAS in sorghum

Sources of variation	df	Mean sum of squares 30 DAS	
		2019-20	**2020-21**
Replication	2	23.51	25.80
Irrigation strategies	3	57.48*	70.61*
Error (a)	6	12.30	3.52
Soil amendments	3	39.42*	48.67*
Interaction A X B	9	0.96	1.28
Error (b)	24	8.62	14.52

*Significant at 5% level of significance

Appendix- VI

Analysis of variance for plant height (cm) of sorghum at various stages

Sources of variation	df	Mean sum of squares					
		30 DAS		60 DAS		At harvest	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	1454.87	1585.81	6723.62	7328.75	9044.01	9857.97
Irrigation strategies	3	113.43*	123.64*	176.73*	192.64*	32.65*	35.59*
Error (a)	6	9.26	10.09	13.26	14.45	26.10	28.45
Soil amendments	3	168.16*	183.29*	324.76*	353.99*	78.56*	85.63*
Interaction A X B	9	2.28	2.49	8.11	8.84	7.18	7.83
Error (b)	24	9.58	10.44	16.17	17.63	39.68	43.25

*Significant at 5% level of significance

Appendix- VII

Analysis of variance for dry matter accumulation (g m^{-2}) at various stages

Sources of variation	df	Mean sum of squares					
		30 DAS		60 DAS		At harvest	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	111.21	121.22	917.91	1000.52	1433.67	1562.70
Irrigation strategies	3	16.45*	17.93*	7.09*	7.73*	4.19*	4.57*
Error (a)	6	2.01	2.19	1.40	1.53	1.46	1.59
Soil amendments	3	26.08*	28.43*	17.79*	19.39*	7.93*	8.64*
Interaction A X B	9	0.002	0.001	0.001	0.002	0.001	0.001
Error (b)	24	3.40	3.71	2.76	3.01	1.62	1.77

*Significant at 5% level of significance

Appendix- VIII

Analysis of variance for green and dry yield (t ha^{-1}) at various stages

Sources of variation	df	Mean sum of squares			
		Green fodder		Dry fodder	
		2019-20	2020-21	2019-20	2020-21
Replication	2	310.84	338.82	37.42	40.79
Irrigation strategies	3	29.23*	31.86*	4.37*	4.76*
Error (a)	6	11.30	12.32	2.36	2.57
Soil amendments	3	52.23*	56.93*	5.52*	6.02*
Interaction A X B	9	0.68	0.74	0.25	0.27
Error (b)	24	11.05	12.04	1.81	1.97

*Significant at 5% level of significance

Appendix- IX

Analysis of variance for N content and uptake (kg ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Nitrogen content (%)		Nitrogen uptake (kg ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.08	0.09	9.70	13.23
Irrigation strategies	3	0.01*	0.01*	5.11*	8.82*
Error (a)	6	0.001	0.001	0.01	0.02
Soil amendments	3	0.01*	0.01*	3.69*	6.75*
Interaction A X B	9	0.001	0.002	0.001	0.001
Error (b)	24	0.002	0.001	0.001	0.002

*Significant at 5% level of significance

Appendix- X

Analysis of variance for protein content and protein uptake (kg ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Protein content (%)		Protein yield (kg ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	17.55	18.52	96479.38	97654.20
Irrigation strategies	3	0.84*	0.92	21755.86*	22568.35*
Error (a)	6	0.01	0.01	447.85	463.40
Soil amendments	3	1.14*	1.21*	17498.26*	18665.10*
Interaction A X B	9	0.02	0.03	64.36	67.30
Error (b)	24	0.02	0.02	148.21	158.08

*Significant at 5% level of significance

Appendix- XI

Analysis of variance for P content and uptake (kg ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Phosphorus content (%)		Phosphorus uptake (kg ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	6.15	6.30	920.01	1008.65
Irrigation strategies	3	0.07*	0.05*	210.13*	257.73*
Error (a)	6	0.01	0.001	16.68	17.15
Soil amendments	3	0.05*	0.04*	156.09*	237.76*
Interaction A X B	9	0.002	0.001	0.002	0.001
Error (b)	24	0.001	0.002	13.58	14.72

*Significant at 5% level of significance

Appendix- XII

Analysis of variance for K content and uptake (kg ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Potassium content (%)		Potassium uptake (kg ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.23	0.24	25.71	33.05
Irrigation strategies	3	0.01*	0.01*	9.45*	11.40*
Error (a)	6	0.001	0.001	0.13	0.14
Soil amendments	3	0.001*	0.002*	6.07*	9.19*
Interaction A X B	9	0.001	0.001	0.002	0.001
Error (b)	24	0.001	0.002	0.14	0.14

*Significant at 5% level of significance

Appendix- XIII

Analysis of variance for Arsenic content and uptake (g ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Arsenic content (ppm)		Arsenic uptake (g ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.002	0.002	0.001	0.002
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*
Error (a)	6	0.001	0.001	0.001	0.001
Soil amendments	3	0.002*	0.002*	0.001*	0.002*
Interaction A X B	9	0.002	0.001	0.002	0.001
Error (b)	24	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XIV

Analysis of variance for Cadmium content and uptake (g ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Cadmium content (ppm)		Cadmium uptake (g ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.06	0.01	0.08	0.02
Irrigation strategies	3	0.29*	0.05*	0.33*	0.07*
Error (a)	6	0.001	0.001	0.001	0.001
Soil amendments	3	0.28*	0.05*	0.44*	0.10*
Interaction A X B	9	0.002	0.002	0.002	0.001
Error (b)	24	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XV

Analysis of variance for Lead content and uptake (g ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Lead content (ppm)		Lead uptake (g ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.02	0.001	0.03	0.001
Irrigation strategies	3	0.18*	0.02*	0.25*	0.04*
Error (a)	6	0.002	0.002	0.001	0.001
Soil amendments	3	0.21*	0.02*	0.35*	0.07*
Interaction A X B	9	0.001	0.001	0.001	0.001
Error (b)	24	0.002	0.002	0.001	0.001

*Significant at 5% level of significance

Appendix- XVI

Analysis of variance for Nickel content and uptake (g ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Nickel content (ppm)		Nickel uptake (g ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.04	0.01	0.03	0.00
Irrigation strategies	3	0.23*	0.04*	0.30*	0.06*
Error (a)	6	0.002	0.002	0.001	0.001
Soil amendments	3	0.26*	0.02*	0.39*	0.10*
Interaction A X B	9	0.002	0.001	0.002	0.002
Error (b)	24	0.002	0.001	0.001	0.002

*Significant at 5% level of significance

Appendix- XVII

Analysis of variance for Iron content and uptake (g ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Iron content (ppm)		Iron uptake (g ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	1841.14	1771.95	2330.56	2755.77
Irrigation strategies	3	1777.37*	1778.37*	1461.64*	2194.56*
Error (a)	6	6.36	6.27	5.01	7.78
Soil amendments	3	1546.14*	1517.82*	3778.38*	4899.96*
Interaction A X B	9	0.002	0.001	0.001	0.002
Error (b)	24	2.99	2.98	3.28	4.65

*Significant at 5% level of significance

Appendix- XVIII

Analysis of variance for manganese content and uptake (g ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Manganese content (ppm)		Manganese uptake (g ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	141.35	122.50	180.17	190.17
Irrigation strategies	3	182.75*	198.40*	171.16*	277.68*
Error (a)	6	1.15	1.20	1.30	1.65
Soil amendments	3	140.84*	135.77*	322.10*	393.98*
Interaction A X B	9	0.002	0.001	0.002	0.001
Error (b)	24	0.73	0.80	0.89	0.94

*Significant at 5% level of significance

Appendix- XIX

Analysis of variance for Zinc content and uptake (g ha^{-1}) of sorghum

Sources of variation	df	Mean sum of squares			
		Zinc content (ppm)		Zinc uptake (g ha^{-1})	
		2019-20	2020-21	2019-20	2020-21
Replication	2	14.86	13.60	18.71	20.75
Irrigation strategies	3	18.37*	17.90*	15.85*	24.87*
Error (a)	6	0.32	0.32	0.35	0.40
Soil amendments	3	15.82*	15.60*	34.97*	44.16*
Interaction A X B	9	0.002	0.002	0.001	0.002
Error (b)	24	0.28	0.28	0.30	0.31

*Significant at 5% level of significance

Appendix- XX

Analysis of variance for BCF shoot, BCF root and TF shoot of arsenic in sorghum

Sources of variation	df	Mean sum of squares					
		BCF shoot		BCF root		TF shoot	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.002	0.001	0.001	0.002	1.30	1.56
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*	0.48*	0.71*
Error (a)	6	0.001	0.002	0.002	0.002	0.01	0.01
Soil amendments	3	0.002*	0.001*	0.001*	0.001*	0.67*	0.80*
Interaction A X B	9	0.001	0.001	0.001	0.001	0.00	0.00
Error (b)	24	0.001	0.001	0.001	0.001	0.00	0.00

*Significant at 5% level of significance

Appendix- XXI

Analysis of variance for BCF shoot, BCF root and TF shoot of cadmium in sorghum

Sources of variation	df	Mean sum of squares					
		BCF shoot		BCF root		TF shoot	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.001	0.001	0.001	0.002	1.33	1.59
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*	0.50*	0.74*
Error (a)	6	0.001	0.002	0.002	0.001	0.01	0.01
Soil amendments	3	0.002*	0.001*	0.001*	0.001*	0.70*	0.83*
Interaction A X B	9	0.001	0.001	0.001	0.001	0.00	0.00
Error (b)	24	0.001	0.001	0.001	0.001	0.00	0.00

*Significant at 5% level of significance

Appendix- XXII

Analysis of variance for lead BCF shoot, BCF root and TF shoot of sorghum

Sources of variation	df	Mean sum of squares					
		BCF shoot		BCF root		TF shoot	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.001	0.001	0.001	0.002	1.29	1.54
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*	0.47*	0.70*
Error (a)	6	0.002	0.002	0.002	0.001	0.01	0.01
Soil amendments	3	0.002*	0.001*	0.001*	0.001*	0.65*	0.78*
Interaction A X B	9	0.001	0.001	0.001	0.001	0.002	0.002
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXIII

Analysis of variance for Nickel (BCF shoot, BCF root and TF shoot) of sorghum

Sources of variation	df	Mean sum of squares					
		BCF shoot		BCF root		TF shoot	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.002	0.001	0.001	0.001	0.12	0.17
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*
Error (a)	6	0.001	0.002	0.002	0.001	0.002	0.001
Soil amendments	3	0.002*	0.001*	0.001*	0.001*	0.001*	0.001*
Interaction A X B	9	0.002	0.001	0.002	0.001	0.002	0.002
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXIV

Analysis of variance for Iron (BCF shoot, BCF root and TF shoot) of sorghum

Sources of variation	df	Mean sum of squares					
		BCF shoot		BCF root		TF shoot	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.001	0.001	0.001	0.002	0.08	0.10
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*	0.01*	0.01*
Error (a)	6	0.002	0.001	0.001	0.002	0.00	0.00
Soil amendments	3	0.001*	0.001*	0.001*	0.001*	0.01*	0.01*
Interaction A X B	9	0.002	0.001	0.002	0.001	0.001	0.002
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXV

Analysis of variance for Manganese (BCF shoot, BCF root and TF shoot) of sorghum

Sources of variation	df	Mean sum of squares					
		BCF shoot		BCF root		TF shoot	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.002	0.001	0.001	0.002	0.10	0.13
Irrigation strategies	3	0.001*	0.002*	0.001*	0.001*	0.01*	0.01*
Error (a)	6	0.001	0.002	0.002	0.002	0.00	0.00
Soil amendments	3	0.002*	0.001*	0.001*	0.001*	0.01*	0.01*
Interaction A X B	9	0.001	0.001	0.001	0.001	0.02	0.01
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXVI

Analysis of variance for Zinc (BCF shoot, BCF root and TF shoot) of sorghum

Sources of variation	df	Mean sum of squares					
		BCF shoot		BCF root		TF shoot	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.002	0.001	0.001	0.002	0.07	0.09
Irrigation strategies	3	0.001*	0.002*	0.001*	0.001*	0.01*	0.01*
Error (a)	6	0.001	0.002	0.002	0.002	0.002	0.001
Soil amendments	3	0.002*	0.001*	0.001*	0.001*	0.01*	0.01*
Interaction A X B	9	0.001	0.001	0.001	0.001	0.02	0.01
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXVII

Analysis of variance for plant population at 30 DAS

Sources of variation	Df	Mean sum of squares	
		30 DAS	
		2019-20	2020-21
Replication	2	26.59	27.86
Irrigation strategies	3	61.51*	75.60*
Error (a)	6	14.39	4.56
Soil amendments	3	42.59*	53.68*
Interaction A X B	9	1.06	1.57
Error (b)	24	10.69	16.59

*Significant at 5% level of significance

Appendix- XXVIII

Analysis of variance for plant height (cm) at various stages

Sources of variation	df	Mean sum of squares							
		30 DAS		60 DAS		90 DAS		At harvest	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	7.23	7.66	25.76	25.52	84.87	90.85	39.10	43.63
Irrigation strategies	3	17.63*	19.91*	36.16*	40.01*	62.58*	67.90*	107.52*	114.54*
Error (a)	6	3.03	3.41	4.36	4.84	4.65	5.04	17.06	18.19
Soil amendments	3	18.26*	20.59*	83.01*	91.75*	124.68*	135.32*	148.68*	158.49*
Interaction A X B	9	0.37	0.42	0.75	0.83	0.35	0.38	0.95	1.01
Error (b)	24	2.76	3.11	9.49	10.48	14.73	15.98	21.64	23.07

*Significant at 5% level of significance

Appendix- XXIX

Analysis of variance for number of tiller (m^{-2}) at various stages

Sources of variation	df	Mean sum of squares							
		30 DAS		60 DAS		90 DAS		At harvest	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	349.0	361.41	859.84	948.88	346.07	387.21	418.77	469.52
Irrigation strategies	3	836.68*	872.39*	3360.17*	3573.35*	1816.47*	1931.71*	2337.40*	2394.16*
Error (a)	6	107.74	112.44	196.34	208.62	78.98	83.89	98.89	101.77
Soil amendments	3	2788.15*	2906.92*	45671.00*	48583.45*	22425.08*	23856.29*	21126.56*	21636.62*
Interaction A X B	9	84.16	87.81	299.68	318.61	141.49	150.41	169.36	173.45
Error (b)	24	215.42	224.59	686.00	730.12	316.68	337.08	335.81	343.86

*Significant at 5% level of significance

Appendix- XXX

Analysis of variance for dry matter accumulation (g m^{-2}) at various stages

Sources of variation	df	Mean sum of squares							
		30 DAS		60 DAS		90 DAS		At harvest	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	44.01	48.95	865.50	974.14	2750.80	3094.36	3559.49	4009.49
Irrigation strategies	3	575.18*	612.14*	15018.76*	15444.58*	48093.96*	49457.90*	63280.87*	65075.87*
Error (a)	6	9.68	10.33	205.89	213.11	631.30	653.29	836.01	865.30
Soil amendments	3	1617.68*	1722.01*	58656.61*	60310.51*	189734.32*	195083.09*	250895.24*	257971.82*
Interaction A X B	9	23.57	25.08	855.41	879.74	2752.12	2830.15	3638.01	3741.15
Error (b)	24	15.24	16.23	661.14	679.78	2147.14	2207.51	2802.32	2881.20

*Significant at 5% level of significance

Appendix- XXXI

Analysis of variance for yield attributes

Sources of variation	df	Mean sum of squares							
		Spike length (cm)		Spikelets $spike^{-1}$		Grains $spike^{-1}$		Test weight (g)	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.65	0.71	1.10	1.37	6.48	7.57	1.68	2.21
Irrigation strategies	3	39.99*	45.07*	43.74*	49.23*	200.17*	216.82*	19.23*	20.89*
Error (a)	6	0.22	0.24	0.27	0.30	1.10	1.20	2.00	2.17
Soil amendments	3	37.00*	41.66*	182.08*	205.02*	1049.04*	1137.00*	76.78*	83.35*
Interaction A X B	9	1.95	2.20	1.75	1.97	10.42	11.30	0.81	0.88
Error (b)	24	0.35	0.40	0.78	0.88	4.54	4.92	7.54	8.19

*Significant at 5% level of significance

Appendix- XXXII

Analysis of variance for yield (q ha^{-1})

Sources of variation	df	Mean sum of squares							
		Grain yield (q ha^{-1})		Straw yield (q ha^{-1})		Biological yield (q ha^{-1})		Harvest index (%)	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	15.08	19.88	7.86	8.50	49.39	14.01	5.66	40.63
Irrigation strategies	3	127.70*	140.85*	164.18*	177.52*	562.82*	614.16*	10.42*	10.48*
Error (a)	6	7.81	7.49	4.30	4.65	21.03	7.80	6.67	14.21
Soil amendments	3	772.79*	852.08*	1807.90*	1955.67*	4942.51*	5386.86*	1.12*	1.13*
Interaction A X B	9	0.54	0.60	3.51	3.79	5.07	5.51	0.61	0.62
Error (b)	24	15.21	16.77	28.79	31.13	37.28	47.70	11.18	6.45

*Significant at 5% level of significance

Appendix- XXXIII

Analysis of variance for nitrogen content (%), nitrogen uptake and total nitrogen uptake (kg ha^{-1}) in grain and straw

Sources of variation	df	Mean sum of squares									
		Nitrogen content (%)				Nitrogen uptake (kg ha^{-1})				Total Nitrogen uptake (kg ha^{-1})	
		Grain		Straw		Grain		Straw			
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.33	0.38	0.03	0.03	1.03	2.26	1.25	0.23	0.88	2.29
Irrigation strategies	3	0.02	0.02	0.01	0.01	6996.63*	6916.16*	1397.69*	1235.39*	14639.41*	13991.25*
Error (a)	6	0.001	0.001	0.001	0.001	2.31	2.12	1.86	2.42	3.10	3.28
Soil amendments	3	0.10	0.04	0.01	0.02	1859.91*	1981.30*	467.65*	457.00*	418561*	4335.84*
Interaction A X B	9	0.01	0.01	0.01	0.01	110.92*	104.85*	22.73*	18.99*	233.69*	212.36*
Error (b)	24	0.01	0.01	0.01	0.01	3.10	2.76	2.26	2.81	3.35	3.48

*Significant at 5% level of significance

Appendix- XXXIV

Analysis of variance for phosphorus content (%), phosphorus uptake and total phosphorus uptake (kg ha^{-1}) in grain and straw

Sources of variation	df	Mean sum of squares									
		Phosphorus content (%)				Phosphorus uptake (kg ha^{-1})				Total Phosphorus uptake (kg ha^{-1})	
		Grain		Straw		Grain		Straw			
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.01	0.01	0.01	0.01	0.55	0.13	0.27	0.20	0.14	0.77
Irrigation strategies	3	0.01	0.01	0.01	0.01	260.35*	187.09*	163.56*	83.14*	835.05*	518.52*
Error (a)	6	0.01	0.01	0.01	0.01	0.82	0.88	0.32	0.39	0.71	0.90
Soil amendments	3	0.01	0.01	0.01	0.01	81.46*	73.94*	47.44*	33.16*	251.37*	205.46*
Interaction A X B	9	0.01	0.01	0.01	0.01	3.97*	3.46*	3.10*	1.33*	13.84*	9.03*
Error (b)	24	0.01	0.01	0.01	0.01	0.95	1.16	0.57	0.51	0.88	1.02

*Significant at 5% level of significance

Appendix- XXXV

Analysis of variance for potassium content (%), potassium uptake and total potassium uptake (kg ha^{-1}) in grain and straw

Sources of variation	df	Mean sum of squares									
		Potassium content (%)				Potassium uptake (kg ha^{-1})				Total Potassium uptake (kg ha^{-1})	
		Grain		Straw		Grain		Straw			
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.02	0.02	0.31	0.34	0.10	0.24	4.68	1.57	1.02	2.30
Irrigation strategies	3	0.01	0.01	0.03	0.03	435.10*	320.81*	14008.96*	12477.29*	19369.21*	16787.99*
Error (a)	6	0.01	0.01	0.01	0.01	0.56	0.41	5.63	2.10	2.41	2.14
Soil amendments	3	0.01	0.01	0.02	0.02	140.74*	130.04*	3291.26*	3455.93*	4784.40*	4920.74*
Interaction A X B	9	0.01	0.01	0.01	0.01	7.38*	5.84*	216.95*	187.49*	304.19*	258.60*
Error (b)	24	0.01	0.01	0.01	0.01	0.88	0.67	6.72	2.84	3.54	2.92

*Significant at 5% level of significance

Appendix- XXXVI

Analysis of variance BCF root, BCF shoot and BCF grain for arsenic in wheat

Sources of variation	df	Mean sum of squares					
		BCF root		BCF shoot		BCF grain	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.001	0.001	0.001	0.001	0.002	0.001
Irrigation strategies	3	0.001*	0.002*	0.001*	0.002*	0.001*	0.002*
Error (a)	6	0.001	0.001	0.001	0.001	0.001	0.001
Soil amendments	3	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*
Interaction A X B	9	0.001	0.001	0.001	0.001	0.001	0.001
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXVII

Analysis of variance for Arsenic (TF shoot and TF grain) of wheat

Sources of variation	df	Mean sum of squares			
		TF shoot		TF grain	
		2019-20	2020-21	2019-20	2020-21
Replication	2	1.38	1.62	0.01	0.01
Irrigation strategies	3	0.54*	0.76*	0.00*	0.00*
Error (a)	6	0.01	0.01	0.00	0.00
Soil amendments	3	0.72*	0.88*	0.00*	0.00*
Interaction A X B	9	0.001	0.002	0.001	0.002
Error (b)	24	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXVIII

Analysis of variance BCF root, BCF shoot and BCF grain for cadmium in wheat

Sources of variation	df	Mean sum of squares					
		BCF root		BCF shoot		BCF grain	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.04	0.06	0.04	0.05	0.04	0.06
Irrigation strategies	3	0.07*	0.09*	0.03*	0.04*	0.02*	0.03*
Error (a)	6	0.001	0.001	0.001	0.001	0.001	0.001
Soil amendments	3	0.07*	0.08*	0.03*	0.03*	0.02*	0.03*
Interaction A X B	9	0.002	0.001	0.002	0.001	0.002	0.001
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXIX

Analysis of variance for Cadmium (TF shoot and TF grain) of wheat

Sources of variation	df	Mean sum of squares			
		TF shoot		TF grain	
		2019-20	2020-21	2019-20	2020-21
Replication	2	17.22	18.77	0.00	0.00
Irrigation strategies	3	50.04*	54.54*	0.00*	0.00*
Error (a)	6	0.50	0.55	0.00	0.00
Soil amendments	3	50.67*	55.23*	0.00*	0.00*
Interaction A X B	9	0.001	0.002	0.001	0.002
Error (b)	24	0.13	0.14	0.00	0.00

*Significant at 5% level of significance

Appendix- XXXX

Analysis of variance BCF root, BCF shoot and BCF grain for lead in wheat

Sources of variation	df	Mean sum of squares					
		BCF root		BCF shoot		BCF grain	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.002	0.001	0.001	0.002	0.001	0.002
Irrigation strategies	3	0.001*	0.002*	0.001*	0.002*	0.001*	0.002*
Error (a)	6	0.001	0.001	0.001	0.001	0.001	0.001
Soil amendments	3	0.001*	0.001*	0.002*	0.002*	0.001*	0.002*
Interaction A X B	9	0.001	0.001	0.001	0.002	0.001	0.001
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXXI

Analysis of variance for Lead (TF shoot and TF grain) of wheat

Sources of variation	df	Mean sum of squares			
		TF shoot		TF grain	
		2019-20	2020-21	2019-20	2020-21
Replication	2	1.94	2.11	0.001	0.001
Irrigation strategies	3	0.15*	0.16*	0.002*	0.001*
Error (a)	6	0.002	0.001	0.001	0.002
Soil amendments	3	0.15*	0.16*	0.002*	0.001*
Interaction A X B	9	0.001	0.002	0.002	0.001
Error (b)	24	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXXII

Analysis of variance BCF root, BCF shoot and BCF grain for nickel in wheat

Sources of variation	df	Mean sum of squares					
		BCF root		BCF shoot		BCF grain	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.001	0.002	0.001	0.001	0.001	0.001
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*
Error (a)	6	0.002	0.001	0.001	0.001	0.002	0.002
Soil amendments	3	0.001*	0.002*	0.002*	0.001*	0.002*	0.001*
Interaction A X B	9	0.001	0.001	0.001	0.001	0.001	0.001
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXXIII

Analysis of variance for Nickel (TF shoot and TF grain) of wheat

Sources of variation	df	Mean sum of squares			
		TF shoot		TF grain	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.14	0.19	0.02	0.02
Irrigation strategies	3	0.001*	0.001*	0.01*	0.01*
Error (a)	6	0.001	0.002	0.002	0.001
Soil amendments	3	0.002*	0.001*	0.01*	0.01*
Interaction A X B	9	0.001	0.001	0.002	0.001
Error (b)	24	0.001	0.002	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXXIV

Analysis of variance BCF root, BCF shoot and BCF grain for iron in wheat

Sources of variation	df	Mean sum of squares					
		BCF root		BCF shoot		BCF grain	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.001	0.002	0.001	0.001	0.02	0.03
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*	0.12	0.14
Error (a)	6	0.002	0.001	0.001	0.001	0.00	0.00
Soil amendments	3	0.001*	0.002*	0.002*	0.001*	0.14	0.16
Interaction A X B	9	0.001	0.001	0.001	0.001	0.00	0.00
Error (b)	24	0.001	0.001	0.001	0.001	0.00	0.00

*Significant at 5% level of significance

Appendix- XXXXV

Analysis of variance for Iron (TF shoot and TF grain) of wheat

Sources of variation	df	Mean sum of squares			
		TF shoot		TF grain	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.10	0.11	0.30	0.33
Irrigation strategies	3	0.01*	0.01*	0.19*	0.21*
Error (a)	6	0.001	0.001	0.001	0.001
Soil amendments	3	0.01*	0.01*	0.20*	0.22*
Interaction A X B	9	0.001	0.001	0.001	0.001
Error (b)	24	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXXVI

Analysis of variance BCF root, BCF shoot and BCF grain for manganese in wheat

Sources of variation	df	Mean sum of squares					
		BCF root		BCF shoot		BCF grain	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.001	0.002	0.001	0.001	0.02	0.03
Irrigation strategies	3	0.001*	0.001*	0.001*	0.001*	0.10	0.12
Error (a)	6	0.002	0.001	0.001	0.001	0.00	0.00
Soil amendments	3	0.001*	0.002*	0.002*	0.001*	0.12	0.13
Interaction A X B	9	0.001	0.001	0.001	0.001	0.002	0.002
Error (b)	24	0.001	0.001	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXXVII

Analysis of variance for Manganese (TF shoot and TF grain) of wheat

Sources of variation	df	Mean sum of squares			
		TF shoot		TF grain	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.12	0.14	0.13	0.15
Irrigation strategies	3	0.01*	0.01*	0.07*	0.08*
Error (a)	6	0.001	0.001	0.001	0.001
Soil amendments	3	0.01*	0.01*	0.07*	0.08*
Interaction A X B	9	0.002	0.001	0.002	0.001
Error (b)	24	0.001	0.001	0.001	0.001

*Significant at 5% level of significance

Appendix- XXXXVIII

Analysis of variance BCF root, BCF shoot and BCF grain for zinc in wheat

Sources of variation	df	Mean sum of squares					
		BCF root		BCF shoot		BCF grain	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Replication	2	0.01	0.01	0.001	0.001	49.30	53.74
Irrigation strategies	3	0.01*	0.01*	0.01*	0.01*	2.09*	2.28*
Error (a)	6	0.001	0.002	0.001	0.001	0.01	0.01
Soil amendments	3	0.01*	0.01*	0.01*	0.01*	2.19*	2.39*
Interaction A X B	9	0.001	0.001	0.001	0.001	0.001	0.001
Error (b)	24	0.001	0.001	0.001	0.001	0.01	0.01

*Significant at 5% level of significance

Appendix- XXXXIX

Analysis of variance for Zinc (TF shoot and TF grain) of wheat

Sources of variation	df	Mean sum of squares			
		TF shoot		TF grain	
		2019-20	2020-21	2019-20	2020-21
Replication	2	0.09	0.11	1605.22	1749.69
Irrigation strategies	3	0.001*	0.001*	1775.17*	1934.94*
Error (a)	6	0.001	0.002	11.98	13.06
Soil amendments	3	0.002*	0.001*	1984.10*	2162.67*
Interaction A X B	9	0.001	0.002	0.002	0.001
Error (b)	24	0.001	0.001	6.32	6.89

*Significant at 5% level of significance

Appendix- XXXXX

S.No. Sorghum	**Particular**	**Quantity ha^{-1}**	**2019-20**	**2020-2021**
A	**Common cost**			
1.	One deep ploughing by tractor draw M.B. Plough	1	1200	1200
2.	One cross ploughing by tractor drawn cultivator with planking	1	900	900
3.	Making of bund and channels	4	1000	1040
4.	Layout and seed bed preparation	3	750	780
5.	Seed treatment Bavistin 2g/kg seed	200g	200	200
6.	Seed cost	35kg	1400	1400
7.	Fertilizer cost • DAP • Urea • MOP	2400 797 1680	4870	4870
8.	Sowing	5 labour	1250	1300
9.	Weed Mgt (Atrazine)	250g	730	740
10.	**IPM(Phorate 10 G)**	18kg	790	800
11.	Harvesting	8 labour	2000	2080
12.	Land rent for crop	-	1000	1000
	Total		16090	16310

Appendix- XXXXXI

S.No. Wheat	**Particular**	**Quantity ha^{-1}**	**2019-20**	**2020-2021**
A	**Common cost**			
1.	One deep ploughing by tractor draw M.B. Plough	1	1200/ha	1200/ha
2.	One cross ploughing by tractor drawn cultivator with planking	1	900/ha	900/ha
3.	Making of bund and channels	4	1000	1040
4.	Layout and seed bed preparation	3	750	780
5.	Seed treatment Bavistin 2g/kg seed	200g	200	200
6.	Seed cost	100kg	2500	2500
7.	Fertilizer cost • DAP • Urea • MOP	3600 1512 840	5952	5952
8.	Sowing	5 labour	1250	1300
9.	Weeding	6	3000	3120
10.	Harvesting	8 labour	2000	2080
11.	Threshing/cleaning bagging	8 labour	2000	2080
	Land rent for crop	-	1000/6 month	1000
	Total		21752	22152

Appendix- XXXXXII

Wheat	2019-20				2019-20			
Treatments	**Irrigation water**	**Soil amendment**	**Fixed cost**	**Total cost of cultivation**	**Irrigation water**	**Soil amendment**	**Fixed cost**	**Total cost of cultivation**
			21752				22152	
I_1S_1 (100% Ground water + Biochar)	1800	10000		33352	1800	10000	22152	33952
I_1S_2(Ground water + activated carbon)	1800	7500		30852	1800	7500	22152	31452
I_1S_3(Ground water + vermicompost)	1800	7500		30852	1800	7500	22152	31452
I_1S_4(Ground water control)	1800	-		23352	1800	-	22152	23952
I_2S_1(50% Ground water + 50 % hindon water + Biochar)	1350	10000		32902	1350	10000	22152	33502
I_2S_2(50% Ground water + 50 % hindon water + activated carbon)	1350	7500		30402	1350	7500	22152	31002
I_2S_3(50% Ground water + 50 % hindon water + vermicompost)	1350	7500		30402	1350	7500	22152	31002
I_2S_4(50% Ground water + 50 % hindon water control)	1350	-		22902	1350	-	22152	23502
I_3S_1(75% Ground water + 25 % hindon water + Biochar)	1590	10000		33142	1590	10000	22152	33742
I_3S_2(75% Ground water + 25 % hindon water + activated carbon)	1590	7500		30642	1590	7500	22152	31242
I_3S_3(75% Ground water + 25 % hindon water + vermicompost)	1590	7500		30642	1590	7500	22152	31242
I_3S_4(75% Ground water + 25 % hindon water control)	1590	-		23142	1590	-	22152	23742
I_4S_1(100% Hindon water + Biochar)	960	10000		32512	960	10000	22152	33112
I_4S_2(100% Hindon water + activated carbon)	960	7500		30012	960	7500	22152	30612
I_4S_3(100% Hindon water + vermicompost)	960	7500		30012	960	7500	22152	30612
I_4S_4(100% Hindon water control)	960	-		22512	960	-	22152	23112

Appendix- XXXXXIII

Sorghum	2019-20				2019-20			
Treatments	**Irrigation water**	**Soil amendment**	**Fixed cost**	**Total cost of cultivation**	**Irrigation water**	**Soil amendment**	**Fixed cost**	**Total cost of cultivation**
			16090				16310	
I_1S_1 (100% Ground water + Biochar)	1800	10000		27890	1800	10000		28110
I_1S_2(Ground water + activated carbon)	1800	7500		25390	1800	7500		25610
I_1S_3(Ground water + vermicompost)	1800	7500		25390	1800	7500		25610
I_1S_4(Ground water control)	1800	-		17890	1800	-		18110
I_2S_1(50% Ground water + 50 % hindon water + Biochar)	1350	10000		27440	1350	10000		27660
I_2S_2(50% Ground water + 50 % hindon water + activated carbon)	1350	7500		24940	1350	7500		25160
I_2S_3(50% Ground water + 50 % hindon water + vermicompost)	1350	7500		24940	1350	7500		25160
I_2S_4(50% Ground water + 50 % hindon water control)	1350	-		17440	1350	-		17660
I_3S_1(75% Ground water + 25 % hindon water + Biochar)	1590	10000		27680	1590	10000		27990
I_3S_2(75% Ground water + 25 % hindon water + activated carbon)	1590	7500		25180	1590	7500		25400
I_3S_3(75% Ground water + 25 % hindon water + vermicompost)	1590	7500		25180	1590	7500		25400
I_3S_4(75% Ground water + 25 % hindon water control)	1590	-		17680	1590	-		17900
I_4S_1(100% Hindon water + Biochar)	960	10000		27050	960	10000		27270
I_4S_2(100% Hindon water + activated carbon)	960	7500		24550	960	7500		24770
I_1S_1 (100% Ground water + Biochar)	960	7500		24550	960	7500		24770
I_1S_2(Ground water + activated carbon)	960	-		17050	960	-		17270

Input price		Output price	
Bavistin	50 Rs./100 g	Grain*2019-20	1925 Rs./q
Urea	5.5 Rs./kg	Grain * 2020-21	1975Rs./q
MOP	840 Rs./50 kg	Straw[@]	250 Rs./q
DAP	1200 Rs./50 kg	Green fodder	2Rs/kg
Biochar	2.0 Rs/kg		
Vermicompost	1.5 Rs/kg		
Activated carbon	1.5 Rs/kg		
Atrazine	420 Rs/ kg		
Phorate 10 G	30Rs/kg		
Mandays	250 Rs		

ABSTRACT

Name Dimple Kaparwan **Id. No.:** 3653

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Major: Agronomy **Minor:** Soil Science

Thesis Title: "Assessment of Heavy Metal Content in Hindon River Belt and An Integrated Approach for Soil and Crop Management"

Advisor: Dr. N. S. Rana

An investigation was undertaken on **"**Assessment of Heavy Metal Content in Hindon River Belt and An Integrated Approach for Soil and Crop Management" to study the physio chemical properties and heavy metal content of Hindon river and adjoining soil and find out the suitability of cultivating crops in this region. The research experiment was conducted in agriculture field at Ator village, Ghaziabad (U.P) where soil was medium in organic carbon (0.60 %) & available nitrogen (290), high in available phosphorus(68.8), potassium(319) with heavy metal content (mg/l) *viz.*, arsenic, cadmium, nickel, lead, iron, manganese and zinc as 5.78, 0.87, 21.5, 11.8, 2159, 512 and 57.5 of which arsenic, iron, manganese and nickel were present above the threshold limits given by WHO. The ph, BOD, COD and heavy metal content (mg/l) *viz.*, arsenic, cadmium, nickel, lead, zinc, manganese and iron at six sampling locations of Hindon river were found in range of 7.5-8.1, 65-185, 195-426, 0.001-0.004, 0.001-0.008, 0.2-0.8, 0.01-0.1, 0.2-0.8, 3.3-4.4 and 6.5-12.6 of which iron, manganese and nickel were found above the permissible limit. Twelve treatments consisting of combinations of 04 irrigation strategies *viz.,* Irrigation at all stages with 100% ground water (I_1), Irrigation at all stages with 75% ground water and 25% Hindon river water (I_2), Irrigation at all stages with 50% ground water and 50% Hindon river water (I_3) and Irrigation at all stages with 100% hindon water (I_4) and 03 soil amendments *viz.*, Biochar @ 5t/ha (S_1), Activated Carbon @ 5t/ha (S_2), Vermicompost @ 5t/ha (S_3) were undertaken in split plot design with 3 replications. Wheat variety - PBW 343 was sown on 20 of November 2019 & 22 of November 2020 and harvested on 07 of April 2020 and 09 of April 2021, respectively. Sorghum variety- Pant chari 5 was sown on 20 of June 2019 & 17 of June 2020 and harvested on 05 of September 2019 & 09 of September 2020, respectively.

The results revealed that the heavy metal content in wheat grain (mg/l) *viz.,* arsenic, cadmium, lead, nickel, iron, manganese and zinc were in range of 0.01-0.10, 0.00-0.04, 0.00-0.04, 0.01-0.10, 126.8-280, 27.8-40.1 and 1101.5-2400 and in fodder sorghum as 0.34-0.91,0.153-0.950, 0.122-0.370, 0.24-0.53, 94.2-152.1, 23.7-42.7, 7.2-8-13.5 of which cadmium, iron, manganese & zinc in wheat grain and arsenic cadmium, iron and manganese in fodder sorghum were found above the permissible limits prescribed by WHO. The Bio concentration factor of heavy metals from soil to grain & Transfer factor of heavy metals from root to shoot & grain in wheat for arsenic (0.001 &0.001 and 0.165 & 0.156), cadmium(0.041 & 0.022 and 0.04 & 0.05), lead(0.003&0.002 and 0.05 & 0.110), nickel(0.009 & 0.004 and), manganese(1.22 & 1.27 and 0.070 &0.078), iron(0.57& 0.12 and 1.8 & 1.7) and zinc(21.5 & 24.1 and 139 & 155) were highest with 100% Hindon water of which BCF of zinc was > 1, which indicates greater accumulation of Zn in wheat seeds and Transfer factor of iron, manganese & zinc was found >1 which signifies possible human exposure of Fe, Mn & Zn through the food chain that might cause metal toxicity. Also, the TF shoot of arsenic, cadmium, lead, manganese and zinc were more than 1 in fodder indicating possible health hazard to animals through ingestion of this fodder.

Among the soil amendments application of Biochar @ 5 t ha^{-1} resulted in lowest heavy metal content in fodder sorghum and wheat grain *viz.*, arsenic, cadmium, lead, nickel, iron, manganese and zinc as 0.05 & 0.03, 0.24 & 0.15, 0.19 & 0.12, 0.25 & 0.24, 94.2 & 92.2, 24.5 & 22.0, 7.71 & 7.15 and 0.001 & 0.001, 0.00 & 0.00, 0.00 & 0.00, 0.02 & 0.02, 140.1 & 128.6, 28.4 & 26.1, 1120.3 & 1104.2 for both the years while highest heavy metal content & uptake was noted in control for the years.

Thus, it can be concluded that use of raw Hindon water for irrigation purpose should be avoided due to high accumulation of heavy metals in soils adjoining river, leading to possible uptake of heavy metals by crops. Incorporation of soil amendments like Biochar @ 5 t ha^{-1} helped to stabilize heavy metals in soil & reduce their uptake by crops.

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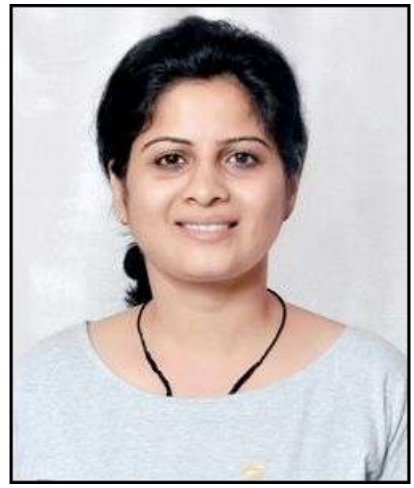
CURRICULUM VITAE



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