RESPONSE OF BIOCHAR ON SOIL PROPERTIES AND YIELD OF SESAME

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CERTIFICATE

This is to certify that the thesis entitled ***"RESPONSE OF BIOCHAR ON SOIL PROPERTIES AND YIELD OF SESAME"*** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (MS)*** *in* ***AGRONOMY****, embodies the result of a piece of bona fide research work carried out by* ***MD. TOWHIDUR RAHMAN, Registration No.*** *16-07539 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged.

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Abstract

The experiment was conducted at the research plot of the Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka during the period from March, 2017 to June, 2017 to study response of biochar on soil properties and on the growth and yield of sesame. In the experiment, the treatment consisted of three varieties, *viz.,* V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4 and five levels of biochar *viz.,* B_0= control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_1= application of biochar 4 t ha^{-1}, B_1= application of biochar 6 t ha^{-1}, B_1= application of biochar 8 t ha^{-1}. The experiment was laid out in a two factors randomized complete block design (RCBD) with three replications. Variety, application of different levels of biochar and their interaction showed statistically significant variation in plant height, number of leaves $plant^{-1}$at 55 days after sowing (DAS), 80 DAS and at harvest, capsules $plant^{-1}$, seeds capsule $^{-1}$, 1000 seeds weight, grain yield, stover yield, biological yield and harvest index. Effect of variety on pH, organic carbon (OC%), N content in soil is insignificant. Effect of application of different levels of biochar on pH, (OC%), N, P and K content in soil are significant. Interaction effect of variety and biochar application on N, P and K content in soil are significant but soil pH and (OC%) are insignificant. The highest plant height (70.34, 110.95 and 109.84 cm), number of leaves $plant^{-1}$ (80.47, 116.70 and 94.54) at 55, 80 DAS and at harvest was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$) and the lowest was observed in variety BARI Til-2 with no biochar application ($V_1 \times B_0$). The highest number of capsules $plant^{-1}$, number of seeds $capsule^{-1}$ and weight of 1000 seeds was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$) and the lowest was found variety BARI Til-2 with no biochar application ($V_1 \times B_0$). Variety V_3 (BARI Til-4) gave the highest yield (1.01 t ha^{-1}) and harvest index(HI) (35.15 %), whereas, the lowest seed yield (0.88 t ha^{-1}) and HI (27.66 %) was observed in variety V_1 (BARI Til-2). The highest grain yield (1.03 t ha^{-1}) and HI (33.40 %) was recorded in B_3 (biochar 6 t ha^{-1}) the lowest grain yield (0.85 t ha^{-1}) and HI (30.43%) was achieved by B_0 (no biochar application). The highest seed yield (1.07 t ha^{-1}) and HI (36.46%) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$). The lowest seed yield (0.75 t ha^{-1}) and HI (25.78%) was observed variety BARI Til-2 with no biochar application ($V_0 \times B_0$). The highest soil pH (6.09), organic carbon (0.70%), total nitrogen (0.073 %), available phosphorus (29.29 µg g^{-1}) and exchangeable potassium (0.40 meq 100 g^{-1}) was recorded in B_0 and the lowest soil pH (5.84), total nitrogen (0.039 %), available phosphorus (14.52 µg g^{-1}) and exchangeable potassium (0.23 meq 100 g^{-1}) was achieved in B_0. The highest available phosphorus (30.35 µg g^{-1}) and exchangeable potassium (0.41 meq 100 g^{-1}) was observed in BARI Til-2 cultivated with application of biochar 8 t ha^{-1} ($V_1 \times B_4$). In respect of seed yield and soil properties BARI Til-4 cultivated with application of biochar 6 t ha^{-1} was suitable compared to other treatment combinations.

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Chapter 1
INTRODUCTION

Sesame (*Sesamum indicum* (L.)) is one of the important edible oil seed cultivated in India. Its oil content generally varies from 46 to 52% and protein between 20-26%. The oil is used for edible purpose (73%), hydrogenation (8.3%) and industrial purpose (4.2%) in the manufacture of paints, pharmaceuticals and insecticides. Sesame oil is also used in soap, cosmetic and skin care. It has antiviral, antibacterial, antifungal and antioxidant properties (Ray, 2009). Hundred gram of sesame seed provide 592 calories energy. Sesame oil is really the poor man's substitute for "ghee". Oilseed crops include a wide variety of plants raised primarily for extracting the oil. Thus, production of oilseeds in India is of great value to the country's economy, since, they not only play a vital role in the industrial sector and indirectly requirements of the people but also serve as a good source of foreign exchange. Sesame as an industrial crop which is potent economically and highly nutrient, per 36 grams of seed contains 206.2 kal, copper 1.48 mg, Mn 0.88 mg, tryptophan 0.12 g, Ca 351 mg, Mg 126.36 mg, Fe 5.24 mg, P 226.44 mg, Zn 2.8 mg, B1 vitamin 0.28 mg and fiber 4.24 g (Ray, 2009). Sesame oil contains oil that ranges between 40 to 50% that is edible and has long shelf life more than one year without any deterioration due to its content of sesamol antioxidant, rich in unsaturated fats especially oleic acid and linoleic acid (Sharar *et al*., 2000). It contains 6.0 -6.2 % nitrogen, 2.0 - 2.2 per cent phosphorus and 1.0 -1.2 per cent potash. It can be used as manure. The cake is edible and is eaten avidly by working classes. It is also valuable and nutritious feed for milch cattle.

Sesame is one of the most important oil crops in Bangladesh and grown in all regions. In the year of 1999- 2000, the crop covered an area of 96000 acres in Bangladesh with production of 25000 M tons (BBS, 2002). Total area coverage of sesame is 33,000 hectors with an annual production of 29,000 metric tones (BARI, 2014). The above information suggests that although the land of cultivation of sesame is decreasing whereas the production is increasing trend from 1999 to 2013. But in a view of population growth, the requirement of edible oil is increasing with high in demand than the production. It is therefore, highly expected that the production of edible oil should be increased considerably to fulfill the increasing demand. The production may be increased either by increasing cropping area under oil crop or increasing yield. But it is difficult to extent the area of oil production in our country due to over population, high demand of cereal crops etc. That is why; the farmers of our country did not get enough interest to grow oil crops. The yield of sesame is much lower in the farmer's field as compared to the research field. Mian *et.al.,* 2002 stated that sesame yield is very low in Bangladesh due to lack of proper management practices. The yield of sesame can be increased in adopting modern technologies. Nutrient management is very important for yield improvement of crop

Biochar is a soil amendment .It provides a better and more nourishing environment for plant root. It must be mixed thoroughly within the soil. If it is just placed under the soil, it can interfere with movement of water or air and growth of the plant roots can be affected (Davis *et al.,* 2002). Biochar is a pyrolysed biomass produced under limited oxygen or oxygen absent conditions. The specific intention of biochar application to soil is to improve its agronomic and bio-chemical quality (Asai *et al*., 2009; Atkinson *et al*., 2010; Brown, 2009; Chan *et al*., 2007, 2008; Glaser *et al*., 2002; Laird *et al*., 2010; Liu *et al*., 2012; Major *et al*., 2010; Singh *et al*., 2010; Steiner *et al*., 2007; Schulz and Glaser, 2012; Sun and Lu, 2014), and to enhance carbon sequestration (Lehmann *et al*., 2006). The use of biochar can be an effective tool for sustainable agriculture in the long term, increasing soil carbon sequestration (C abatement strategy), fertility and productivity (soil quality) and reducing greenhouse gas emissions (Jeffery *et al*., 2014). It can increase soil aeration (Laird, 2008) and reduce soil emissions of N_2O, a greenhouse gas (Spokas *et al*., 2009, Singh *et al*., 2010). In current years, biochar has shown as one promising mean of reducing the atmospheric CO_2 concentration because biochar slows the rate at which photosynthetically fixed carbon (C) is returned to atmosphere (Lehmann, 2007; Sohi *et al*., 2010; and Krishnakumar *et al*., 2014).

International Biochar Initiative (IBI) recommended the use of biochar as a material for soil amendment. Because biochar is a stable form of carbon that can last for hundreds of years in the soil, compare to compost that breaks down so quickly to release nitrous oxide, methane and carbon dioxide into the atmosphere thereby increasing global warming. Biochar is a stable form of charcoal produced from heating natural organic materials(crop biomass, woodchips, manure and other agricultural waste) in a high temperature, low oxygen process known as pyrolysis (Lehmann *et al*., 2008). The addition of biochar as amendment materials to agricultural soils is receiving much attention due to the apparent benefits of biochar to soil quality and enhanced crop yields, as well as the potential to gain carbon credits by active carbon sequestration (Major, 2011). Considering the low yield of sesame obtained in most growing areas as a result of non application of fertilizers and the poor fertility status. From the above discussion this study was conducted for the following objective:

Objectives:

i. to study the effect of biochar on yield of sesame.

ii. to study the effect of biochar on soil properties.

iii. to evaluate the interaction effect of variety and biochar on yield and soil properties of sesame.

CHAPTER 2

REVIEW OF LITERATURE

This chapter includes research findings of different researchers in home and abroad regarding the effect of varieties on the growth, yield parameters and yields of sesame and other crops. The information have been reviewed and cited under the following headings.

2.1 Effect of variety on the growth and yield of sesame

Variations in plant height among various sesame varieties had been reported extensively (Gangakishan *et al*.,1983; Abdulkhader and Gopinathannair, 1984; Narayanan and Ravindrakumar, 1988; Sverup *et al*., 1989 and Ghungarde *et al*., 1992). Increased plant height of sesame with Gowri variety than other varieties viz., Madhavi, N 62-39 and X 79 1 was reported at various locations (Rao *et al*., 1985; and Rao *et al*., 1991). According to Patra and Mishra (2000) sesame variety B 67 expressed more plant height than Krishna during post rainy season conditions. In an experiment conducted at Vridhachalam, Tamil Nadu on sandyloam soils, TMV 4 variety recorded the maximum plant height than TMV3 (Kathiresan and Gnanamoorthy, 2001 and Kathiresan, 2002).

Samui *et al*. (1990) reported higher drymatter production with Phule Til No.1 than other varieties. Rao *et al.,* (1991) reported that on sandyloam soils of Anakapalle, X-79-1 variety produced more drymatter than other varieties, contrarily, Sumathi (1992) reported the maximum drymatter per plant with Madhavi variety than X-79-1 and Tanuku brown variety. On sandyloam soils of Vridhachalam, TMV 4 sesame variety recorded more drymatter per plant than TMV 3 (Kathiresan and Gnanamoorthy, 2001 and Kathiresan, 2002).

Production of the maximum number of branches per plant in Gowri variety than other varieties was widely reported (Rao *et al.,* 1985, Narayan and Narayanan, 1987 and Asharani *et al.,* 1992). Experiments conducted at Regional Research Station, Vridhachalam, Tamil Nadu indicated that number of primary branches per plant was higher with VS-345 followed by TMV 4 and TMV 3 varieties of sesame during summer (Kandasamy and Balasubramanian, 1991). Rao *et al*. (1991) reported more number of branches per plant (3.8) with X-79-1 variety than Gowri (3.0) and Madhavi (2.7) on sandy loam soils of Anakapalle during kharif season.

Experiments conducted by Patra and Mishra (2000) indicated that Kanak variety produced more number of primary branches (4.3) followed by B-67 variety (3.8) of sesame during post rainy season.

Chakraborty *et al*. (1984) reported that T-4 variety recorded more test weight (3.07 g) than that of B-67 (2.81 g) of sesame on sandy loam soils of West Bengal during dry season. Studies conducted at Vellayani by Abdulkhader and Gopinathannair (1984) revealed that P-38-1 variety recorded the highest test weight in upland (3.8 g) and rice fallow (2.5 g) situations. Gowri recorded the highest number of capsules per plant and more test weight than that of Madhavi and X-79-1 at various locations (Rao *et al*., 1985; Narayan and Narayanan, 1987 and Rao *et al*., 1991). The highest test weight (3.5 g) of sesame was recorded with Tapi (JLT-7) variety compared to other varieties on sandy loam soils of Jalgoan (Deokar *et al*., 1989).

Deshmukh *et al*. (1990) stated that the number of capsules per plant recorded with T-85 variety was higher than that of Punjab-1 at Parbhani on sandy loam soils during kharif season. On red lateritic soils of Regional Research Station, Vridhachalam during summer season, sesame variety OMT-11-6-5 recorded significantly more number of capsules (83.6) per plant followed by TMV 3 (74.7) (Kandasamy and Balasubramanian, 1991). The varieties TMV 3 and TMV 4 shown negligible variation in their test weights during various seasons (Kathiresan and Gnanamoorthy, 2001 and Kathiresan, 2002).

According to Asharani *et al*. (1992) on sandyloam soils of Tirupati (A.P.) Gowri produced more test weight (2.89 g) than Madhavi (2.28 g). However, Madhavi recorded more number of capsules per plant. Sumathi (1992) reported that Tanuku brown variety recorded more number of capsules per plant than Madhavi, R 84-4-2 and X-79-1. Patra and Mishra (2000) noted more number of capsules per plant in Kalika (44) followed by Kanak (41.5) variety in dry season on sandyloam soils of West Bengal.

Many workers reported the maximum mean seed yield with Gowri variety than Madhavi on sandyloam soils (Rao *et al.*, 1985; Rao *et al.*, 1990 and Asharani *et al.*, 1992). Sekhar (1988) stated that average seed yield was the maximum with Punjab Til-1 (593 kg ha^{-1}) than local variety (456 kg ha^{-1}) on sandy loam soils at Solan, Himachalpradesh. Sasikumar *et al*. (1989) at Tripura tested 6 cultivars and reported that T-3 variety recorded the highest yield (1550 kg ha^{-1}) while B-67 variety recorded the lowest yield (1140 kg ha^{-1}). Desmukh *et al*. (1990) reported higher seed yield with Punjab-1 (1032 kg ha^{-1}) over T-85 (371 kg ha^{-1}) variety on clay soils of Parbhani.

In an experiment conducted on sandyloam soils during kharif season at Regional Agricultural Research Station (RARS), Anakapalle, Andhra Pradesh, Rao *et al*. (1991) reported that variety X-79-1 recorded higher seed yield (489 kg ha^{-1}) than Gowri (471 kg ha^{-1}). Experiments conducted at Rajendranagar, Andhra Pradesh on sandyloam soils revealed that TKG-21 variety of sesame recorded the maximum seed yield than JLSC-8 and JLI-7 (DOR, 1991). Ghungarde *et al*. (1992) reported that variety JLT-7 produced the higher seed yield (679 kg ha^{-1}) than Punjab-1 variety (523 kg ha^{-1}) on clay soils of Parbhani.

Mishra and Yadav (1993) while reviewing research work conducted at various centres across India reported that RI-57 variety recorded the maximum yield (473 kg ha^{-1}) but was on a par with TKG-21 (472 kg ha^{-1}). On sandy loam soils of Rajendranagar (A.P.) two varieties of sesame viz., TMV-6 and TMV 4 produced equal seed yields (677 kg ha^{-1}) but the yields were more when compared to that of V-S 350 (604 kg ha^{-1}) (DOR, 1994). Madhavi produced the highest seed yield of 445 kg ha^{-1} than other varieties in an field experiment on sandy loam soils of Tirupati (Sumathi and Jaganmohan, 1999). The average seed yield of sesame was more with Kalika (918 kg ha^{-1}) followed by Kanak (873 kg ha^{-1}) on sandy loam soils during dry season (Patra and Mishra, 2000).

2.1 Effect of biochar on the growth and yield of sesame

Biochar is a product of a biomass burning process in an oxygen limited environment (pyrolysis). This process also produces syngas and bio-oil that can be used in heat and power generation. The yields of each component (syngas and bio-oil and biochar) are dependent upon the temperature of pyrolysis, the residence time of the process and the type of feedstock used. Biochar holds the potential to reduce atmospheric CO_2 concentrations by sequestering carbon from the atmosphere, into biomass, and 'locking-up' this carbon when this biomass is converted into biochar. Biochar is recalcitrant and physically stable; to the extent that, once applied to soil, it becomes a persistent component within the soil matrix. Embracing all of these aspects, the European Commission (Verhaijen *et al*., 2010) recently defined biochar as: "charcoal (biomass that has been pyrolyzed in a zero or low oxygen environment) for which, owing to its inherent properties, scientific consensus exists that application to soil at a specific site is expected to sustainably sequester carbon and concurrently improve soil functions (under current and future management), while avoiding short- and long-term detrimental effects to the wider environment as well as human and animal health."

Properties of biochar

The matrix of biochar has been determined by X-ray diffraction (Lehmann and Joseph, 2009). This work revealed an essential amorphous structure with crystalline areas (Lehmann and Joseph, 2009) consisting of random polycyclic aromatic (graphene) layers rimmed by functional groups (Zhu *et al*., 2005) and mineral compounds (Lehmann and Joseph, 2009). Associated with the pyrolysis process above 330˚C is the formation of polyaromatic sheets which create turbostratic structures (Keiluweit *et al*., 2010) and increased porosity as temperatures increase. Studies have demonstrated that higher temperatures lead to a decrease in particle size (Downie *et al*., 2009) and the development of microporosity (< 2nm), which underpin the high surface area of biochar (Downie *et al*., 2009). Physical properties, of course, vary depending upon the biomass feedstock used and the thermochemical conditions of char formation.

Importance of biochar

Biochar chemical properties Owing to different production conditions and indeed variety in feedstock materials used to produce biochar chemical attributes vary considerably. At an elemental level biochar properties can be ascribed with respect to ratios of C, H, O and N. Particularly, ratios of H/C and O/C are used to determine the degree of biochar aromaticity i.e. the lower is the ratio, the greater is the aromaticity (Kookana *et al*., 2011). H/C and O/C ratios have 6 been reported to be higher in biochars produced at low-temperatures, due to incomplete charring of the feedstock; H/C and O/C ratios decrease with increasing temperatures of production (Baldock and Smernik, 2002). Thus, higher temperature chars are inherently more resistant to chemical modifications and therefore are more recalcitrant. The nutrient content in biochar also varies depending upon feedstock type and pyrolysis conditions used. Higher temperatures and faster heating rates strongly influence the retention nutrients within the biochar formed: nitrogen (N) and sulphur (S) compounds, for example, volatilize at 200˚C and 375˚C respectively; while biochar becomes depleted in potassium (K) when produced above 700˚C and of phosphorous (P) above 800˚C (DeLuca *et al*., 2009). Minerals such as magnesium (Mg), calcium (Ca) and manganese (Mn) volatilize at temperature above 1000˚C (Neary *et al*., 1999; DeLuca *et al*., 2009); pH, electrical conductivity (EC) and extractable NO3 - tend to be higher with high-temperatures (800˚C), while low temperature (350˚C) result in greater extractable amounts of P, NH4 + and phenols. Feedstock type is responsible for different ratio of C/P and C/N; in particular, wood- and nut-based biochars show high ratio of C/P and C/N ratios, while manure- crop- and food-waste biochars have lower ratios (Kookana *et al*., 2011).

Benefit of Biochar

Although the composition of biochars depends upon the nature of the feedstocks and the operating conditions of pyrolysis, biochars are generally expected to be rich in nutrients. These characteristics can have a direct effect on the plant growth. For example, the addition of 68t C ha^{-1} increased rice biomass by 17 per cent while the presence of 135 t C $ha^{-1}$of biochar enhanced the growth by 43 per cent (Glaser *et al*., 2002; Lehmann *et al*., 2003). Improved crop yields have been attributed to improvement in P, K and possibly Cu levels following the addition of biochar (Chan and Xu, 2009). Biochar has the potential to increase cation exchange, soil water-holding and surface sorption capacity on account of its physical and chemical characteristics of biochar; specifically: its high surface-area, high porosity and variable-charge (Amonette and Joseph, 2009; Yang *et al*., 2010). Therefore the application of biochar is expected to enhance soil properties in terms of increasing or maintaining the pH of the soils (Rondon *et al*., 2007), toxin neutralization (Wardle *et al*., 1998), and reduce soil strength (Chan *et al*., 2007). Again these properties vary depending upon the properties of the biochar and also on account of the original characteristics of the soil and the plant species of interest. In support of these benefits, Zwieten *et al* (2007) reported a nearly 30-40 per cent increase in wheat height when biochar produced from paper mill sludge was applied at a rate of 10 t ha^{-1} to an acidic soil . Hoshi (2001) suggested that the biomass increase of tea trees (20 per cent in height and 40 per cent in volume) were partly due to the ability of biochar to keep pH constant in soil. Chan *et al.* (2007) found that the dry matter of radish in a pot increased by up to 266 per cent when N fertilizer was applied at 100kg ha^{-1} compared to a control with the same treatment but in absence of biochar. Another important area where biochar might contribute is to levels of soil carbon. Significantly, modern agricultural practices have resulted in degradation of soil carbon and as a consequence levels of carbon are much lower now than they were several decades ago (Jones *et al*., 2011). Biochar has recently come to the fore as an additional soil amendment source of carbon. Of greatest significance is the fact that biochar is inherently stable and as a consequence, offers the opportunity to replenish soil carbon reservoirs in a long-lasting way. Measurements of biochar over time were taken; Preston and Schmidt (2006) determined an average of half-life of biochar in coastal temperate rainforest of western Vancouver of 6623 years, while Hammes *et al.* (2008) 8 calculated a turnover time of biochar from fires in a Russian steppe of only 293 years. There exists uncertainty on the residence of time of biochar as the calculation could be affected by spatial variabilities (Lehmann *et al*., 2009) and the decomposition or mineralization of biochar can be affected by several physical conditions. Nevertheless, although biochar is subjected to decomposition processes, its stability remains high over long periods of time.

Wacal *et al.* (2016) was conduct a field experiment with four established plots of 1, 2, 3 and 4 years of continuous sesame were used to cultivate two sesame cultivars, " Nishikimaru " and " Gomazou " in 2015. Biochar treatments included four rates of rice husk biochar (0, 5, 10, and 15t/ha) with inorganic fertilizer; N: P: K= 70 kg, 105 kg, 70 kg and lime at 1000 kg ha^{-1}, respectively in each continuous cropping plot. Results indicated that plant height, seed yield, and 1000-seed weight were all significantly influenced by biochar application. Compared to control, 10 t/ha rice husk biochar increased yield of sesame by 34% in " Nishikimaru " and 45% in " Gomazou " in 1 year plot. 15t/ha increased yield by 25% in " Gomazou " and 5t ha^{-1} by 15% in " Nishikimaru " in 2 years plot while 10t/ha resulted in 45% yield increase in " Nishikimaru " and 5t/ha in " Gomazou " caused 6% yield increment in 3 years plot. 15t ha^{-1} increased yield of

"Nishikimaru " by 32% while 10t/ha by 4% in " Gomazou " in 4 years plot. Biochar improved soil porosity, bulk density, compactness and volumetric moisture.

Ndor *et al*. (2015) were conducted these experiments during 2011 and 2012 rainy season at the research and teaching farm of the college of agriculture, Lafia, Nasarawa state, Nigeria; to evaluate the effect of biochar amended soil on soil properties and yield of sesame varieties. The treatments consisted of three rates of rice husk biochar (0, 5 and 10 t/ha) and three rates of sawdust biochar (0, 5 and 10 t ha^{-1}) and two varieties of sesame (Yandev 55 and local variety) which were factorially combined and laid in a Randomized Complete Block Design (RCBD) and replicated three times. The result showed that the soil is low in major nutrients before the incorporation of biochar. The soil was also acidic in nature (pH: 5.98). After incorporation of biochar and two y ears of cropping. Result revealed that both rice husk and sawdust biochars rates did not showed any significant effect on sand, clay and silt; but had a significant effect on % soil moisture content, bulk density, % porosity and % soil water-filled pore space. Application of 10 t ha^{-1} produced the highest value of 10.697% and 10.77% soil moisture content, 36.47% and 35.58% of soil porosity, 50% and 50.6% soil water filled pore space in both rice husk and sawdust biochar. This is at par with application of 5 t/ha of both biochars, but it is higher than the control treatment. However, bulk density decreases with increased rates of biochar application. Therefore, the control produced soils with the higher bulk density of 1.67 g cm^{-3} and 1.69 g cm^{-3} with rice husk and sawdust biochar respectively. Also, Rice husk and sawdust biochars rates had a significant effect on all the chemical properties in the soil. 10 t/ha of rice husk and sawdust biochar produced the highest levels of pH, = 6.80:6.74; %TN, =0.15: 0.14; K, =0.59: 0.65; %OC, = 0.68:0.75; Mg, = 0.75: 1.14; Na = 0.71:0.79 and CEC= 7.83:8.05, respectively. This is at par with application of 5 t ha^{-1}, but higher than the control. Increased biochar application resulted in a gradual increase in all the chemical properties in the soil except H+Al which displayed an opposite trend. Application of 10 t ha^{-1} of sawdust and rice husk biochar produced the highest seed weight of 0.93: 0.83 t ha^{-1} and 0.90:0.95 t/ha in both years, respectively. This is at par with application of 5 t ha^{-1} of both biochars in the two cropping season, but higher than control. Sesame varieties also showed a significant effect in both cropping season; Yandev 55 demonstrated its superiority against the local variety by producing 0.76 t ha^{-1} and 0.77 t ha^{-1} in 2011 and 2012 cropping season.

However, the combine effect of sawdust biochar and rice husk biochar did not produce any significant effect on the soil properties and sesame yield.

The agricultural area has continued to shrink and is a huge issue for agriculture-based countries, such as Indonesia. Contrary, the coastal sandy land area of Indonesia is large enough, but it has low productivity due to dominant soil constituent material of sand (>80%) so that it affects the availability of water and plant nutrient negatively. To improve the water-holding capacity, an applied technology is urgently needed so that it can be used as a growing material of sesame. A novel technology through the use of activated coconut shell charcoal was proposed. Due to its functions in optimizing growing medium, improving soil properties physically, chemically, and biologically as well as in holding water and providing nutrients, the used biological charcoal would work as biological soil amendments. The experiment was factorial design laid out in Randomized Complete Block Design involved 14 treatments with three replications consisting of combinations of seven biochar applications and two sesame varieties. The data were subjected to analysis of variance and Tukey's Honestly Significant Difference test were used as a post-hoc analysis (α = 5%). The experimental results showed that the highest oil content obtained from the application of coconut shell charcoal at a dose of 10 ton/ha combined with chicken manure at a dose of 30 t ha^{-1}. The application of biochar more or less than 10 ton/ha combined with chicken manure decreased oil content. The significant effect on oil content was not found when the plant was treated only with the biochar at any dose level (Nurhayati, 2017).

Rebecca *et al.* (2018) was conducted a field studied of biochar addition to soil and nutrient cycling using N fertilizers in temperate agriculture are scant. These data are required in order to make evidence based assessments. This study was conducted to test the hypothesis that biochar application can increase crop yields through improving the nitrogen uptake and utilization of added inorganic fertilizer, whilst sequestering significant quantities of carbon. Results showed that although biochar addition led to significant spring barley grain yield increases in the first year of biochar application, an unusually dry year; this was possibly not solely the result of improved nitrogen uptake, as total crop N was similar in both treatments. Results suggested it was improved water utilization, indicated by the crop carbon isotope values and soil moisture characteristics. In the second year, there were no significant effects of the previous year's biochar addition on the sunflower yield, N status, fertilizer recovery or any signs of improved water utilization. These data add to a growing body of evidence, suggesting that biochar addition has only slightly positive or neutral effects on crop growth and fertilizer retention but has the potential to sequester vast amounts of carbon in the soil with minimal yield losses in temperate agriculture.

From the review of literatures it may be concluded that variety and different level of biochar application had significant influence on sesame and other crops to produce increased plant growth and yield characters.

Chapter 3
MATERIALS AND METHODS

The experiment was conducted at the Agronomy field of the Sher-e-Bangla Agricultural University, Dhaka, during the period of March 2017 to June 2017 to to study response of biochar on soil properties and on the growth and yield of sesame. Materials used and methodologies followed in the present investigation have been described in this chapter.

3. Description of the experimental site

3.1 Location

The field experiment was conducted at the Agronomy field of Sher-e-Bangla Agricultural University, Dhaka during the period from March to June, 2017.

3.2 Site and soil

Geographically the experimental field was located at 23° 77′ N latitude and 90° 33' E longitudes at an altitude of 9 m above the mean sea level. The soil belonged to the Agro-ecological Zone - Modhupur Tract (AEZ-28). The land topography was medium high and soil texture was silty clay with pH 6.1. The morphological, physical and chemical characteristics of the experimental soil have been presented in Appendix II.

3.3 Climate and weather

The climate of the locality is subtropical which is characterized by high temperature and heavy rainfall during Kharif season (April-September) and scanty rainfall during Rabi season (October-March) associated with moderately low temperature. The mean maximum air temperature and minimum air temperature range were (30.18-31.46) and (14.85-15.27) respectively. The mean relative humidity range from (67.82-74.41%), rainfall varies from (4.2-6.3 mm day^{-1}), wind speed (1-3 km hr^{-1}), sunshine hour (4.15-7.48) and evaporation rate range from (2.04-2.07 mm day^{-1}) were recorded from the SAU meteorological station, Dhaka. However the prevailing weather conditions during the study period (March-June) have been presented in Appendix III.

3.4 Plant materials

BARI Til-2 was used as planting material. BARI Til-2 was developed by Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh in 2001. Plant height is 100-120 cm, leaf light green, lower leaf comparatively wide and gradually upper leafs narrow and pointed, corolla of flower color is pink, number of capsules plant^{-1} 60-70, seeds capsule^{-1} 60-70, skin black in color, crop duration 90- 100 days. Planting season and time, Kharif season:, in kharif-1 February to March and kharif-2 Mid August to Mid September.This variety is suitable early sowing. Average yield of this cultivar is about 1.20-1.30 t ha^{-1}.

BARI Til-3 was used as planting material. BARI Til-3 was developed by Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh in 2001. Plant height 100-110 cm, stem, branch, sub –branch without hair, leaf deep green, rough, 3-5 primary branch has present in each plant, branch is grown slight up on main stem, flower light pink, capsules plant^{-1} 60-65, four chamber has present, seeds capsule^{-1} 50-55, seed coat deep reddish color, crop duration 90-100 days. Planting season and time, Kharif season:, in kharif-1 February to March and kharif-2 Mid August to Mid September. Average yield of this cultivar is about 1.20-1.40 t ha^{-1}.

BARI Til-4 was used as planting material. BARI Til-4 was developed by Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh in 2009. Plant height 90-120 cm, about 70% capsules 8 –chamber, capsules plant^{-1} 85-90, number of seeds capsule^{-1} 75-77, seed brown in color, 20-40% seed greater than BARI Til-2 and BARI Til-3, seed coat deep reddish color, crop duration 90-95 days. Average yield of this cultivar is about 1.4-1.5 t/ha which is greater than BARI Til-2 and BARI Til-3. It is tolerant to disease and insect. All the varieties were collected from Bangladesh Agricultural Research Institute (BARI).

3.5 Treatments

The experiment consisted with following two treatment factor:

Factor A: Varieties - 3

V_1 = BARI Til-2

V_2 = BARI Til-3

V_3 = BARI Til-4

Factor B: Biochar level- 5

B_0= Control (no biochar application)

B_1=application of biochar 2 t ha^{-1}

B_1= application of biochar 4 t ha^{-1}

B_1= application of biochar 6 t ha^{-1}

B_1= application of biochar 8 t ha^{-1}

Treatment combination: Fifteen treatment combinations were as follows

i. $V_1 \times B_0$

ii. $V_1 \times B_1$

iii. $V_1 \times B_2$

iv. $V_1 \times B_3$

v. $V_1 \times B_4$

vi. $V_2 \times B_0$

vii. $V_2 \times B_1$

viii. $V_2 \times B_2$

ix. $V_2 \times B_3$

x. $V_2 \times B_4$

xi. $V_3 \times B_0$

xii. $V_3 \times B_1$

xiii. $V_3 \times B_2$

xiv. $V_3 \times B_3$

xv. $V_3 \times B_4$

3.6 Experimental design and layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) having 3 replications. There were 15 treatment combinations and 45 unit plots. The unit plot size was 3.60 m^2 (1.8 m X 2.0 m). The blocks and unit plots were separated by 0.50 m and 0.3 m spacing respectively.

3.7 Land preparation

The experimental land was opened with a power tiller on 20 March, 2017. Ploughing and cross ploughing were done with power tiller followed by laddering. Land preparation was completed on 25 March, 2017 and was ready for sowing seeds.

3.8 Fertilizer application

The recommended doses of Urea, TSP, MoP, Gypsum, Zinc sulphate and Boric acid as per BARC (2012) are 125, 150, 50, 110, 5 and 10 kg ha^{-1}. All fertilizers were applied as per recommendation as basal dose except urea were applied 2 splits.

3.9 Sowing of seeds

Seeds were sown in the furrow on 28 March, 2017 and the furrows were covered with the soils soon after seeding. The seed were sown continuously in 30 cm apart rows.

3.10 Intercultural operations

3.10.1 Thinning

Thinning was done to maintain 5 cm plant to plant distance in each row after 10 days of germination.

3.10.2 Weed control

Weed control was done as per experimental treatments.

3.10.3 Irrigation and drainage

Pre-sowing irrigation was given to ensure the maximum germination percentage. During experimental period, there was heavy rainfall for several times. So it was essential to remove the excess water from the field.

3.11 Harvesting and sampling

The crop was harvested at 87 DAS. The crop was harvested plot wise when about 80% of the pods became matured. Samples were collected from different places of each plot leaving undisturbed plant in the center. The plant sample were tied into bundles and carried to the threshing floor. The sample bundles were sun dried by spreading those on the threshing floor. The seeds were separated, cleaned and dried in the sun for 3 to 5 consecutive days for achieving safe moisture of seed.

3.12 Threshing

The crop was sun dried for three days by placing them on the open threshing floor. Seeds were separated from the plants by beating the bundles with bamboo sticks.

3.13 Drying, cleaning and weighing

The seeds thus collected were dried in the sun for reducing the moisture in the seeds to a safe level. The dried seeds and straw were cleaned and weighed. The sample plants after separating seeds were oven dried at a constant weight for determining dry matter.

3.14 Recording of data

The data were recorded on the following parameters

A. Growth parameters

a. Plant height (cm) at 55 DAS, 80 DAS and at harvest

b. Number of leaf plant^{-1} at 55 DAS, 80 DAS and at harvest

B. Yield contributing parameters

a. Capsules plant^{-1} (no.)

b. Seeds capsule $^{-1}$ (no.)

c. 1000 seeds weight (g)

C. Yields parameter

a. Grain yield (t ha^{-1})

b. Stover yield (t ha^{-1})

c. Biological yield (t ha^{-1})

d. Harvest index (%)

D. Soils parameter

a. Soil pH

b. OC%

c. Nitrogen (N) %

d. Phosphorus (P) (µg g^{-1}soil)

e. Potassium (K) (meq 100g^{-1}soil)

3.15. Procedure of recording data

3.15.1 Crop growth and soil parameter

i. Plant height (cm)

Ten plants were collected randomly from each plot. The height of the plants were measured from the ground level to the tip of the plant at 55 and 80 days after sowing (DAS) and at harvest time.

ii. Number of leaves plant^{-1}

Ten plants were collected randomly from each plot. Number of leaf per plant was counted from each plant sample and then averaged at 55 and 80 days after sowing (DAS) and at harvest time.

iii. Capsules plant^{-1} (no.)

Number of capsules plant^{-1} was counted from the 10 plant sample and then the average capsule number was calculated.

iv. Seeds capsule^{-1} (no.)

Number of seeds capsule^{-1} was counted from 10 pods of plants and then the average seed number was calculated.

v. Weight of 1000 seeds (g)

1000-seeds were counted which were taken from the seeds sample of each plot separately, then weighed in an electrical balance and data were recorded.

vi. Seed yield (t ha^{-1}**)**

Seed yield was recorded on the basis of total harvested seeds plot^{-1} (1 m^2) and was expressed in terms of yield (t ha^{-1}). Seed yield was adjusted to 12% moisture content.

vii. Stover yield (t ha^{-1}**)**

After separation of seeds from plant, the straw and shell of harvested area was sun dried and the weight was recorded and then converted to t ha^{-1}.

viii. Biological yield (t ha^{-1}**)**

The summation of seed yield and above ground stover yield was the biological yield

Biological yield = Grain yield + Stover yield.

ix. Harvest index (%)

Harvest index was calculated on dry basis with the help of following formula

Economic yield (seed weight)

$$\text{HI (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

Here, Biological yield = Grain yield + stover yield

x. Estimation Soil pH

Soil pH was determined by glass electrode pH meter. Twenty gram of air-dried soil was taken in 100 ml beaker and 50 ml of distilled water added to each beaker. The suspension was stirred well for several times during the next 30 minutes and allowed to stand for about an hour. Soil pH was measured using glass electrode pH meter method (Soil: water ratio being 1: 2.5).

xii. Organic carbon

Organic carbon was estimated by the Walkley and Black method. In this method, organic matter in the soil is oxidized with a mixture of potassium dichromate ($K_2Cr_2O_7$) and concentrated H_2SO_4 utilizing the heat of dilution of H_2SO_4. Unused normal $K_2Cr_2O_7$ is back titrated with N/2 ferrous ammonium sulphate using diphenyl amine as indicator.

xiii. Estimation of nitrogen

The estimation of N was made by modified micro-Kjeldahl method (AOAC), which depends on the fact that organic nitrogen, when digested with concentrated sulphuric acid that converted into ammonium sulphate. Ammonia liberated by making the solution alkaline is distilled into a known volume of standard boric acid, which is then back titrated.

Reagents:

i. Kjel Tab./Catalyst mixture (Potassium sulphate +Selenium)
ii. Concentrated sulphuric acid (H_2SO_4) solution
iii. 2% Boric acid (HBO_3) solution
iv. Hydrochloric acid (0.01 N HCl) solution
v. 40% sodium hydroxide solution (NaOH)
vi. Mixed indicator (Methyl red and Methyline blue)

About 0.2 g of grain, straw and soil dried ground samples was taken in weighing paper and measured accurately. Then it was poured into a 75 ml clean and dry Kjedahl flask, to which 5 ml conc. H_2SO_4, 1 gel tab, 2 ml H_2O_2 and 2-3 glass ball were added. The sample mixture was heated at 370°C for 1 hr, over a preheated heater. When the sample color become colorless then the digestion of the sample was completed. The digested sample was cooled at room temperature (25°C) and diluted to 75 ml. Ten milliliter of the digested diluted sample solution was taken in a distillation apparatus with 10 ml 40% NaOH. The distillate (about 60 ml), was collected in a conical flask containing 10 ml 2% boric acid solution and 2 drops of mixed indicator (methyl red and methyline blue).The total distillate was collected and titrated with standardized HCI solution (0.01 N HCl).

Calculation:

The amount of nitrogen was calculated according to the following equation:

$$\%\text{Nitrogen} = \left[\frac{(\text{TS - TB}) \times \text{Strength of HCl acid} \times .014}{\text{Weight of the sample (g)}} \times 100\right]$$

Where,

T_S= Titrate value of sample in ml

T_B= Titrate value of blank in ml

Strength of HCl acid=0.01N

xiv. Estimation of phosphorus

Preparation of fruit extract for different nutrients

Exactly 1 g of finely grind fruit materials were taken into a 250 mL conical flask and 10 mL of di-acid mixture (HNO_3 ; $HClO_4$=2:1) was added to it. Then it was placed on an electric hot plate for heating at 180 - 200° C until the solid particles disappeared and white fumes were evolved from the flask. Then it was cooled at room temperature, washed with distilled water and filtered into 100 mL volumetric flask through Whatman No. 42 filter paper making the volume up to the mark with distilled water following wet oxidation method. The solution was used for the estimation of P.

Phosphorus (P)

Phosphorus of leaf, stem, root and fruit extract was determined colorimetrically by stannous chloride method- In this method, stannous chloride ($SnCl_{2.}$ $2H_2O$) was used as a reducing agent to form molybdophosphoric blue complex with sulphomolybdic acid. One mL fruit extract sample was taken in a 100 ml volumetric flask followed by the addition of 4 mL of sulphomolybdic acid and 5 drops of stannous chloride solution. Then the volume was made up to the mark with distilled water and the content was shaken thoroughly. Finally the intensity of blue color was measured with the help of Spectrophotometer (model: Spectrum 21D) set as 660 nm wave length within 15 minutes after the addition of stannous chloride reagent following the procedure.

xv. Potassium (K)

Total potassium was estimated by using flame photometer. In this method the soil sample is digested with hydrofluoric (48%) and perchloric acid (70-72%) in platinum crucible. The results were expressed in µg g^{-1}.

3.16. Data analysis technique

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program MSTAT- C and the mean differences were adjusted by Least Significance Difference (LSD) test at 5% level of significance.

Chapter 4
RESULT AND DISCUSSION

This chapter comprises the presentation and discussion of the results obtained from the experiment. The experiment was conducted to determine the effects of variety and different level of biochar and their interaction effects on vegetative growth and yield of sesame. The growth and yield components such as plant height, leaf number, capsule number and yield of sesame as influenced by variety and different levels of biochar are presented in Table and Figures. The results of each parameter have been adequately discussed and possible interpretations whenever necessary have been given under the following headlines:

4.1 Growth character

4.1.1 Plant height

Varieties showed statistically significant variation in respect of plant height (Figure 1). However, among the different varieties V_3 (BARI Til-4) showed the highest plant height (68.29, 107.72 and 106.64 cm at 55, 80 DAS and at harvest, respectively). The lowest plant height (60.51, 95.44 and 95.43 cm at 55, 80 DAS and at harvest, respectively) was observed in the V_1 (BARI Til-2). Variations in plant height among various sesame varieties had been reported extensively (Gangakishan *et al*.,1983; Abdulkhader and Gopinathannair, 1984; Narayanan and Ravindrakumar, 1988; Sverup *et al*., 1989 and Ghungarde *et al*., 1992).

The plant height was significantly influenced by different level of biochar application at all growth stages of sesame (Figure 2). At 55, 80 DAS and at harvest, the highest plant height (66.13, 104.30, and 103.58 cm, respectively) was recorded in B_3 (application of biochar 6 t ha^{-1}) which was statistically similar with the treatment B_4 (application of biochar 8 t ha^{-1}) where the lowest was measured at 55, 80 DAS and at harvest (61.74, 97.39 and 96.72 cm, respectively) in B_0 (no biochar application). Van Zwieten *et al* (2007) reported a nearly 30-40 per cent increase in wheat height when biochar produced from paper mill sludge was applied at a rate of 10 t ha^{-1} to an acidic soil. Wacal *et al.* (2016) found that plant height of sesame was significantly influenced by biochar application.

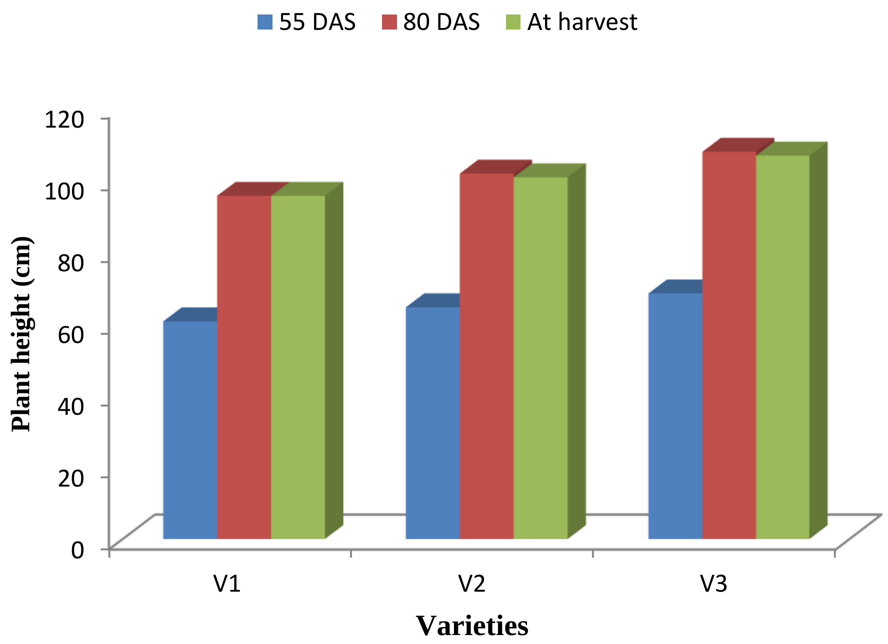

Figure 1. Effect of varieties on plant height of sesame at different days after sowing (DAS) [(LSD $_{(0.05)}$ 0.865, 1.255 and 1.24 at 55, 80 DAS and at harvest, respectively)]

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

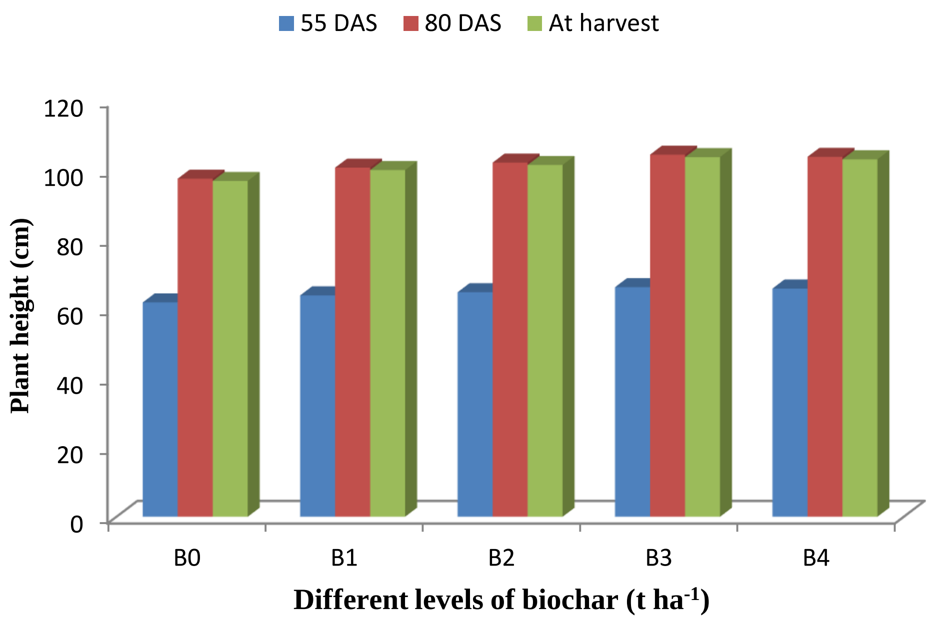

Figure 2. Effect of different levels of biochar on plant height of sesame at different days after sowing (DAS) [(LSD $_{(0.05)}$ 1.476, 1.622 and 1.601at 55, 80 DAS and at harvest respectively)]

B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar exerted significant effect on plant height (Table 1). The highest plant height (70.34, 110.95 and 109.84 at 55, 80 DAS and at harvest, respectively) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$). The lowest plant height (58.19, 91.78 and 91.77 cm at 55, 80 DAS and at harvest, respectively) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

Table 1. Interaction effect of varieties and different levels of biochar on plant height of sesame at different days after sowing (DAS)

Interaction	Plant height (cm) at		
	55 DAS	80 DAS	Harvest
$V_1 \times B_0$	58.19g	91.78h	91.77i
$V_1 \times B_1$	60.11fg	94.81g	94.81h
$V_1 \times B_2$	60.99f	96.20g	96.19h
$V_1 \times B_3$	61.67f	97.28g	97.27gh
$V_1 \times B_4$	61.58f	97.12g	97.11gh
$V_2 \times B_0$	61.67f	97.27g	96.30h
$V_2 \times B_1$	63.67f	100.43f	99.42fg
$V_2 \times B_2$	64.58e	101.87ef	100.85ef
$V_2 \times B_3$	66.36de	104.67de	103.62de
$V_2 \times B_4$	65.84cd	103.85de	102.81de
$V_3 \times B_0$	65.37cd	103.11ef	102.08ef
$V_3 \times B_1$	67.50bc	106.46cd	105.39cd
$V_3 \times B_2$	68.46ab	107.98b	106.90bc
$V_3 \times B_3$	70.34a	110.95a	109.84a
$V_3 \times B_4$	69.79a	110.08ab	108.9ab
CV (%)	1.933	2.806	2.773
$LSD_{(0.05)}$	6.37	7.31	6.55
LS	NS	**	**

Figures in a column followed by different letter(s) differs significantly whereas figures having common letter(s) do not differ significantly from each other as adjusted by LSD.

CV= Coefficient of variation, LS= Level of significance, $LSD_{(0.05)}$= Least significant difference, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4, B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

4.1.2 Number of leaves $plant^{-1}$

Varieties showed significant variation on the number of leaves $plant^{-1}$ of sesame (Figure 3). Among the different varieties V_3 (BARI Til-4) showed the highest number of leaves $plant^{-1}$ (78.13, 113.30 and 91.79 cm at 55, 80 DAS and at harvest, respectively). The lowest number of leaves $plant^{-1}$ (69.22, 100.39 and 77.31 cm at 55, 80 DAS and at harvest, respectively) by the variety V_1 (BARI Til-2). The genetic factor of variety might be increased the vegetative growth of sesame that lead to the highest number of leaves $plant^{-1}$.

Leaves $plant^{-1}$ was significantly influenced by different levels of biochar application at all growth stages of sesame (Figure 4). At 55, 80 DAS and at harvest, the highest number of leaves $plant^{-1}$ (75.65, 109.71 and 86.41, respectively) was recorded in B_3 (application of biochar 6 t ha^{-1}) and the lowest was achieved with B_0 (no biochar application) (70.64, 102.43 and 80.68 respectively).

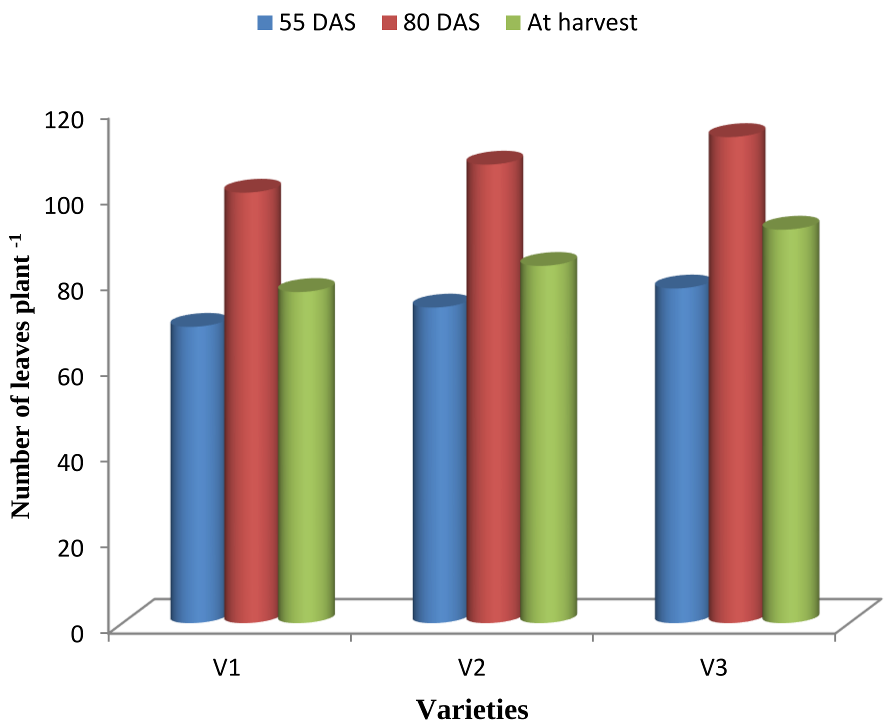

Figure 3. Effect of varieties on number of leaves $plant^{-1}$of sesame at different days after sowing (DAS) [(LSD $_{(0.05)}$ 0.769, 1.159, and 0.735 at 55, 80 DAS and at harvest, respectively)].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

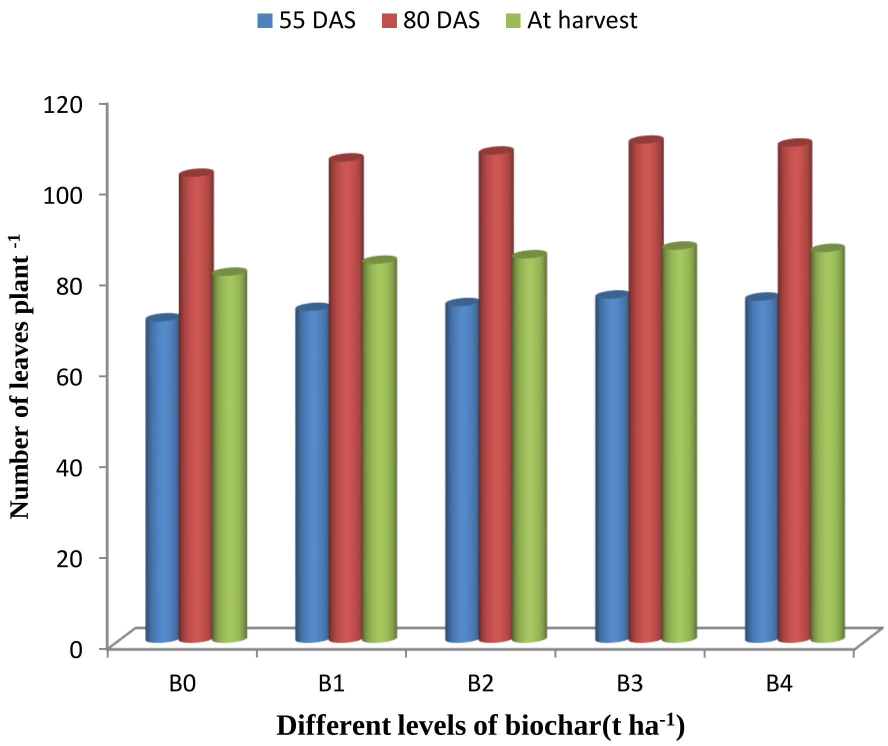

Figure 4. Effect of different levels of biochar on number of leaves plant^{-1}of sesame at different days after sowing (DAS) [(LSD $_{(0.05)}$ 0.990, 1.496 and 55, 80 DAS and at harvest, respectively)].

B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar exerted significant effect on number of leaves at all DAS (Table 2). The highest number of leaves (80.47, 116.70 and 94.54 cm at 55, 80 DAS and at harvest, respectively) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$) at harvest. The lowest number of leaves (66.55, 96.54 and 74.35 at 55, 80 DAS and at harvest, respectively) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$) at 55 DAS and 80 DAS at harvest.

Table 2. Interaction effect of varieties and different levels of biochar on number of leaves plant^{-1} of sesame at different days after sowing (DAS)

Interaction	Number of leaves plant^{-1}		
	55 DAS	80 DAS	Harvest
$V_1 \times B_0$	66.57j	96.54i	74.35i
$V_1 \times B_1$	68.77i	99.76h	76.80h
$V_1 \times B_2$	69.77hi	101.17h	77.92gh
$V_1 \times B_3$	70.56h	102.33h	78.80gh
$V_1 \times B_4$	70.44hi	102.17h	78.67gh
$V_2 \times B_0$	70.55h	102.31h	79.82g
$V_2 \times B_1$	72.84g	105.67g	82.41f
$V_2 \times B_2$	73.89fg	107.17fg	83.59ef
$V_2 \times B_3$	75.92de	110.10de	85.89e
$V_2 \times B_4$	75.32ef	109.23ef	85.22d
$V_3 \times B_0$	74.79ef	108.43ef	87.86d
$V_3 \times B_1$	77.21cd	111.97cd	90.71c
$V_3 \times B_2$	78.32bc	113.60bc	92.01bc
$V_3 \times B_3$	80.47a	116.70a	94.54a
$V_3 \times B_4$	79.84ab	115.80ab	93.80ab
CV (%)	1.721	2.591	2.345
$LSD_{(0.05)}$	5.46	9.54	5.42
LS	**	**	**

Figures in a column followed by different letter(s) differs significantly whereas figures having common letter(s) do not differ significantly from each other as adjusted by LSD.

CV= Coefficient of variation, LS= Level of significance, $LSD_{(0.05)}$= Least significant difference, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4, B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

4.1.3 Number of branches plant^{-1}

Varieties showed significant variation on the number of branches plant^{-1} of sesame (Figure 5). Among the different fertilizer level V_3 (BARI Til-4), showed the highest number of branches plant^{-1} (3.48). The lowest number of branches plant^{-1} (3.11) was observed in variety V_1 (BARI Til-2). Optimum fertilizer level might be increased the vegetative growth of sesame that lead to the highest number of branch per plant. Production of the maximum number of branches per plant in Gowri variety than other varieties was widely reported (Rao *et al.*, 1985, Narayan and Narayanan, 1987 and Asharani *et al.*, 1992).

Branches plant^{-1} was significantly influenced by different levels of biochar application at all growth stages of sesame (Figure 6). The highest number of branches plant^{-1} (3.49) was recorded in B_3 (Application of biochar 6 t ha^{-1}) which was statistically similar with B_4 (application of biochar 8 t ha^{-1}) and the lowest number of branches plant^{-1} (3.02) was achieved with B_0 (no biochar application).

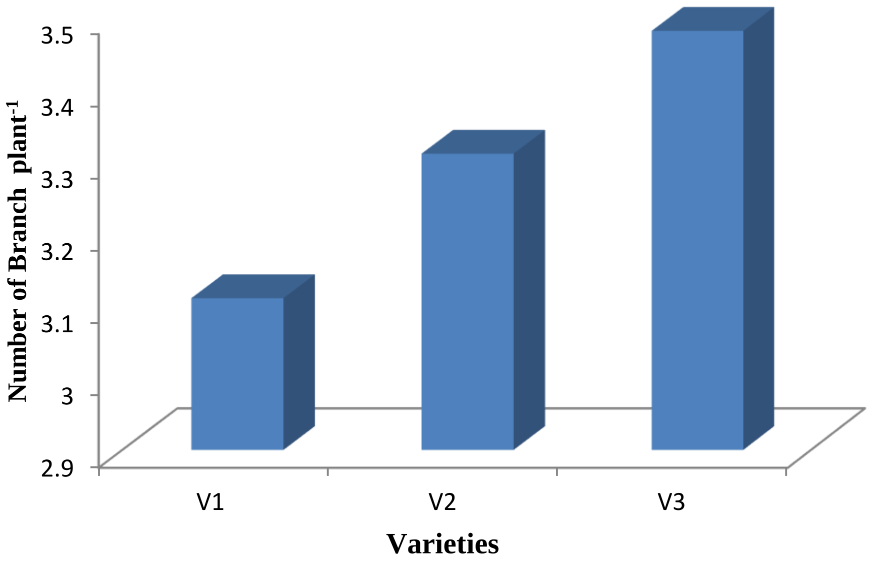

Figure 5. Effect of varieties on number of branches plant^{-1} of sesame [(LSD $_{(0.05)}$ 0.047].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

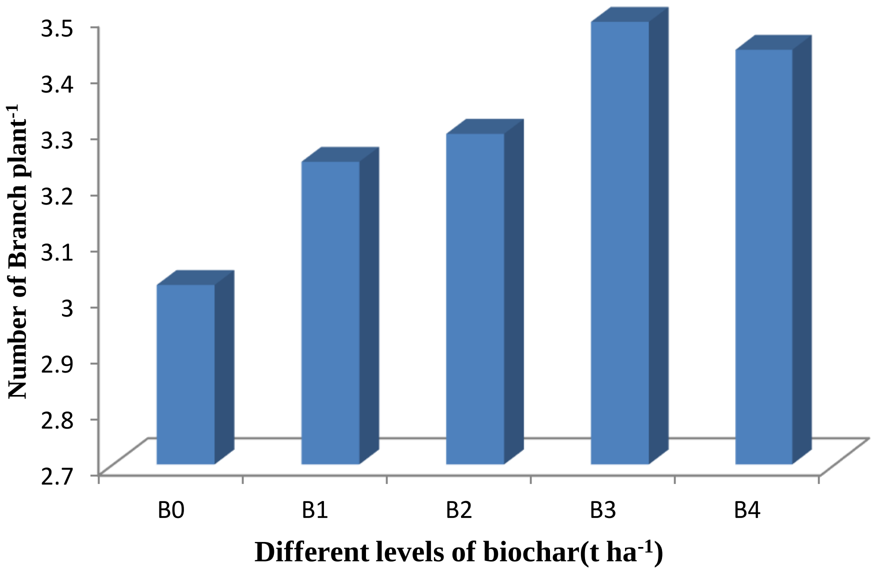

Figure 6. Effect of different levels of biochar on number of branches plant^{-1} of sesame [(LSD $_{(0.05)}$ 0.061].

B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar exerted significant effect on number of leaves (Table 3). The highest number of leaves (3.60) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$). The lowest number of leaves (2.73) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$) at 55 DAS, 80 DAS and at harvest.

Table 3. Interaction effect of varieties and different levels of biochar on number of branches plant^{-1} of sesame

Interaction	Number of branches plant^{-1}
$V_1 \times B_0$	2.73h
$V_1 \times B_1$	3.07f
$V_1 \times B_2$	3.13f
$V_1 \times B_3$	3.33de
$V_1 \times B_4$	3.27e
$V_2 \times B_0$	2.93g
$V_2 \times B_1$	3.27e
$V_2 \times B_2$	3.33de
$V_2 \times B_3$	3.53ab
$V_2 \times B_4$	3.47bc
$V_3 \times B_0$	3.40cd
$V_3 \times B_1$	3.40cd
$V_3 \times B_2$	3.40cd
$V_3 \times B_3$	3.60a
$V_3 \times B_4$	3.60a
CV (%)	8.52
$LSD_{(0.05)}$	0.105
LS	**

Figures in a column followed by different letter(s) differs significantly whereas figures having common letter(s) do not differ significantly from each other as adjusted by LSD.

CV= Coefficient of variation, LS= Level of significance, $LSD_{(0.05)}$= Least significant difference, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4, B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

4.2 Yield contributing parameters

4.2.1 Number of capsules plant^{-1}

Number of capsules plant^{-1} showed significant variation due to the effects of variety (Figure 7).The highest number of capsules per plant (78.13) was obtained from the variety V_3 (BARI Til-4). The lowest number of capsules per plant (73.70) was found when the variety V_2 (BARI Til-3).

Number of capsules plant^{-1} was significantly influenced by different levels of biochar application of sesame (Figure 8). It was remarked from the present study that the increasing rate of biochar significantly increased number of capsules plant^{-1}. B_3 (application of biochar 6 t ha^{-1}) treatment produced maximum number of capsules plant^{-1} (75.41) which was statistically similar result with B_4 (application of biochar 8 t ha^{-1}). The lowest number of capsules plant^{-1} (70.08) was achieved with B_0 (no biochar application).

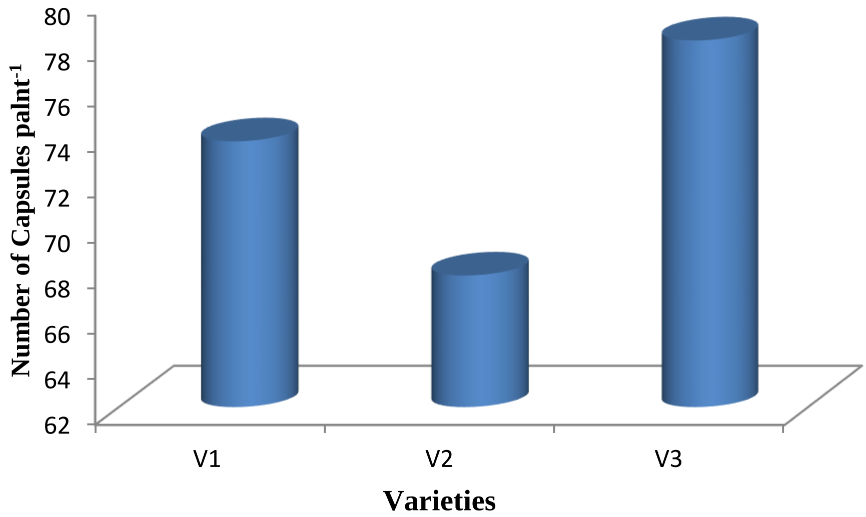

Figure 7. Effect of varieties on number of capsules plant^{-1} of sesame [(LSD $_{(0.05)}$ 0.897].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

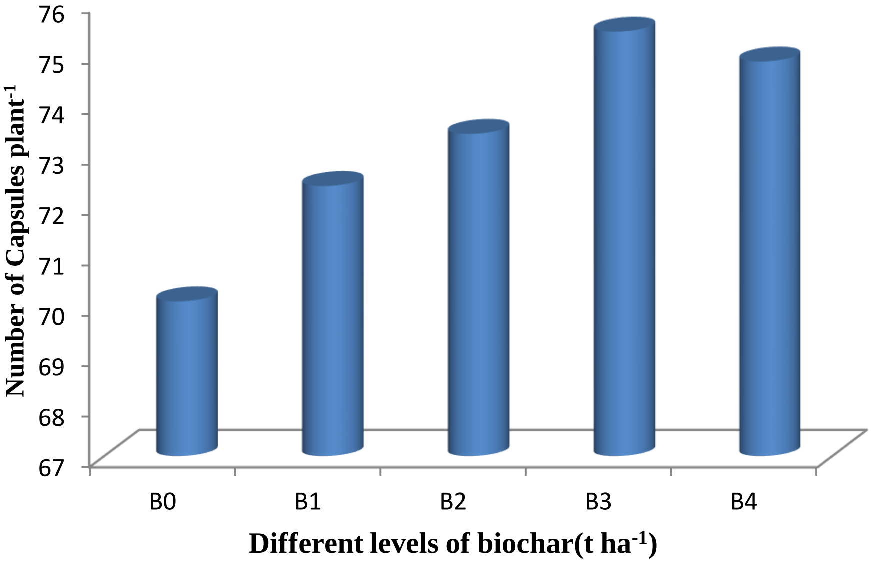

Figure 8. Effect of different levels of biochar on number of capsules plant^{-1} of sesame [(LSD $_{(0.05)}$ 1.159].

B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar exerted significant effect on number of capsules plant^{-1} (Table 4). The highest capsule plant^{-1} (80.47) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$) which was statistically similar result BARI Til-4 cultivated with application of biochar 8 t ha^{-1} ($V_3 \times B_4$). The lowest number of capsules per plant (70.55) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

Table 4. Interaction effect of varieties and different levels of biochar on yield attributes of sesame

Interaction	Capsules plant^{-1} (no.)	Seeds capsule^{-1} (no.)	1000 seeds weight (g)
$V_1 \times B_0$	70.55h	47.07h	2.81i
$V_1 \times B_1$	72.84g	48.59g	2.90gh
$V_1 \times B_2$	73.89fg	49.29fg	2.94f-h
$V_1 \times B_3$	75.92de	50.64e	3.02c-f
$V_1 \times B_4$	75.32d-f	50.25ef	3.00d-f
$V_2 \times B_0$	64.91k	39.09k	2.97e-h
$V_2 \times B_1$	67.01j	40.35j	3.06c-e
$V_2 \times B_2$	67.98ij	40.93ij	3.10a-c
$V_2 \times B_3$	69.84hi	42.06i	3.18a
$V_2 \times B_4$	69.30hi	41.73i	3.16ab
$V_3 \times B_0$	74.79e-g	52.06d	2.89hi
$V_3 \times B_1$	77.21cd	53.75c	2.98e-g
$V_3 \times B_2$	78.32bc	54.52bc	3.02c-f
$V_3 \times B_3$	80.47a	56.02a	3.10a-c
$V_3 \times B_4$	79.84ab	55.58ab	3.08b-d
CV (%)	2.008	1.256	0.091
$LSD_{(0.05)}$	4.53	6.51	2.54
LS	**	**	**

Figures in a column followed by different letter(s) differs significantly whereas figures having common letter(s) do not differ significantly from each other as adjusted by LSD.

CV= Coefficient of variation, LS= Level of significance, $LSD_{(0.05)}$= Least significant difference, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4, B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

4.2.2 Seeds capsule^{-1} (no.)

Varieties showed significant variation on number of seeds capsule^{-1} (Figure 9). Among the different varieties V_3 (BARI Til-4) showed the highest number of seeds capsule^{-1} (54.39). The lowest number of seeds capsule^{-1} (49.17) was recorded variety V_2 (BARI Til-3). Genetically controlled character might be increased the vegetative growth and development of sesame that lead to the highest number of seeds capsule^{-1}. Deshmukh *et al*. (1990) stated that the number of capsules per plant recorded with T-85 variety was higher than that of Punjab-1 at Parbhani on sandy loam soils during kharif season. On red lateritic soils of Regional Research Station, Vridhachalam during summer season, sesame variety OMT-11-6-5 recorded significantly more number of capsules (83.6) per plant followed by TMV 3 (74.7) (Kandasamy and Balasubramanian, 1991).

Results presented in Figure 10 on number of seeds capsule^{-1} influenced by different levels of biochar application were statistically significant. It was mentioned from the present study that the highest number of seeds capsule^{-1} (49.57) was recorded in B_3 (application of biochar 6 t ha^{-1}) which was statistically similar with B_4 (application of biochar 8 t ha^{-1}). The lowest number of seeds capsule^{-1} (46.07) was achieved by B_0 (no biochar application). The results from B_1 and B_2 on number of seeds capsule^{-1} were intermediate compared to highest and lowest number of seeds capsule^{-1}.

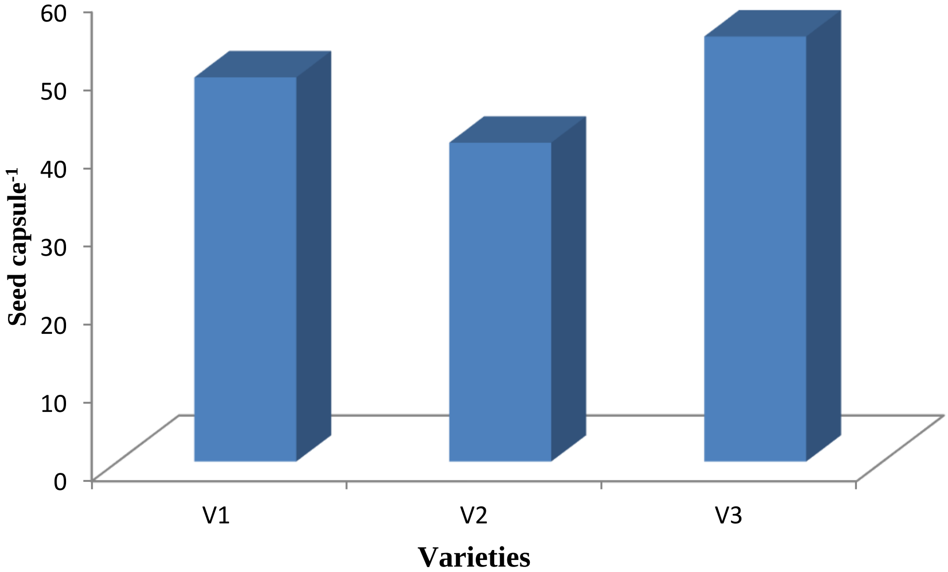

Figure 9. Effect of varieties on number of capsules capsule^{-1} of sesame [(LSD $_{(0.05)}$ 0.897].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

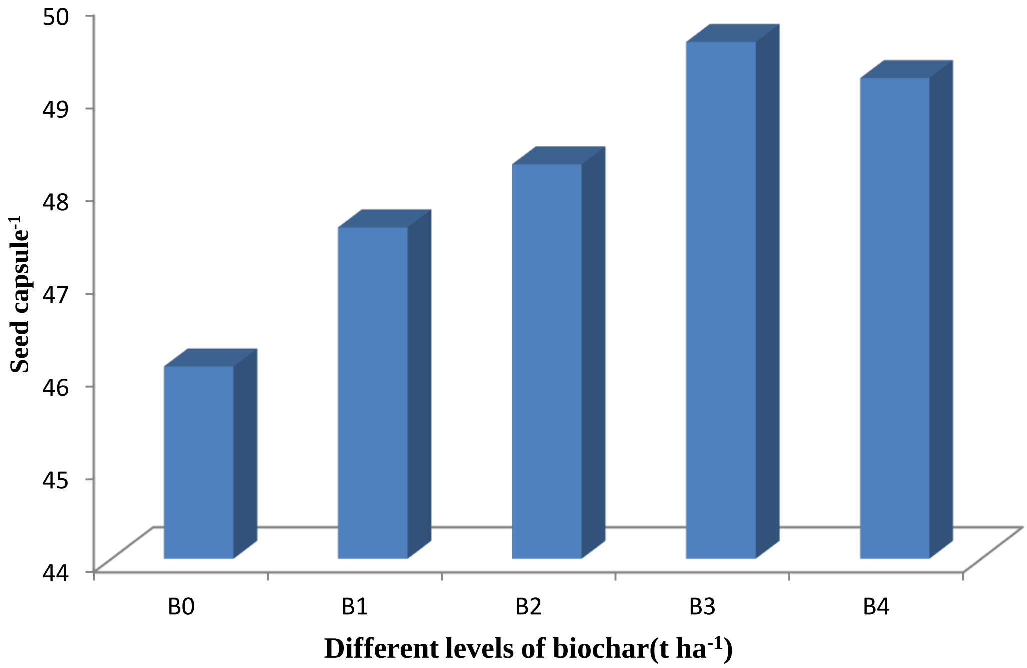

Figure 10. Effect of different levels of biochar on seed capsule^{-1} of sesame [(LSD $_{(0.05)}$ 0.1.159].

B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar showed significant effect on seeds capsule^{-1} at harvest (Table 4). The highest seeds capsule^{-1} (56.02) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$) which was statistically similar with the result obtained from $V_3 \times B_4$. The lowest seeds capsule^{-1} (47.07) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

4.2.3 Weight of 1000 seeds (g)

Varieties showed significant variation on thousand seed weight (Figure 11). Among the different fertilizer level V_2 (BARI Til-3) showed the highest thousand seed weight (3.10 g). The lowest thousand seed weight (2.94 g) was recorded in variety V_1 (BARI Til-2).

Results showed that weight of 1000 seeds influenced by different levels of biochar application were statistically significant (Figure 12). It is mentioned from the present study that the highest weight of 1000 seeds (3.10 g) was recorded in B_3 (application of biochar 6 t ha^{-1}) which was statistically similar with B_4 (application of biochar 8 t ha^{-1}) whereas the lowest weight of 1000 seeds was achieved by B_0 (no biochar application) (2.89 g). Wacal *et al.* (2016) found that 1000-seed weight was all significantly influenced by biochar application.

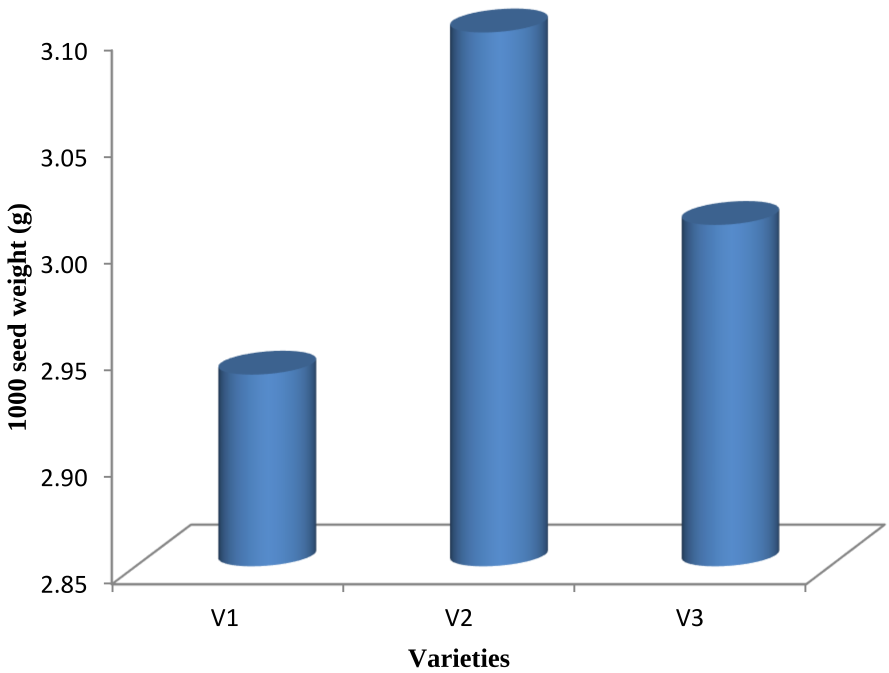

Figure 11. Effect of varieties on 1000 seed weight of sesame [(LSD $_{(0.05)}$ 0.041].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

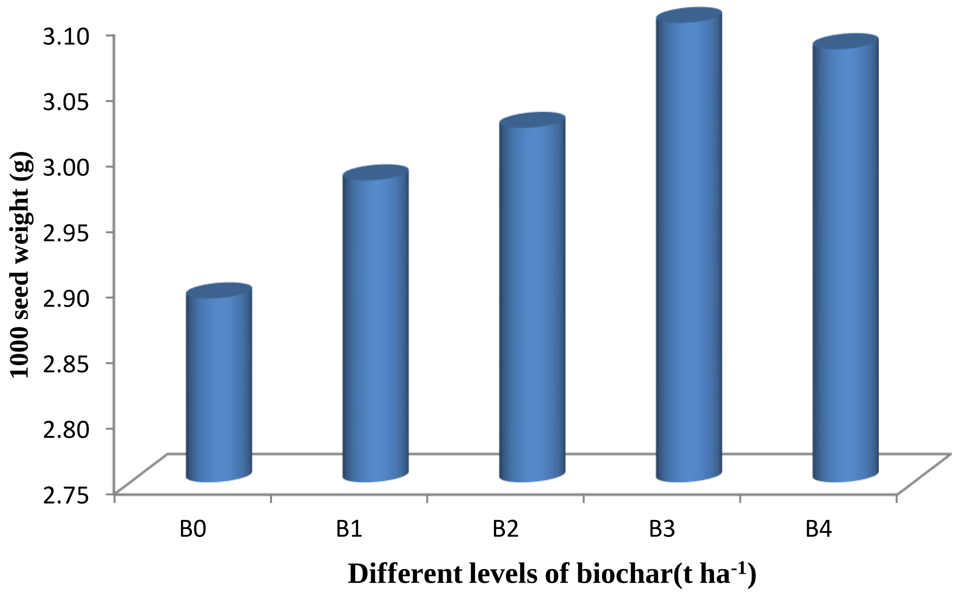

Figure 12. Effect of different levels of biochar on 1000 seed weight of sesame [(LSD $_{(0.05)}$ 0.052].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar showed significant effect on weight of 1000 seeds at harvest (Table 4). The highest weight of 1000 seeds (3.18 g) was observed in the BARI Til-3 cultivated with application of biochar 6 t ha^{-1} ($V_2 \times B_3$). The lowest seeds capsule^{-1} (2.81 g) was observed variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

4.3 Yield parameters

4.3.1 Seed yield (t ha^{-1})

The results of the single effects of varieties have been shown in (Figure 13). From the table it was apparent that V_3 (BARI Til-4) gave the highest yield (1.01 t ha^{-1}). On the contrary, the lowest seed yield (0.88 t ha^{-1}) was observed with variety V_1 (BARI Til-2). Many workers reported the maximum mean seed yield with Gowri variety than Madhavi on sandyloam soils (Rao *et al*., 1985; Rao *et al*., 1990 and Asharani *et al*., 1992). Sekhar (1988) stated that average seed yield was the maximum with Punjab Til-1 (593 kg ha^{-1}) than local variety (456 kg ha^{-1}) on sandy loam soils at Solan, Himachalpradesh. Sasikumar *et al*. (1989) at Tripura tested 6 cultivars and reported that T-3 variety recorded the highest yield (1550 kg ha^{-1}) while B-67 variety recorded the lowest yield (1140 kg ha-1). Desmukh *et al*. (1990) reported higher seed yield with Punjab-1 (1032 kg ha^{-1}) over T-85 (371 kg ha^{-1}) variety on clay soils of Parbhani.

Grain yield of sesame influenced by application of different level of biochar were statistically significant (Figure 14). The highest grain yield (1.03 t ha^{-1}) was recorded in B_3 (Application of biochar 6 t ha^{-1}) which was statistically similar with B_4 (Application of biochar 8 t ha^{-1}) while the lowest grain yield (0.85 t ha^{-1}) was achieved by B_0 (no biochar application). Yield components of cotton are number of bolls per plant, number of seeds per boll, boll weight, and lint yield. Lint yield was defined as a function of components including plant density, bolls per plant, and average boll size. The number of bolls per plant is the most important yield variable (Fageria *et al*., 1997). Wacal *et al.* (2016) found that seed yield of sesame was significantly influenced by biochar application. Ndor *et al*. (2015) found that application of 10 t/ha of sawdust and rice husk biochar produced the highest seed weight of sesame 0.93: 0.83 t/ha and 0.90:0.95 t/ha in both years, respectively.

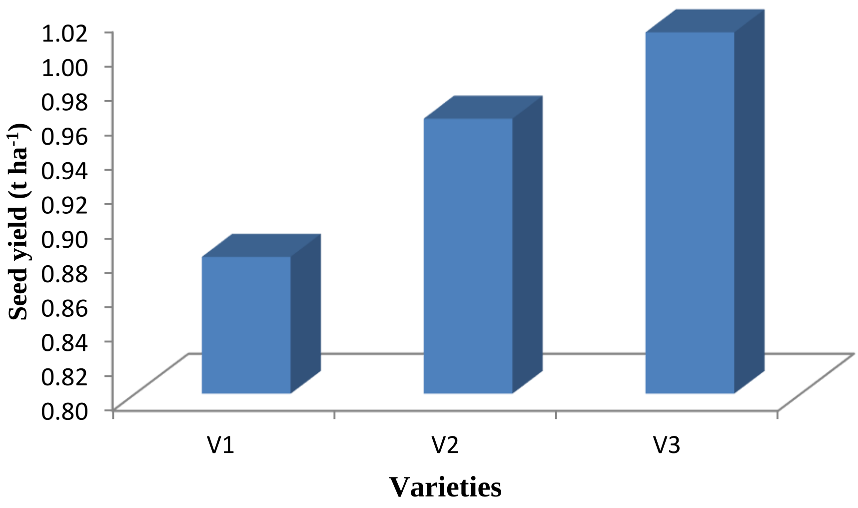

Figure 13. Effect of varieties on seed yield of sesame [(LSD $_{(0.05)}$ 0.014].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

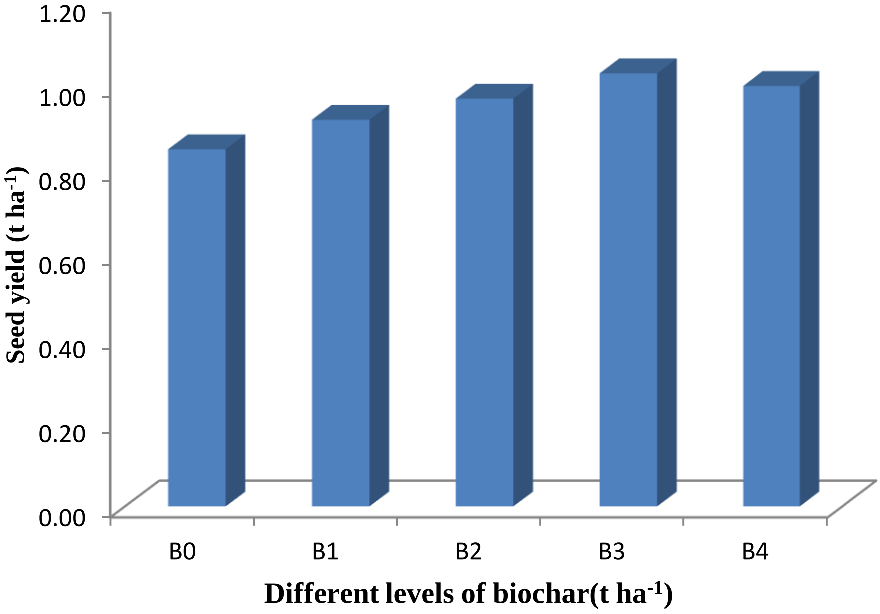

Figure 14. Effect of different levels of biochar on seed yield of sesame [(LSD $_{(0.05)}$ 0.019].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different level of biochar showed significant effect on seed yield at harvest (Table 5). The highest seed yield (1.07 t ha^{-1}) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$) which was statistically similar with the result obtained from $V_3 \times B_4$. The lowest seed yield (0.75 t ha^{-1}) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

Table 5. Interaction effect of varieties and different levels of biochar on yields of sesame

Interaction	Seed yield ($t\ ha^{-1}$)	Stover yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	HI (%)
$V_1 \times B_0$	0.75j	2.17d	2.92cd	25.78g
$V_1 \times B_1$	0.83i	2.32bc	3.15b	26.38g
$V_1 \times B_2$	0.92g	2.26c	3.18b	28.90ef
$V_1 \times B_3$	0.98de	2.36ab	3.34a	29.24e
$V_1 \times B_4$	0.94e-g	2.42a	3.37a	28.02f
$V_2 \times B_0$	0.87h	1.86gh	2.73f	31.91d
$V_2 \times B_1$	0.94e-g	1.87f-h	2.81ef	33.57c
$V_2 \times B_2$	0.97d-f	1.86f-h	2.83de	34.35bc
$V_2 \times B_3$	1.03bc	1.95e	2.98c	34.50bc
$V_2 \times B_4$	1.01cd	1.93ef	2.94c	34.24bc
$V_3 \times B_0$	0.94fg	1.86gh	2.80ef	33.62c
$V_3 \times B_1$	0.98de	1.83h	2.80ef	34.85b
$V_3 \times B_2$	1.02c	1.91e-g	2.93c	34.78b
$V_3 \times B_3$	1.07a	1.87f-h	2.94c	36.46a
$V_3 \times B_4$	1.06ab	1.89e-h	2.95c	36.05a
CV (%)	0.033	0.074	0.091	1.088
$LSD_{(0.05)}$	6.67	7.85	6.54	2.01
LS	**	*	*	*

Figures in a column followed by different letter(s) differs significantly whereas figures having common letter(s) do not differ significantly from each other as adjusted by LSD.

CV= Coefficient of variation, LS= Level of significance, $LSD_{(0.05)}$= Least significant difference, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4, B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

4.3.2 Stover yield (t ha^{-1})

Different varieties showed significant variations in respect of stover yield of sesame (Figure 15). Among the different varieties V_1 (BARI TIl-2) showed the highest stover yield (2.31 t ha^{-1}). On the contrary, the lowest stover yield (1.87 t ha^{-1}) was observed with V_2 (BARI Til-3) which was statistically similar with V_3 (BARI Til-4).

Stover yield of sesame varied significantly due to different levels of biochar applications (Figure 16). The highest stover yield (2.08 t ha^{-1}) was observed from B_4 (application of Biochar 8 t ha^{-1}) which was statistically similar with B_3 while the lowest stover yield (1.96 t ha^{-1}) from B_0 (no biochar application).

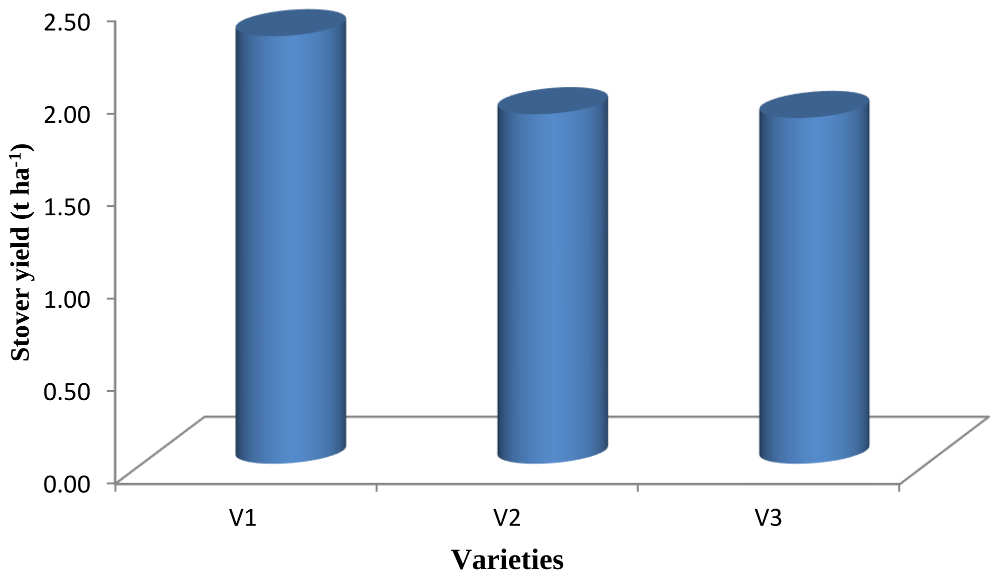

Figure 15. Effect of varieties on stover yield of sesame [(LSD $_{(0.05)}$ 0.033].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

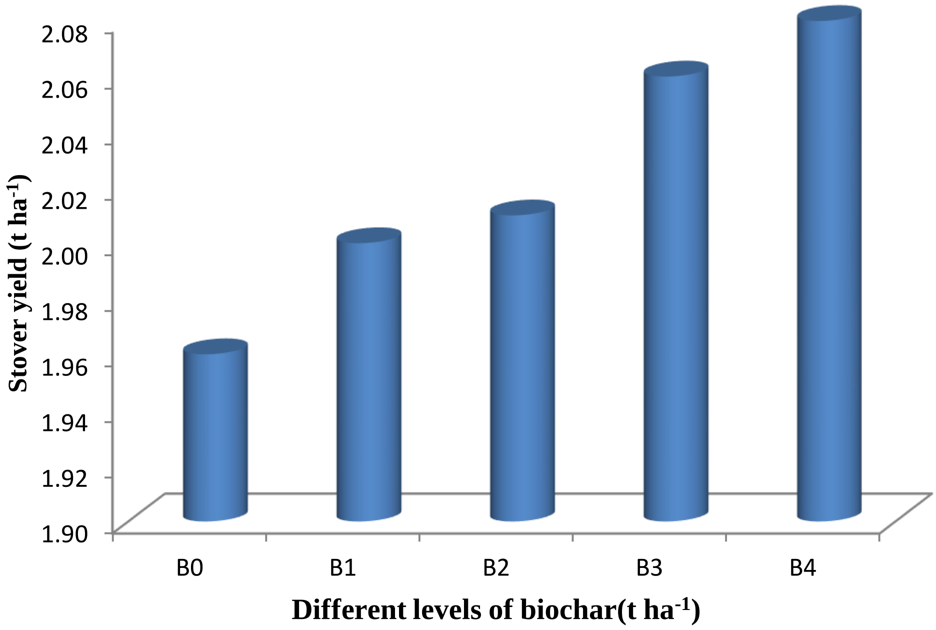

Figure 16. Effect of different levels of biochar on stover yield of sesame [(LSD $_{(0.05)}$ 0.043].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar showed significant effect on strove yield (t ha^{-1}) at harvest (Table 5). The highest strove yield (2.42 t ha^{-1}) was observed in the variety BARI Til-2 cultivated with application of biochar 8 t ha^{-1} ($V_1 \times B_4$). The lowest strove yield (1.83 t ha^{-1}) was observed Variety BARI Til-4 with 2 t ha^{-1} biochar application ($V_3 \times B_1$).

4.3.3 Biological yield (t ha^{-1})

Different varieties showed significant variations in respect of biological yield of sesame (Figure 17). Among the different varieties V_1 (BARI Til-2) showed the highest biological yield (3.19 t ha^{-1}), On the contrary, the lowest biological yield (2.86 t ha^{-1}) was observed with V_2 (BARI Til-3) which was statistically similar with V_3 (BARI Til-4).

Biological yield was significantly influenced by different levels of biochar application (Figure 18). The maximum biological yield (3.09 t ha^{-1}) was recorded in B_3 and B_4 (application of biochar 6 and 8 t ha^{-1}) and the minimum biological yield (2.82 t ha^{-1}) was achieved by B_0 (No biochar application). The results from B_2 on biological yield were intermediate compared to highest and lowest biological yield. The application of 68 t C ha^{-1} increased rice biomass by 17 per cent while the presence of 135t C ha^{-1} of biochar enhanced the growth by 43 per cent (Glaser *et al*., 2002; Lehmann *et al*., 2003).

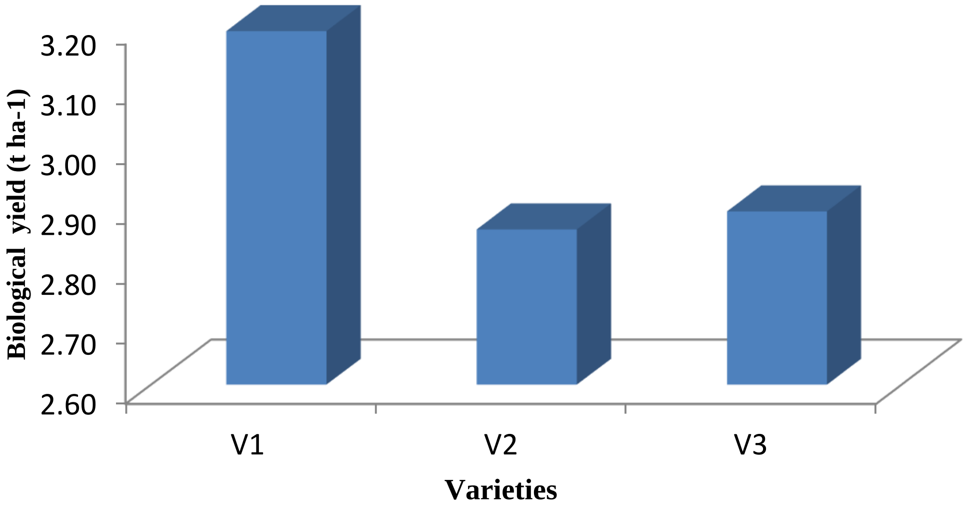

Figure 17. Effect of varieties on biological yield of sesame [(LSD $_{(0.05)}$ 0.041].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

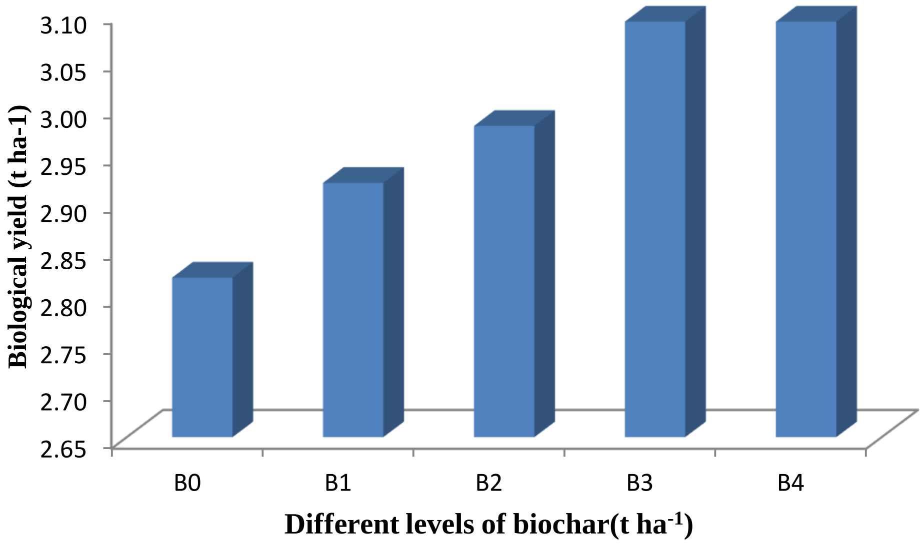

Figure 18. Effect of different levels of biochar on biological yield of sesame [(LSD $_{(0.05)}$ 0.052].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different level of biochar showed significant effect on biological yield at harvest (Table 5). The highest biological yield (3.37 t ha^{-1}) was observed in the variety BARI Til-2 cultivated with application of biochar 8 t ha^{-1} ($V_1 \times B_4$) which was statistically similar with $V_1 \times B_3$. The lowest biological yield (2.73 t ha^{-1}) was observed variety BARI Til-3 with no biochar application ($V_2 \times B_0$).

4.3.4 Harvest Index

Potassium fertilizers showed significant variations in respect of harvest index of sesame (Figure 19). V_3 (BARI Til-4) showed the highest harvest index (35.15 %). On the contrary, the lowest harvest index (27.66 %) was observed with V_1 (BARI Til-2)

Harvest index was significantly influenced by different levels of biochar application (Figure 20). It stated from the present study that the highest harvest index (33.40 %) was recorded in B_3 (application of biochar 6 t ha^{-1}) and the lowest harvest index (30.43%) was achieved by B_0 (no biochar application). The results from B_1, B_2 and B_4 on harvest index showed intermediate results compared to highest and lowest harvest index.

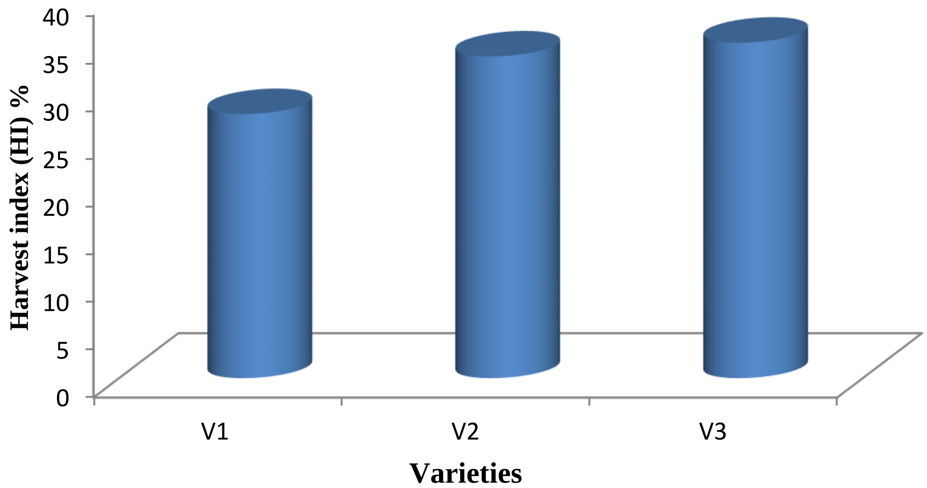

Figure 19. Effect of varieties on harvest index of sesame [(LSD $_{(0.05)}$ 0.486].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

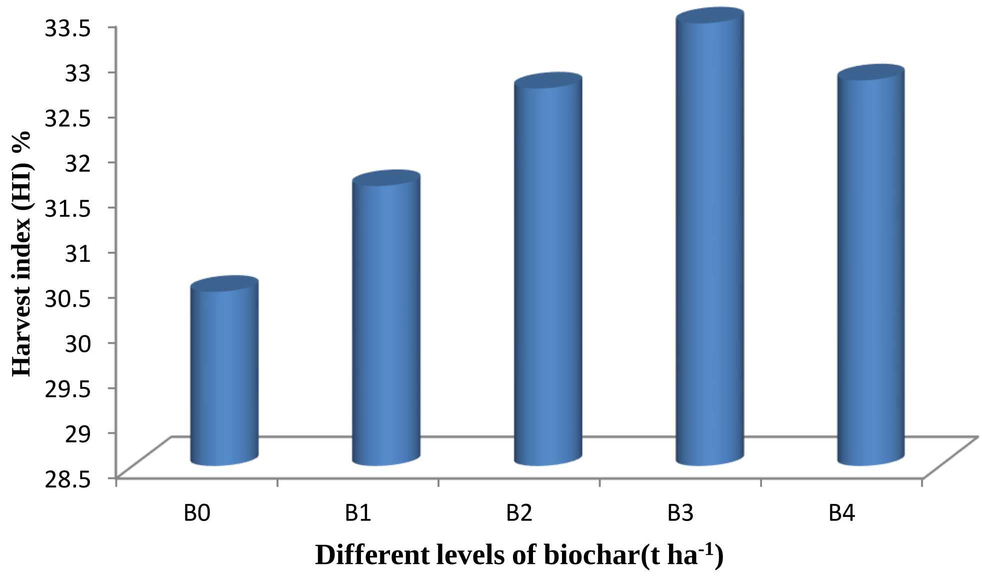

Figure 20. Effect of different levels of biochar on harvest index of sesame [(LSD $_{(0.05)}$ 0.682].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar showed significant effect on harvest Index at harvest (Table 5). The highest harvest Index (36.46%) was observed in the variety BARI Til-2 cultivated with application of biochar 8 t ha^{-1} ($V_3 \times B_3$) which was statistically similar with $V_3 \times B_4$. The lowest harvest index (25.78%) was observed variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

4.4 Soil parameters

4.4.1 Soil pH

Varieties showed non significant variation on the soil pH (Figure 21). Among the different varieties V_3 (BARI Til-4) showed the highest soil pH (5.98). The lowest soil pH (5.94) was observed in variety V_2 (BARI Til-3).

Soil pH was not significantly influenced by different level of biochar application (Figure 22). The highest soil pH (6.09) was recorded in B_0 (no biochar application) and the lowest soil pH (5.84) was achieved with B_1 (application biochar 2.0 t ha^{-1}). Nutrient availability can be affected by increasing cation exchange capacity, altering soil pH, or direct nutrient contributions from biochar (Lehmann *et al.*, 2003). Therefore the application of biochar is expected to enhance soil properties in terms of increasing or maintaining the pH of the soils (Rondon *et al.*, 2007), toxin neutralization (Wardle *et al.*, 1998), and reduce soil strength (Chan *et al.*, 2007).

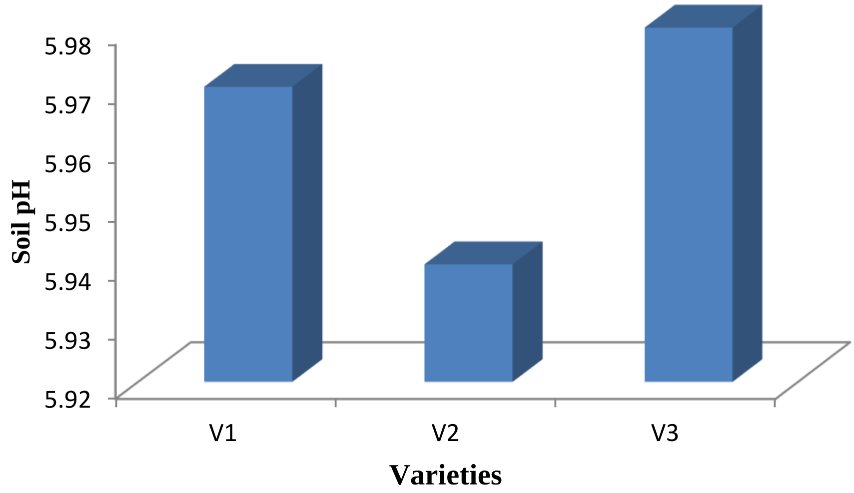

Figure 21. Effect of varieties on soil pH of soil [(LSD $_{(0.05)}$ 0.118].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

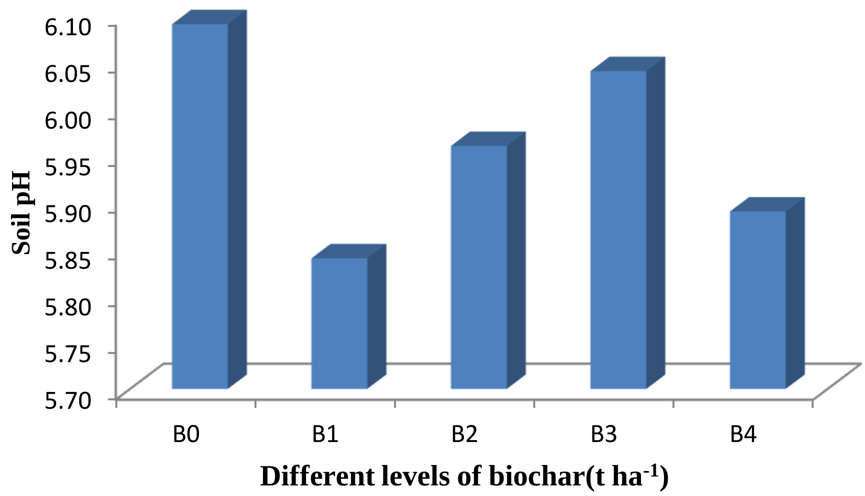

Figure 22. Effect of different levels of biochar on soil pH of soil [(LSD $_{(0.05)}$ 0.152].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar exerted non significant effect on soil pH (Table 6).

Table 6. Interaction effect of varieties and different levels of biochar on soil chemical properties

Varieties	pH	OC%	Total N (%)	Available P ($\mu g\ g^{-1}$)	Exchangeable K (meq $100g^{-1}$)
$V_1 \times B_0$	6.00	0.40f	0.039	15.04k	0.23fg
$V_1 \times B_1$	5.87	0.48e	0.048	18.22i	0.26e
$V_1 \times B_2$	6.07	0.58d	0.057	21.89g	0.30d
$V_1 \times B_3$	5.93	0.64c	0.064	26.50d	0.37b
$V_1 \times B_4$	6.00	0.71a	0.067	30.35a	0.40a
$V_2 \times B_0$	6.13	0.40f	0.039	14.60kl	0.23fg
$V_2 \times B_1$	5.83	0.48e	0.048	17.69i	0.26e
$V_2 \times B_2$	5.77	0.58d	0.057	21.25g	0.30d
$V_2 \times B_3$	6.13	0.64c	0.064	25.73e	0.37b
$V_2 \times B_4$	5.83	0.67b	0.067	29.46b	0.41a
$V_3 \times B_0$	6.13	0.40f	0.039	13.91l	0.22g
$V_3 \times B_1$	5.83	0.47e	0.048	16.85j	0.25ef
$V_3 \times B_2$	6.03	0.58d	0.057	20.24h	0.29d
$V_3 \times B_3$	6.07	0.64c	0.064	24.51f	0.34c
$V_3 \times B_4$	5.83	0.71a	0.067	28.06c	0.38b
CV (%)	2.03	1.82	1.68	2.74	2.13
$LSD_{(0.05)}$	0.364	0.023	0.290	0.768	0.016
LS	NS	**	NS	*	*

Figures in a column followed by different letter(s) differs significantly whereas figures having common letter(s) do not differ significantly from each other as adjusted by LSD.

CV= Coefficient of variation, LS= Level of significance, $LSD_{(0.05)}$= Least significant difference, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4, B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

4.4.2 Organic carbon (OC%)

Organic carbon showed non significant variation due to the effects of variety (Figure 23). The highest organic carbon (0.56%) was obtained from the variety V_1 (BARI Til-2) and V_3 (BARI Til-4). The lowest organic carbon (0.55%) was found when the variety V_2 (BARI Til-3).

Organic carbon was significantly influenced by different levels of biochar application of sesame (Figure 24). B_3 (application of biochar 8 t ha^{-1}) treatment produced maximum organic carbon (0.70). The lowest organic carbon (0.40) was achieved with B_0 (no biochar application).

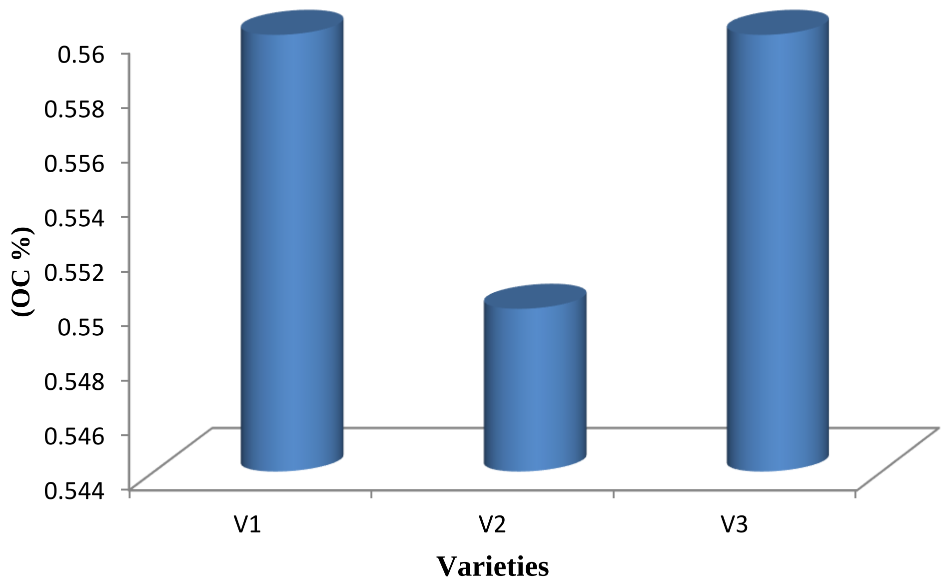

Figure 23. Effect of varieties on OC% of soil [(LSD $_{(0.05)}$ 0.010].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

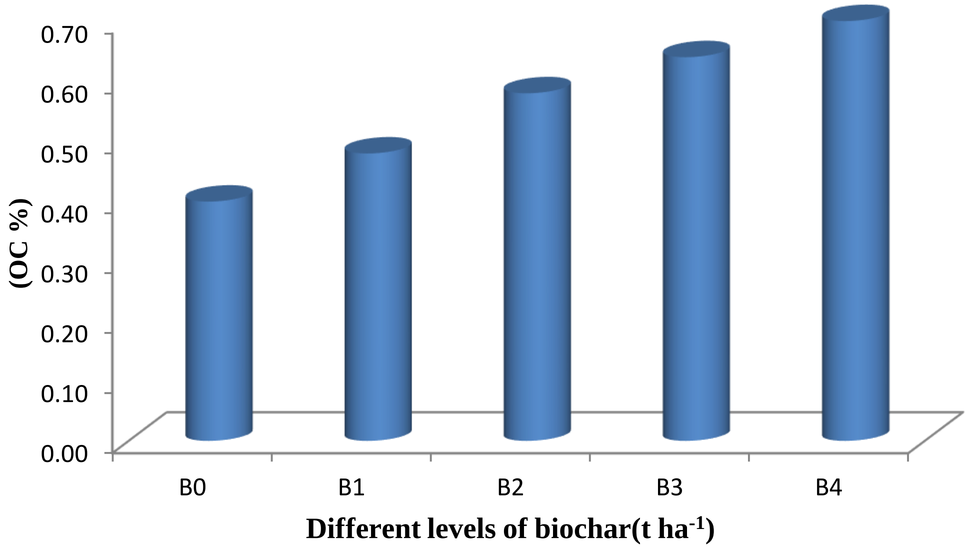

Figure 24. Effect of different levels of biochar on OC% of soil [(LSD $_{(0.05)}$ 0.073].

B_0= Control (No biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar exerted significant effect on organic carbon (Table 6). The highest organic carbon (0.71 %) was observed in the variety BARI Til-4 cultivated with application of biochar 8 t ha^{-1} ($V_3 \times B_4$). The lowest organic carbon (0.40 %) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

4.4.3 Nitrogen

Varieties showed non significant variation on total nitrogen in soil (Figure 25). Among the different varieties V_1 (BARI Til-2) and V_3 (BARI Til-4) showed the highest total nitrogen (0.055 %). The lowest total nitrogen (0.0554 %) was recorded variety V_2 (BARI Til-3).

Results presented in Figure 26 on total nitrogen influenced by different levels of biochar application were statistically significant. It was mentioned from the present study that the highest total nitrogen (0.073 %) was recorded in B_4 (Application of biochar 6 t ha^{-1}). The lowest total nitrogen (0.039 %) was achieved by B_0 (no biochar application). Xie *et al.* (2013) studied the effects of wheat straw biochar (12 Mg ha^{-1}) and corn stalk biochar (12 Mg ha^{-1}) on rice nitrogen nutrition and GHG emissions in a slightly alkaline sandy loamy Inceptisol and an acidic clayey loamy Ultisol. In biochar applied soils, the mechanisms controlling N_2O emission by biochar application are attributed to increased soil aeration (Yanai *et al.*, 2007; Van Zweiten *et al.*, 2010), sorption of NH_4+ or NO_3- (Singh *et al.*, 2010; Van Zweiten *et al.*, 2010) or presence of microbial inhibitor compounds such as ethylene (Spokas *et al.*, 2010).

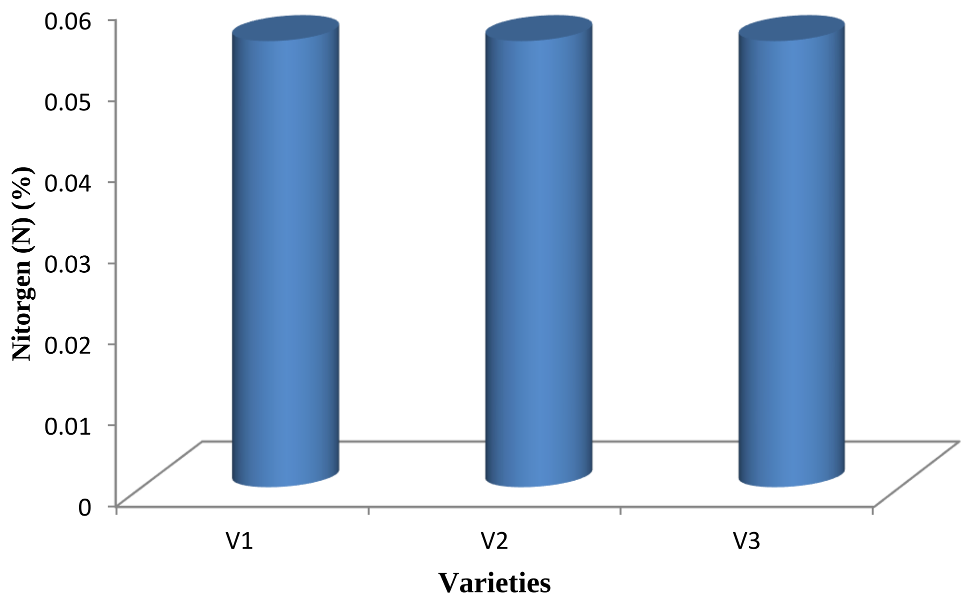

Figure 25. Effect of varieties on nitrogen of soil [(LSD $_{(0.05)}$ 0.010].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

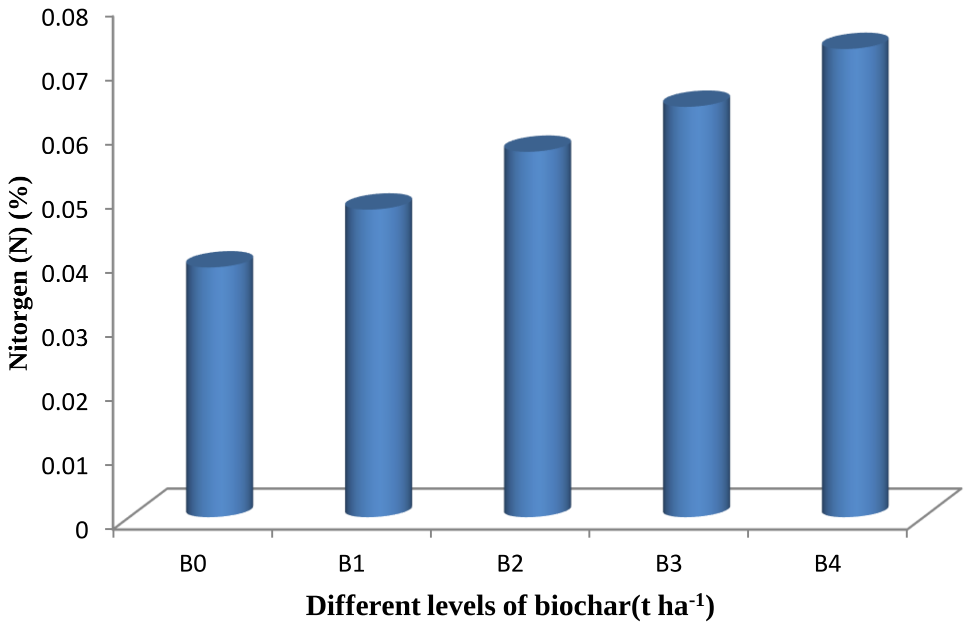

Figure 26. Effect of different levels of biochar on nitrogen of soil [(LSD $_{(0.05)}$ 0.013].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar showed non significant effect on total nitrogen (Table 6). The highest total nitrogen (0.067 %) was observed in the variety BARI Til-4 cultivated with application of biochar 8 t ha^{-1} ($V_3 \times B_4$). The lowest total nitrogen (0.039 %) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

4.4.4 Phosphorus

Varieties showed significant variation on available phosphorus on soil (Figure 27). Among the varieties V_1 (BARI Til-2) showed the available phosphorus (22.40 µg g^{-1}). The lowest available phosphorus (20.71 µg g^{-1}) was recorded in variety V_3 (BARI Til-4).

Results showed that available phosphorus influenced by different levels of biochar application were statistically significant (Figure 28). It is mentioned from the present study that the highest available phosphorus (29.29 µg g^{-1}) was recorded in B_4 (application of biochar 8 t ha^{-1}) whereas the lowest available phosphorus B_0 (14.52 µg g^{-1}) was achieved by B_0 (no biochar application).

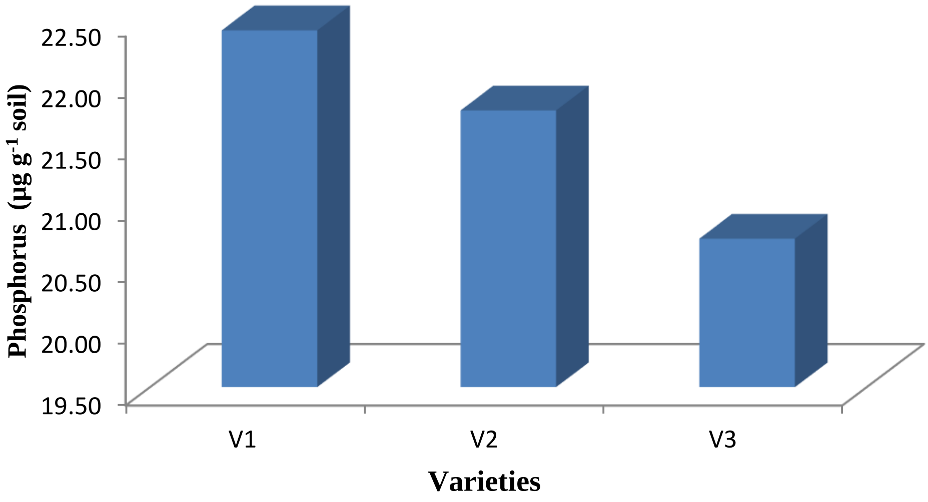

Figure 27. Effect of varieties on phosphorus of soil [(LSD $_{(0.05)}$ 0.011].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

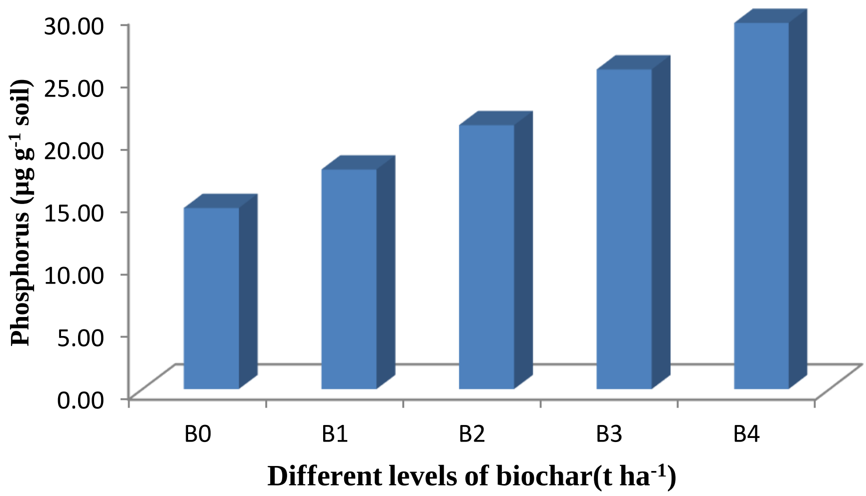

Figure 28. Effect of different levels of biochar on phosphorus of soil [(LSD $_{(0.05)}$ 0.44].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar showed significant effect on available phosphorus content in soil (Table 6). The highest available phosphorus (30.35 µg g^{-1}) was observed in the BARI Til-2 cultivated with application of biochar 8 t ha^{-1} ($V_1 \times B_4$). The lowest available phosphorus (13.91 µg g^{-1}) was observed variety BARI Til-2 with no biochar application ($V_3 \times B_0$).

4.4.5 Potassium

The results of the single effects of varieties showed non significant effect on exchangeable potassium (Figure 29). From the table it was apparent that V_1 (BARI Til-2) and V_2 (BARI Til-3) gave the exchangeable potassium (0.31 meq $100g^{-1}$) content in soil. On the contrary, the lowest exchangeable potassium (0.29 meq $100g^{-1}$) was observed with variety V_3 (BARI Til-4)

Exchangeable potassium of soil influenced by different levels of biochar application were statistically significant (Figure 30). The highest exchangeable potassium (0.40 meq $100g^{-1}$) was recorded in B_4 (Application of biochar 8 t ha^{-1}) while the lowest exchangeable potassium (0.23 meq $100g^{-1}$) was recorded by B_0 (no biochar application). About 90% of total K in rice straw was in water-soluble form before pyrolysis and this K was lost when heating up to 673°C. With the temperatures above 600°C, a greater proportion of the remaining K was found in exchangeable and acid extractable form (Yu *et al.*, 2005; Chan and Xu, 2009).

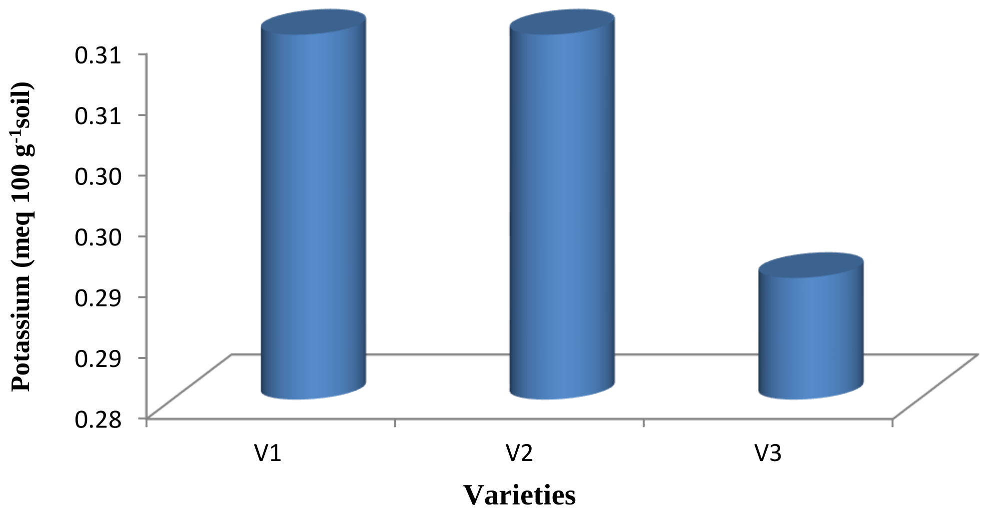

Figure 29. Effect of varieties on potassium of soil [(LSD $_{(0.05)}$ 0.007].

V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4

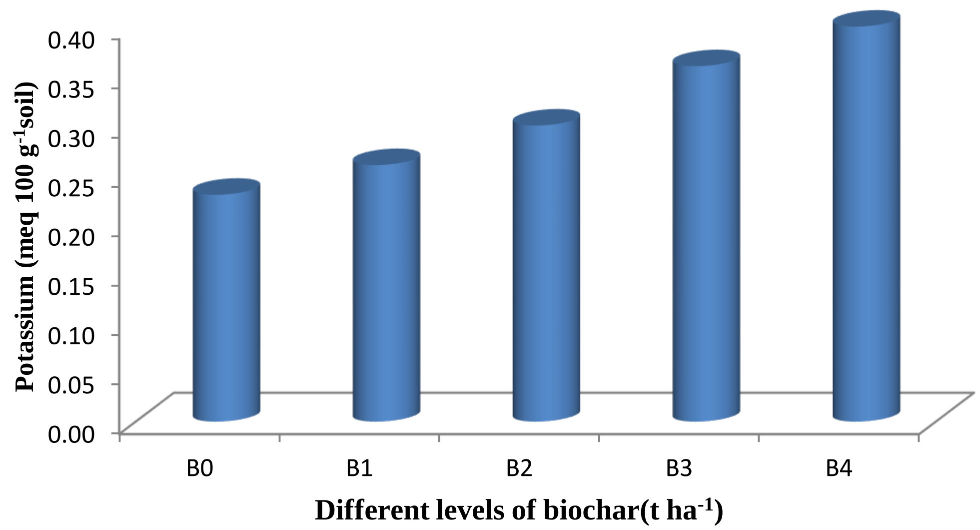

Figure 30. Effect of different levels of biochar on potassium of soil [(LSD $_{(0.05)}$ 0.009].

B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_2= application of biochar 4 t ha^{-1}, B_3= application of biochar 6 t ha^{-1}, B_4= application of biochar 8 t ha^{-1}.

Interaction effect between varieties and different levels of biochar showed significant effect on exchangeable potassium content in soil (Table 6). The highest exchangeable potassium (0.41 meq 100g^{-1}) was observed in the BARI Til-3 cultivated with application of biochar 8 t ha^{-1} ($V_2 \times B_4$). The lowest exchangeable potassium (0.22 meq 100g^{-1}) was observed variety BARI Til-4 with no biochar application ($V_3 \times B_0$).

Chapter 5

SUMMARY AND CONCLUSION

The experiment was conducted at the research plot of the Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka during the period from March, 2017 to June, 2017 to study response of biochar on soil properties and on the growth and yield of sesame. In experiment, the treatment consisted of three varieties, *viz.*, V_1 = BARI Til-2, V_2 = BARI Til-3, V_3 = BARI Til-4 and different level of biochar *viz.*, B_0= Control (no biochar application), B_1= application of biochar 2 t ha^{-1}, B_1= application of biochar 4 t ha^{-1}, B_1= application of biochar 6 t ha^{-1}, B_1= application of biochar 8 t ha^{-1}. The experiment was laid out in a two factors randomized complete block design (RCBD) with three replications. Necessary intercultural operations were done as and when necessary.

Variety, application of different levels of biochar and their interaction showed statistically significant variation plant height, number of leaf $plant^{-1}$at 55 DAS, 80 DAS and harvest, capsule $plant^{-1}$, seeds capsule $^{-1}$, 1000 seeds weight, grain yield, stover yield, biological yield and harvest index. Effect of variety on P and K content soil is significant but pH, OC(%), N content in soil is insignificant. Effect of application of different level of biochar on pH, OC%, N, P and K content soil is significant. Interaction effect of variety on N, P and K content soil is significant but soil pH, OC(%) is insignificant.

Varieties V_3 (BARI Til-4) showed the highest plant height (68.29, 107.72 and 106.64 cm at 55, 80 DAS and at harvest, respectively) and the lowest plant height (60.51, 95.44 and 95.43 cm at 55, 80 DAS and at harvest, respectively) was observed in the V_1 (BARI Til-2). V_3 (BARI Til-4) showed the highest number of leaves $plant^{-1}$ (78.13, 113.30 and 91.79 cm at 55, 80 DAS and at harvest, respectively) and the lowest number of leaves $plant^{-1}$ (69.22, 100.39 and 77.31 cm at 55, 80 DAS and at harvest, respectively) by the variety V_1 (BARI Til-2). The highest number of branches $plant^{-1}$ (3.48) found in V_3 (BARI Til-4) and the lowest (3.11) was observed in variety V_1 (BARI Til-2). At 55, 80 DAS and at harvest, the highest plant height (66.13, 104.30, and 103.58 cm, respectively), number of leaves plant^{-1} (75.65, 109.71 and 86.41, respectively) was recorded in B_3 (application of biochar 6 t ha^{-1}) the lowest was found in B_0 (no biochar application). The highest number of branches plant^{-1} (3.49) was recorded in B_3 (application of biochar 6 t ha^{-1}) and the lowest (3.02) was achieved with B_0 (no biochar application). The highest plant height (70.34, 110.95 and 109.84), number of leaves (80.47, 116.70 and 94.54 cm) at 55, 80 DAS and at harvest was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$). The lowest plant height and number of leaves was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$). The highest number of leaves (3.60) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$).

The highest number of capsules per plant (78.13), number of seed capsule^{-1} (54.39) and 1000 seed weight (3.10 g) were obtained from the variety V_3 (BARI Til-4). The lowest number of capsules per plant (73.70), number of seed capsule^{-1} (49.17) and 1000 seeds (2.89 g) was found when the variety V_1 (BARI Til-2). B_3 (application of biochar 6 t ha^{-1}) treatment produced maximum number of capsules plant^{-1} (75.41), number of seeds capsule^{-1} (49.57) and weight of 1000 seeds (3.10 g) and the lowest number of capsules plant^{-1} (70.08), number of seeds capsule^{-1} (46.07) and 1000 seeds (2.89 g) was achieved with B_0 (no biochar application). The highest capsule per plant, number of seeds capsule^{-1} and weight of 1000 seeds was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$) and lowest was found variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

Variety V_3 (BARI Til-4) gave the highest yield (1.01 t ha^{-1}) and harvest index (35.15 %) whereas the lowest seed yield (0.88 t ha^{-1}) and harvest index (27.66 %) and was observed with variety V_1 (BARI Til-2). The highest grain yield (1.03 t ha^{-1}) and harvest index (33.40 %) was recorded in B_3 (Application of Biochar 6 t ha^{-1}) which was statistically similar with B_4 (Application of biochar 8 t ha^{-1}) while the lowest grain yield (0.85 t ha^{-1}) and harvest index (30.43%) was achieved by B_0 (no biochar application). The highest seed yield (1.07 t ha^{-1}) and harvest Index (36.46%) was observed in the variety BARI Til-4 cultivated with application of biochar 6 t ha^{-1} ($V_3 \times B_3$). The lowest seed yield (0.75 t ha^{-1}) and harvest index (25.78%) was observed Variety BARI Til-2 with no biochar application ($V_1 \times B_0$).

Varieties showed non significant variation on the soil pH (Figure 21). Among the different varieties V_3 (BARI Til-4) showed the highest soil pH (5.98) and the lowest (5.94) was observed in variety V_2 (BARI Til-3). The highest soil pH (6.09), organic carbon (0.70%), total nitrogen (0.073 %), available phosphorus (29.29 µg g^{-1}) and exchangeable potassium (0.40 meq $100g^{-1}$) was recorded in B_0 (no biochar application) and the lowest soil pH (5.84), total nitrogen (0.039 %), available phosphorus (14.52 µg g^{-1}) and exchangeable potassium (0.23) was achieved with B_0 (no biochar application). The highest available phosphorus (30.35 µg g^{-1}) and exchangeable potassium (0.41 meq $100g^{-1}$) was observed in the BARI Til-2 cultivated with application of biochar 8 t ha^{-1} ($V_1 \times B_4$). The lowest available phosphorus (13.91 µg g^{-1}) and exchangeable potassium (0.22 meq $100g^{-1}$) was observed variety BARI Til-4 with no biochar application ($V_3 \times B_0$).

The results in this study indicated that the plants performed better in respect of seed yield and soil properties, BARI Til-4 cultivated with application of biochar 6 t ha^{-1} compared to other treatment combinations showed the best performance.

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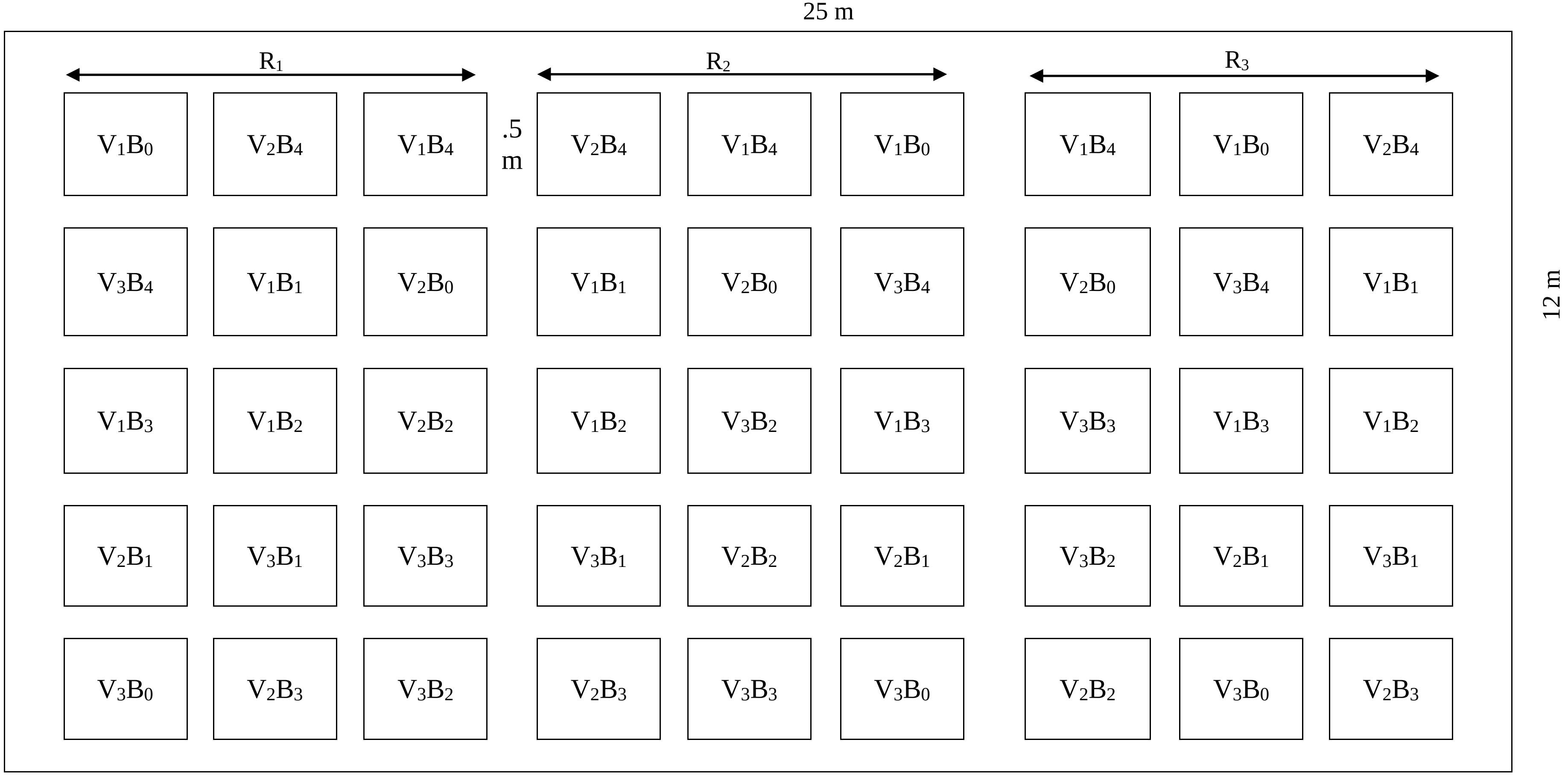
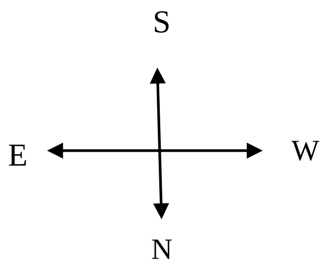
Appendix I. A Field lay out of the two factor experiment in RCBD Design



Legend:

1. Width of the plot = 1.8 m
2. length of the plot = 2.0 m
3. Space around the land = 0.75m
4. Space between the block =0.50 m
5. Space between the plot =0.30 m



Appendix II: Soil characteristics of experimental farm of Sher-e-Bangla Agricultural University are analyzed by soil Resources Development Institute (SRDI), Farmgate, Dhaka.

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Farm, SAU, Dhaka
AEZ	Modhupur tract (28)
General soil type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	**N/A**

B. Physical and chemical properties of the initial soil

B. Physical and chemical properties of the initial soil Characteristics	Value
Practical size analysis	
Sand (%)	16
Silt (%)	56
Clay (%)	28
Silt + Clay (%)	84
Textural class	Silty clay loam
pH	5.56
Organic matter (%)	1.00
Total N (%)	0.06
Available P (µ gm/g soil)	42.64
Available K (me/100 g soil)	0.13

Source: SRDI

Appendix III. Monthly average temperature, relative humidity and total rainfall of the experimental site during the period from October 2016 to March 2017

Month	Air temperature (^0C)		R. H. (%)	Total rainfall (mm)
	Maximum	Minimum		
February,17	27.1	16.7	67	3
March,17	31.4	19.6	54	11
April, 17	36.4	22.5	63	17
May, 17	34.4	21.46	68	39

Source: Bangladesh Metrological Department (Climate and weather division) Agargaon, Dhaka

Appendix IV. Analysis of variance (ANOVA)of plant height of sesame at different days after sowing (DAS)

Sources of variation	d. f	Mean Square values of plant height at		
		55 DAS	80 DAS	at harvest
Replication	2	0.808	2.012	1.993
Factor A	2	227.257**	565.073**	471.954**
Factor B	4	27.692**	68.855**	67.909**
AB	8	12.348**	11.855*	33.813**
Error	28	1.336	2.814	2.748
Total	44			

NS= Not Significant, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

Appendix V. Analysis of variance (ANOVA)of number of branch plant^{-1}of sesame at different days after sowing (DAS)

Sources of variation	d. f	Number of leaves		
		55 DAS	80 DAS	at harvest
Replication	2	1.056	2.131	1.385
Factor A	2	297.265**	624.565**	792.757**
Factor B	3	36.211**	76.430**	47.396**
AB	6	11.452*	0.954*	23.708*
Error	18	1.059	2.400	1.966
Total	35			

NS= Not Significant, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

Appendix VI. Mean Square Value of yield attributes of sesame

Sources of variation	d. f	Number of leaves	Capsules plant^{-1}	Seeds capsule^{-1}	Weight of 1000 seeds
Replication	2	0.015	1.297	0.563	0.002
Factor A	2	0.524**	401.950**	701.131**	0.095**
Factor B	4	0.308**	40.433**	17.473**	0.066**
AB	8	0.028*	23.067**	9.117**	0.012**
Error	28	0.004	1.441	0.564	0.004
Total	44				

NS= Not Significant, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

Appendix VII. Mean Square Value of yield of sesame

Sources of variation	d. f	Seed yield	Strover yield	Biological yield	HI
Replication	2	0.000	0.000	0.000	0.293
Factor A	2	0.064**	0.905**	0.515**	236.987**
Factor B	4	0.044**	0.021**	0.121**	12.309**
AB	8	0.002**	0.008**	0.012**	0.988*
Error	28	0.001	0.002	0.003	0.423
Total	44				

NS= Not Significant, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

Appendix VIII. Mean Square Value of soil properties

Sources of variation	d. f	pH	OC%	Total N (%)	Available P (µg g^{-1}soil)	Exchangeable K (meq 100g^{-1}soil)
Replication	2	0.025	0.001	0.000	0.198	0.000
Factor A	2	0.007^{NS}	0.000^{NS}	0.000^{NS}	10.871**	0.002**
Factor B	4	0.095*	0.133**	0.001**	318.332**	0.045**
AB	8	0.008^{NS}	0.001**	0.001^{NS}	25.165**	0.001**
Error	28	0.025	0.000	0.000	0.211	0.000
Total	44					

NS= Not Significant, *= Significant at 5% level of Probability, **= Significant at 1% level of Probability.

Plate 1. Biochar

Plate 2. Application of biochar

Plate 3. Seedling stage of Sesame

Plate 4. Flowering stage of sesame

Plate 5. Experimental signboard

Plate 6. Capsules of sesame

Plate 7. Determination of 1000 seed weight of sesame