EFFECT OF SOLE AND COMBINED APPLICATION OF BIOCHAR AND GYPSUM ON WHEAT PRODUCTIVITY UNDER SALINE SODIC AND SODIC SOIL CONDITION

Teshome Bekele¹, Bethel Nekir¹, Lemma Mamo¹, Ashenafi Worku¹,

¹EthiopiaInstitute of Agricultural Research/Werer Agricultural Research Center
Corresponding author email: teshbekbej@gmail.com

Abstract: Reports indicated that nearly 11 million hectare of soils in Ethiopia is salt affected and Abundance of soil with saline sodic property in Amibara irrigated farms is becoming a threat to crop productivity. As part of the solution to such problem soils, a field Experiment was conducted at Werer Agricultural Research during 2016,2017 and 2018 cropping season .The overall objective of this study was to ameliorate saline sodic soils through application of biochar and gypsum and subsequently to increase the grain yield of wheat. The 3² factorial experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Factor one was biochar with three levels; 0 (control), 4 and 8 t ha⁻¹ and factor two was Gypsum with three levels; 0 (control), 50 % gypsum requirement and 100 % gypsum requirement. Composite surface soil samples before experiment and from each treatment after harvest were collected for laboratory analysis. The experiment revealed that application of biochar and gypsum clearly influenced soil chemical properties, number of seed per panicle, thousand seed weight and grain yield. Generally, gypsum application was superior on most crop parameters compared to biochar. The highest grain yield was also recorded at 100 % gypsum applied treatment. Due to applied amendment fertility of saline sodic soils improved and soil pH, Na⁺ and ESP showed reduction compared to control. The lowest pH (7.60) was from 4 ton/ha Biochar + 100 % gypsum, and relative to control 4 ton/ha biochar showed 26.30 % in ESP reduction at surface, while at 30-60 cm 100 % gypsum improve sodicity problem by 31.42 %. As a result, it would be more cost-effective to use 100 % gypsum for the case of study area. Moreover, in future the benefit of biochar in such soil should have to be studied carefully.

Keywords: Exchangeable Sodium percentage, Soil Organic matter, Saline Sodic soil, Soil properties.

1. INTRODUCTION

Soil degradation resulting from salinity and/or sodicity is a major environmental impediment with severe adverse impacts on agricultural productivity and sustainability in arid and semi-arid climates (Qadir et al., 2007). Arnous and Green (2015) ascertained that changes to land-cover caused by human activities particularly irrigated agriculture and land reclamation as well as urban expansion lead to a serious deterioration in the environment through waterlogging and salinization presenting future difficulties for any sustainable development. Moreover, saline and sodic soils in arid and semi-arid areas cause unfavorable soil physical and chemical properties, which would impose restrictions on plant growth (Jalaliet et al., 2017), including wheat (Ghulam et al., 2013; Bethel et al., 2019a). As a result, the study of arid lands and salt affected...
soils has been important, particularly an important issue for Ethiopia where arid and semi-arid climatic zones occupy over 60% of the total land area (Kidane et al., 2006), and about 11,033,000 ha are have been affected by saline soil (FAO, 1988). Moreover, decline in vegetation growth due to salt toxicity and detrimental osmotic potential results in lower carbon (C) inputs into these soils and further deterioration of their physical and chemical properties (Wong et al. 2009).

Biochar is defined by Lehmann and Joseph (2009) as a carbon (C) rich product derived from the pyrolysis of organic material at relatively low temperatures (<700 °C). There is intense interest in using this biochar as a means to sequester C in soils as a tool for offsetting anthropogenic carbon dioxide (CO₂) emissions, and as a soil amendment due to its potential agronomic benefits (Lehmann and Joseph, 2009). Besides potentially sequestering C biochar has been observed to have agronomic benefits (Spokas et al., 2012) to alter the nitrogen (N) dynamics in soils (Clough and Condron, 2010) and also improve salt affected soils (Akhtar et al., 2015a).

Therefore, development of the most suitable reclamation technology or a combination of technologies may be critical to improve the physical and chemical properties of salt affected soils. Remediation of salt-affected soils using chemical agents, including gypsum and organic matter (biochar, farmyard manure, green manure, organic amendment and municipal solid waste), is a successful approach that has been implemented worldwide, being effective, low cost, and simple (Mitchell et al., 2000; Hanayet et al., 2004; Sharma and Minhas, 2005; Tejada et al., 2006; Major et al., 2010; Akhtar et al., 2015a; Teshome, 2019). Even though, there is large area of Amibara is affected by salinity problem (Heluf, 1985; Tena, 2002; Gedion, 2009; Wondimagegne and Abere, 2012; Frewet al., 2015; Ashenafi and Bobe, 2016; Melese et al., 2016), there is no enough a possible mitigation study conducted particularly on effect of biochar and gypsum. The overall objective of this study was to ameliorate saline sodic soils through application of biochar and gypsum and subsequently to increase the grain yield of wheat.

2. MATERIALS AND METHODS

Description of the Study Area

The study was conducted at Amibara District, Gebiresu zone of Afar National Regional State, located at 9°20’31” N latitude and 40°10’11” E longitude and the elevation is at about 740 meters above sea level.

Climate: The climate is semi-arid with a bimodal rainfall of 533 millimeters annually. The mean annual minimum temperature is 19.4 °C in, while the maximum temperature is 34.6°C. The average daily sunshine hours is 8.5 with an average solar radiation of 536 calories per square centimeter per day (cal/cm²/day). Annual precipitation and evapotranspiration rate of Amibara is 550 mm and 2829 mm, respectively.

Soil Type: Generally, the widespread occurrence of salinity and sodicity problem in irrigated area of Amibara District farms is mainly due to weathering of Na, Ca, Mg and K rich igneous rocks and poor irrigation water management (Heluf, 1985; Ashenafi and Bobe, 2016). Organic matter and micronutrient (Fe, Zn and Mn) were found to be deficient in salt affected soil (Ashenafiet al., 2016b).

Vegetation Cover: The major crops grown is cotton and sugar cane with minor crops including maize, sesame, rice, wheat, date palm, banana and vegetables in some areas of Werer Agricultural Research Center (WARC). The main problem of the area is the introduction and invasion of a thorny shrub by the name of Prosopis juliflora, wheremostsalinity and sodicity/alkalinity impacted abandoned areas are covered by Prosopis juliflora(Zeraye, 2015).

Experimental Design and Treatments

The 3² factorial experiments was laid out in Randomized Complete Block Design (RCBD) with three replications. Factor one was biochar with three levels; 0 (control), 4 and 8 t ha⁻¹ and factor two was Gypsum with three levels; 0 (control), 50 % gypsum requirement and 100 % gypsum requirement. Biochar was prepared from prosopisjuliflora using the pyrolysis system. Gypsum treatment was also calculated from gypsum requirement, the treatments combinations were: T1-control, T2- 4t/ha biochar, T3- 8t/ha biochar, T4- 100 % gypsum, T5- 50% gypsum, T6- 4t/ha biochar + 50% gypsum, T7- 8t/ha biochar + 50% gypsum, T8- 4t/ha biochar + 100% gypsum and T9- 8t/ha biochar + 100% gypsum.
Data Collection and Analysis

**Soil Data:** composite and plot wise soil sample was collected before experiment and after harvesting, respectively. Analyses of soil salinity and sodicity parameters was carried out at Werer Agricultural Research Laboratory following appropriate procedure.

**Agronomic Parameters:** Yield attributes and grain yield data were collected following appropriate methodology.

**Statistical Analysis:** Analysis of variance (ANOVA) on grain yield and agronomical parameters of wheat were carried out using SAS version 9.4 statistical software program (SAS, 2016). Significant difference between and among treatment means were assessed using the least significant difference (LSD) at 0.05 level of probability (Gomez and Gomez, 1984).

### 3. RESULT AND DISCUSSION

**Initial Soil physicochemical Properties**

The soil of the experimental site was dominated by the siltclay, soil bulk density and particle density of the study site were 1.48 g cm\(^{-3}\) and 2.53 g cm\(^{-3}\), respectively. The soil reaction (pHe) of the experimental site was 8.63, which was alkaline. Based on initial soil sample analysis the soils of study area had 20.81% ESP and soluble salt concentration in the soil was 6.20 ds/m as measured in electrical conductivity (ECe) which indicates that the soils of the study site was saline-sodic.

**Plant Height, Shoot and Root Length**

Combined statistical analysis indicates that the main and interaction effect of biochar and gypsum were not on wheat plant height, shoot and root length. However, there was numerical variation among tested treatments and the highest plant height (71.06 cm) was recorded at 100% gypsum application, while the smallest plant height (68.36 cm) was recorded at plot without gypsum. The result in lined with Senevirathne et al., (2019) who reported after application of biochar with combination of compost didn’t show difference among treatment. Figure 1 exhibit that there was numerical variation among treatment for wheat shoot and root length.

**Effective Tiller Number**

The main and interaction effect of biochar with gypsum was not significant (P≤0.05) to affect effective tiller number. However there was noticeable variation between treatment, the highest (2.84) effective tiller number was recorded equally from 0 ton/ha biochar and 100 gypsum application. However, the lowest effective tiller number was also equally obtained at 8 ton/ha biochar and 0 gypsum application. In contrast to this Akhtar et al. (2015a) reported the positive effects of biochar on growth, physiology, and yield of pot grown wheat under salinity stress and also on reducing Na\(^+\) uptake.

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**Figure 1:** Effect of biochar and gypsum on shoot height and root length

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Shoot Length (cm)</th>
<th>Root Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1</td>
<td>56</td>
<td>10</td>
</tr>
<tr>
<td>T-2</td>
<td>56</td>
<td>11</td>
</tr>
<tr>
<td>T-3</td>
<td>61</td>
<td>12</td>
</tr>
<tr>
<td>T-4</td>
<td>61</td>
<td>13</td>
</tr>
<tr>
<td>T-5</td>
<td>66</td>
<td>14</td>
</tr>
<tr>
<td>T-6</td>
<td>66</td>
<td>15</td>
</tr>
<tr>
<td>T-7</td>
<td>71</td>
<td>15</td>
</tr>
<tr>
<td>T-8</td>
<td>71</td>
<td>15</td>
</tr>
<tr>
<td>T-9</td>
<td>71</td>
<td>15</td>
</tr>
</tbody>
</table>

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**Figure 1:** Effect of biochar and gypsum on shoot height and root length
Analysis of variance showed that thousand seed weight (TSW) of wheat was not significantly influenced by the main effect of biochar nor the interaction effect of biochar with gypsum affected number of seed per spike (Table 1). The highest number of seed per spike (39.10) was recorded from sole application of 100% gypsum. However, the smallest number of seed (34.33) was obtained from 0 gypsum (control). The highest number of grain per spike with amendments plot might be that reduction in osmotic stress through improving soil properties (Akhtar et al., 2014; Rizwan et al., 2018). Different authors reported Combinations of organic amendments and gypsum significantly improved soil properties, which in turn supported prolific root growth of plants (Gill et al., 2009; Alcivare et al., 2018).

Analysis of variance showed that thousand seed weight (TSW) of wheat was not significantly influenced by the main effect of gypsum as well as their interaction of biochar with gypsum. However, the main effect of biochar was significantly affected thousand seed weight. The highest thousand seed weight (42.61 g) was obtained at 8 ton/ha biochar, while the lowest from 0 gypsum (40.35 g).

### Table 1: Analysis of variance for effect of biochar and gypsum on wheat yield and growth parameters

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Plant Height (cm)</th>
<th>Effective Tiller (#)</th>
<th>Spike Length (cm)</th>
<th>Number of seed/spike (#)</th>
<th>Grain Yield (Kg/ha)</th>
<th>TSW (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Squares</td>
<td>df</td>
<td>6.38 NS</td>
<td>0.27 NS</td>
<td>0.15 NS</td>
<td>34.45 NS</td>
<td>1748944.72</td>
<td>33.94*</td>
</tr>
<tr>
<td>Biochar</td>
<td></td>
<td>49.59 NS</td>
<td>0.24 NS</td>
<td>0.09 NS</td>
<td>170.04***</td>
<td>1530531.52**</td>
<td>26.62NS</td>
</tr>
<tr>
<td>Gypsum</td>
<td></td>
<td>19.16 NS</td>
<td>0.17 NS</td>
<td>0.18 NS</td>
<td>9.24 NS</td>
<td>922163.59NS</td>
<td>16.94NS</td>
</tr>
<tr>
<td>Biochar * Gypsum</td>
<td></td>
<td>1046.88***</td>
<td>55.78***</td>
<td>25.85***</td>
<td>0.83 NS</td>
<td>3831393.21**</td>
<td>4.40NS</td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td>8.07 NS</td>
<td>0.15 NS</td>
<td>0.85 NS</td>
<td>52.01*</td>
<td>304723.56NS</td>
<td>2.21NS</td>
</tr>
<tr>
<td>Biochar * Year</td>
<td></td>
<td>31.59 NS</td>
<td>0.03 NS</td>
<td>0.18 NS</td>
<td>0.205 NS</td>
<td>580212.43NS</td>
<td>14.23NS</td>
</tr>
<tr>
<td>Gypsum * Year</td>
<td></td>
<td>18.04 NS</td>
<td>0.59 NS</td>
<td>0.63 NS</td>
<td>8.87 NS</td>
<td>146256.712NS</td>
<td>10.51NS</td>
</tr>
<tr>
<td>Biochar * Gypsum * Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS (non-significant); df (degree of freedom); *, ** and *** (indicate significance difference at probability level of 5%, 1% and 0.1%, respectively)

### Number of Seed per Spike and Thousand Seed weight

The main effect of gypsum significantly ($P \leq 0.05$) affected wheat number of seed per spike. Whereas, neither the main effect of biochar nor the interaction effect of biochar with gypsum affected number of seed per spike (Table 1). The highest number of seed per spike (39.10) was recorded from sole application of 100% gypsum. However, the smallest number of seed (34.33) was obtained from 0 gypsum (control). The highest number of grain per spike with amendments plot might be that reduction in osmotic stress through improving soil properties (Akhtar et al., 2014; Rizwan et al., 2018). Different authors reported Combinations of organic amendments and gypsum significantly improved soil properties, which in turn supported prolific root growth of plants (Gill et al., 2009; Alcivare et al., 2018).

Table 2: Main effect of biochar and gypsum on wheat yield and growth parameters: three years combined analysis

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Plant Height (cm)</th>
<th>Effective Tiller (#)</th>
<th>Spike Length (cm)</th>
<th>Number of seed/spike (#)</th>
<th>Grain Yield (Kg/ha)</th>
<th>TSW (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 ton/ha</td>
<td>69.99</td>
<td>2.84</td>
<td>7.72</td>
<td>36.12</td>
<td>2814.5*</td>
<td>41.16b</td>
</tr>
<tr>
<td>4 ton/ha</td>
<td>69.22</td>
<td>2.81</td>
<td>7.71</td>
<td>37.02</td>
<td>2506.90b</td>
<td>40.41b</td>
</tr>
<tr>
<td>8 ton/ha</td>
<td>70.11</td>
<td>2.66</td>
<td>7.68</td>
<td>38.36</td>
<td>3011a</td>
<td>42.61a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>334.69</td>
<td>1.68</td>
</tr>
<tr>
<td>Gypsum Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 Gypsum</td>
<td>68.36</td>
<td>2.66</td>
<td>2.56</td>
<td>34.33b</td>
<td>2539.30b</td>
<td>40.35</td>
</tr>
<tr>
<td>50% Gypsum</td>
<td>69.9</td>
<td>2.81</td>
<td>7.88</td>
<td>38.08a</td>
<td>2778.80ab</td>
<td>41.51</td>
</tr>
<tr>
<td>100% Gypsum</td>
<td>71.06</td>
<td>2.84</td>
<td>7.68</td>
<td>39.10a</td>
<td>3015.30a</td>
<td>42.32</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>2.16*</td>
<td>334.69*</td>
<td>NS</td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>74.97a</td>
<td>4.01a</td>
<td>8.19a</td>
<td>36.99</td>
<td>3198.9a</td>
<td>41.30</td>
</tr>
<tr>
<td>2017</td>
<td>71.49b</td>
<td>1.20b</td>
<td>8.34a</td>
<td>37.45</td>
<td>2661.6b</td>
<td>41.83</td>
</tr>
<tr>
<td>2018</td>
<td>62.87c</td>
<td>3.10c</td>
<td>6.58c</td>
<td>7.17</td>
<td>2472.8b</td>
<td>41.04</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>2.76</td>
<td>0.31</td>
<td>0.42</td>
<td>NS</td>
<td>3.19.73</td>
<td>NS</td>
</tr>
<tr>
<td>CV (%)</td>
<td>7.43</td>
<td>18.97</td>
<td>9.95</td>
<td>10.65</td>
<td>22.06</td>
<td>7.41</td>
</tr>
</tbody>
</table>
Similar letters or no letters with column indicate that there is no significant difference among treatment levels, \( \alpha = 0.05 \), based on LSD test. Where: TSW (thousand seed weight), LSD (List significant difference); CV (coefficient of variance); NS (non-significant)

Grain Yield

Application of biochar and gypsum was apparently affected the grain yield of wheat grown on saline sodic soil at Werer Agricultural Research Center. The interaction of biochar with gypsum was not significant on wheat grain yield, whereas the main effect of biochar and gypsum were significant (Table 1). The highest grain yield (3015.30 kg ha\(^{-1}\)) was obtained at sole application of 100 % gypsum. However, the lowest grain yield (2506.90 kg ha\(^{-1}\)) was recorded from 4 ton/ha biochar (Table 2). Field studies showed that biochar and gypsum addition to salt-affected soils improved grain yield.

The probable reason is salinity also causes nutritional disorders (Grattan and Grieve, 1998) and limits the uptake of essential plant nutrients (K, Ca, Mg, P etc.), and ultimately results in crop yield losses, while due to applied amendments improvement in physical, chemical and biological properties of salt-affected soils that increase wheat grain yield. Many Authors reported biochar directly through the release of essential macro- and micro-nutrients such as Ca, K, N, P and Zn in soil to help offset the adverse impacts of salts (Thomas et al., 2013; Hammer et al., 2014; Kim et al., 2016) gypsum also had a positive effect on sodic soil (Hanayet et al., 2004; Joachim et al., 2007; Mohamed and Abdel-Fattah, 2012; Ashenafiet al., 2016a). Moreover, growth, physiology and yield of wheat were affected positively with biochar amendment, particularly under high salinity level. Akhtar et al., (2015a) concluded that addition of biochar had significant residual effect on reducing Na\(^+\) uptake in wheat under salinity stress.

Soil Chemical Properties

Soil reaction and Electrical conductivity

The result suggests sole and combined application of biochar and gypsum affected soil pH, with some inconsistency with increasing depth soil pH decreased. On surface soil the highest pH (8.24) was observed from control, while the lowest pH (7.60) was from 4 ton/ha Biochar + 100 % gypsum. This might be due to the effect of decomposition of organic matter which released organic acid that lower soil pH and/or the direct effect of gypsum that excessive exchangeable sodium substituted by calcium. Similar to this finding sole and combined application of biochar and gypsum decrease soil pH (Lentz and Ippolito, 2012; Lashari et al. (2013); Lashari et al. (2014); Ashenafiet al., 2016a; Chultz et al., 2017). And also oxidation of organic matter in soil produce acidic matter, is also promoted by the presence of biochar. The formation of the acidic functional groups can neutralize alkalinity and eventually decrease soil pH (Zavalloniet al., 2011; Bethel et al., 2019b).

Figure 2: effect of biochar and gypsum on soil pH and ESP with depth

Electrical conductivity affected due to applied treatments, the highest ECe (3.12 and 3.20 ds/m) was recorded from 8 ton/ha Biochar + 100 % gypsum at 0-30 and 30-60 cm depth, respectively. While the lowest ECe was observed from 4 ton/ha biochar + 50% gypsum at 0-30 cm and from 8 ton/ha biochar at 30-60 cm. The reason with biochar and gypsum increment of electrical conductivity might be the result of the dissolution of Ca\(^{2+}\) and sulfate of gypsum. Thomas et al. (2013) after conducted experiment concluded that biochar increase electrical conductivity. However, Hammeraet al. (2015), reported biochar reduced salt stress by its ion sorption capacity, Shaaban et al., (2013) also stated gypsum as decrease ECe.
Generally, gypsum application was superior on most crop parameters compared to biochar. The highest grain yield was also recorded at 100% gypsum applied treatment. Due to applied amendment fertility of saline sodic soils improved and soil pH, Na+ and ESP showed reduction compared to control. The lowest pH (7.60) was from 4 ton/ha Biochar + 100% gypsum, and relative to control 4 ton/ha biochar showed 26.30% in ESP reduction at surface, while at 30-60 cm 100% gypsum improved sodicity problem by 31.42%. As a result, it would be more cost-effective to use 100% gypsum for the case of study area. Moreover, in future the benefit of biochar in such soil should have to be studied carefully.

4. CONCLUSION

The experiment revealed that application of biochar and gypsum clearly influenced soil chemical properties, number of seed per panicle, thousand seed weight and grain yield. Generally, gypsum application was superior on most crop parameters compared to biochar. The highest grain yield was also recorded at 100% gypsum applied treatment. Due to applied amendment fertility of saline sodic soils improved and soil pH, Na+ and ESP showed reduction compared to control. The lowest pH (7.60) was from 4 ton/ha Biochar + 100% gypsum, and relative to control 4 ton/ha biochar showed 26.30% in ESP reduction at surface, while at 30-60 cm 100% gypsum improved sodicity problem by 31.42%. As a result, it would be more cost-effective to use 100% gypsum for the case of study area. Moreover, in future the benefit of biochar in such soil should have to be studied carefully.
REFERENCES


