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Evaluation of Gypsum and Leaching Application on Salinity Reclamation and Crop Yield at Dugada District, East Shoa Zone of Oromia

Abay Challa*, Kasahun Kitila, Mekonnen Workina

Adami Tulu Agricultural Research Centre, Batu, Ethiopia

Email address:
abaychalla@gmail.com (A. Challa)
*Corresponding author

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Abstract: In Ethiopia, soil salinity and sodicity are the most limiting factors affecting the irrigated agriculture and limit crop productivity in arid and semi-arid regions. To such, the study was conducted in Dugda district of East Shoa Zone of Oromia, Ethiopia from 2018 to 2020 with the aim to evaluate the effect of leaching and gypsum treatments on the removal of exchangeable sodium and soluble salts and the effects of these treatments on crop yield. Onion variety (Bombe red), the most commonly produced crop by farmers, was used as the test crop. Three levels of gypsum (50%, 75% and 100% GR) and leaching were combined and arranged in RCBD design with three replications having an area of 3mx4m plot each. It was identified that application of 100% GR (gypsum requirement (and leaching produced economically optimum yield (326 ku/ha). The effect of Gypsum (100% GR) combined with leaching enhanced reclamation process and caused more decreases in EC, pH, SAR, ESP (exchangeable sodium percentage) and Na^+ concentration were highly significant ($p<0.05$). The level of EC, pH, SAR and ESP showed a decreasing trend as the level of Gypsum requirement increases from 50% to 100% combined with leaching. Moreover, the effect of leaching alone did not significantly affect ($p<0.05$) the levels of Na^+ compare to application of 100% GR both alone and supported by leaching. In general, the present results showed that combined application of gypsum and leaching were relatively superior to either one alone in reducing the soil sodicity and increasing the yield. Hence application of combined gypsum and leaching is recommended to improve onion yield on sodic soils. Therefore, considering its economic benefit and its effect on soil sodicity reclamation potential, the results of the study showed that 100% GR combined with leaching is preferred as a strategy in reclamation of salt affected soil.

Keywords: Soil Sodicity, Application, Gypsum, Leaching, Reclamation, Irrigation, Yield

1. Introduction

Salinity is a major abiotic stress responsible for reduced crop production in many parts of the world. In Ethiopia, salinity, sodicity and water-logging are the most serious problems affecting the irrigated agriculture and limit crop productivity in arid and semi-arid regions [6]. In East Shewa Zone of Oromia Region, most ground water sources are of poor quality for irrigation purpose that contains soluble salts in amounts that are harmful to plants or have adverse effects to convert soils into saline or sodic which require improvements in existing soil management systems and irrigation practices [1].

Studies in different areas of semi-arid regions of the world have compared the effectiveness of various amendments in improving physico-chemical properties of saline-sodic soils [3]. The relative effectiveness of gypsum has received most attention because it is widely used as a reclamation amendment. It is, however, blamed for its slow reaction but being still much popular due to its low cost and availability [10]. One way to alleviate salinity hazards in crop production is to remove the salts from the root zone by leaching. Salt leaching requires adequate irrigation management, which is based on adding sufficient amounts of water beyond the water requirement for meeting evapotranspiration demands, in order to leach the excess salt from the root zone [19]. It follows that the higher the salt concentration in the irrigation water, the greater the amount of water that must be passed through the soil to keep the salt concentration in the root zone at or below a critical level. This approach to overcoming salinity has been intensively studied for many years. One of the earliest reports on this issue can be found in a handbook published by the U.S. Salinity Laboratory Staff [21], which was further discussed by [18]. Since these publications, many other studies and reviews have been published on this subject [20, 19].

Research information with regard to the role of combining gypsum and leaching treatments in improving saline-sodic properties and their residual effect on crop production is inadequate particularly in East Shewa Zone of Oromia Region. The present study was conducted to evaluate the effect of leaching and gypsum treatments on the removal of exchangeable sodium and soluble salts and the effects of these treatments on crop yield.

2. Material and Methods

The study was conducted in Dugda District of East Shewa Zone of Oromia where small scale irrigation is the main economic activity for many farmers. The district is generally characterized by dry low land agro-climate with the altitude ranging from 1576-1750 m.a.s.l. The rainfall pattern is erratic, insignificant mean monthly precipitation and higher potential evapo-transpiration as compared with precipitation. Mean daily temperature is 25°C during the rainy season. Sandy loam is the dominant soil texture identified during the soil salinity assessment and characterization [13]. As far as vegetation is concerned, mid rift valley in general and Dugda district in particular is characterized by scattered acacia wood lands.

2.1. Farmers Selection and Treatments

Two farmers who are using ground water for irrigation were purposively selected depending on their interest for evaluation of different soil salinity management interventions. The treatments considered for the experiment had two factors, gypsum and leaching. Three levels of Gypsum requirement (50%, 75% and 100%) were applied. From previous study by [14], 100% gypsum requirement for study area is 4 t ha^{-1}.

The implemented treatments were assessed with a randomized complete block design (RCBD) with three replicates. The experimental treatments were:

T1- control (no treatment)
T2- gypsum (50% GR) + leaching
T3- Gypsum (75% GR) + leaching
T4- Gypsum (100% GR) + leaching
T5- Gypsum (100% GR) alone
T6- leaching alone

Onion variety (bombe red), which is one of the major vegetable crops produced by the farmers in the area, is used as the test crop. The treatments were replicated three times having $12m^2$ (3m*4m) area for each plot. Site management (weeding, pesticide application, monitoring and watering) was done uniformly for all plots and experimental sites.

Estimating applied water for a desired leaching requirement to determine how much water to apply to meet crop ET demands and the leaching requirement, the following equation were used:

$$AW=\frac{ETc}{1-\left(\frac{LR}{100}\right)} \quad (1)$$

Where AW is applied water depth in inches, ETc is crop evapotranspiration in inches, and LR is the leaching requirement (%).

Determining the leaching requirement for a crop (LR) is defined as the amount of water that is needed to maintain crop productivity. It depends on the salinity of water, soil salinity, salt crop tolerance and other factors. To determine the LR the following steps were followed.

Step 1. Determine the soil salinity (ECe) threshold that causes the loss for crop type [20].

Step 2. Determine the average salinity of the water (ECw) used to irrigate the crop. Most water suitability tests report salinity concentration either in units of electrical conductivity (dS/m)

Step 3. The final step is to use the equation below to estimate the leaching requirement:

$$L\,R = \frac{(ECw*100)}{5ECe-ECw} \quad (2)$$

Where ECw is the salinity of the irrigation water and ECe is the soil salinity threshold in the root zone above which crop yield is reduced.

Once the depth of application (AW) and leaching requirement is known, the next step is for how long it will be irrigated. To calculate time required to irrigate a predetermined amount of water the following formula can be used through the using the 3-inch parshall flume.

$$\text{Time require (t)} = \frac{10*a*d}{q*60} \quad (3)$$

Where q is flow rate as measured l/sec, a is area of the plot to be irrigated in sq.m and d is the depth of the water to be irrigated in cm.

2.2. Soil Sampling and Data Collection

Soil samples were collected from each plot before application and after harvesting to the depth of 20cm and were sent to soil laboratory for soil physiochemical analysis. The extent of salinity before and after intervention were identified based on four main parameters such as EC (electrical conductivity), pH, ESP (exchangeable sodium percentage), SAR (sodium adsorption ratio) because these values are used in the guidelines for classification of salt affected soil by different authors and organizations [7, 17, 9]. In addition, Exchangeable cations such as CEC, Calcium, Magnesium, Sodium, and Potassium were analyzed. Crop yield was also taken and recorded to evaluate the effect of the treatments on total onion yield.

3. Results and Discussion

3.1. Soil Sample Collection and Laboratory Analysis

The initial obtained data showed that, physical and chemical properties of the studied soil of the experimental area are sodic and the dominant textural class is sandy loam.

Table 1. *Soil physical and chemical characteristics of experimental site before treatments application.*

Soil characteristics	value
Sand%	54
Silt%	6
Clay%	40
Texture	sandy loam
PH	8.61
Ec (dsm^{-2})	3.54
Exchangeable Na^+ Cmol (+) kg^{-1} soil	19.45
Exchangeable Ca^{++} Cmol (+) kg^{-1} soil	12.33
Exchangeable Mg^{++} Cmol (+) kg^{-1} soil	5.62
SAR (mmol l^{-1})	15.82
ESP (%)	45

Table 2. *The Effect of Leaching and Gypsum Treatments upon the Yield of Onion.*

Treatments	yield in ku/ha
control	249.13c
50% GR and leaching	305.09b
75% GR and leaching	307.7b
100% GR and leaching	326.34a
100% GR alone	310.15b
Leaching alone	298.72b
mean	293.16
CV%	10.66
LSD (p,0.05)	16.85

Means with the same letters are not significantly different.

3.2. The Effect of Leaching and Gypsum Treatments upon the Yield of Onion

Biological yield as affected by leaching and gypsum amendments at harvesting are given in Table 2. The yield in ku/ha was increased steadily from 305 to 326 as gypsum application rates increased from 50% to 100% GR with leaching. Treatments with leaching plus gypsum were far superior to control and as well as gypsum and leaching alone. Significantly a higher value of yield was recorded when leaching and gypsum 100% GR rate applied together than their application alone. The statically significant yield of onion is due to the replacement of exchangeable Na^+ by Ca^{++} and leaching of the released Na^+ below the root zone. This result was supported by [12] who noted that gypsum was effective in lowering the chemical parameters that might be due to substitution of exchangeable Na^+ by Ca^{++} that produced more soluble salts and was leached by the irrigation water.

The yield of onion is lower in leaching alone when compare with that of gypsum treated one. This finding is in line with work of [10] who suggested that the decrease in yield as a result of leaching the soil without treatments might be due to the aggravated effect of exchangeable Na^+ on soil properties with decreasing electrolyte concentration of soils. On the other hand, the relative increment in the yield with increasing percentage of GR rates might be due to the reduction of the toxic concentration of Na^+ at the soil exchange site. This result was also supported by [5, 16] who suggested that applied chemical treatments on saline sodic soils and then leached with water can significantly wash down the toxic concentration of Na^+.

Table 3. *Chemical characteristics of studied soil as affected by gypsum and leaching treatments after onion harvesting.*

treatments	pH	Ec (mmhos/cm)	Exchangeable cations (cmol (+) /kg^{-1}			SAR	ESP
			Ca^{++}	Mg^{++}	Na^+		
T1=control	8.62a	3.64a	12.13b	9a	18.76a	17.1a	43a
T2=50% GR and leaching	8.55a	2.69a	13.51b	10.18a	17.5a	13.6bc	22.5b
T3=75% GR and leaching	8.50a	2.64a	13.6b	10.15a	17.10a	13.4bc	20.37b
T4=100% GR and leaching	7.77b	0.75b	20.98a	10.2a	11.37b	10.9b	13c
T5=100% GR alone	8.37ab	0.95b	19.65a	11.18a	13.13b	12.8bc	14.7c
T6=Leaching alone	8.56a	2.83a	13.03b	9.03a	17.43a	14.5c	22b
mean	8.43	2.83	14.66	9.16	16.22	13.91	25.13
CV%	4.7	17	5.7	16.25	16.36	3.12	5.63
LSD (p,0.05)	1.4	1.95	2.06	NS	1.66	3.07	5.37

Means with the same letters are not significantly different.

3.3. The Effect of Leaching and Gypsum Treatments upon Soil Chemical Properties

3.3.1. Effect on Soil pH

The soil-pH at end of the experiment is shown in Table 3. The result showed that application of gypsum at rate 100% GR combining with leaching significantly affected soil pH. The minimum decrease in soil pH was recorded in the control soil (treated with neither of the treatments) while the greater decrease in soil pH over the control was recorded in the soil treated by combined application of 100% GR along with leaching. The initial soil-pH (having 8.61) was reduced to 7.77. Though, statistically they were not deferrer among other treatments they have showed a decline trend when compare to the control one. Efficiency of the treatments was T4 > T5 > T3 > T2 > T6 > T1. The decrease in soil pH due to gypsum application was probably due to combination of more than one factor, mainly the replacement of sodium by calcium and the formation of neutral salts with SO_4^{2-}. The decrease in soil pH may have been related to a decrease in sodium concentration as a result of application of gypsum followed by leaching.

3.3.2. Effect on Electrical Conductivity (Ec in ds/m)

The changes in the EC of the untreated and treated sodic soil are shown in (Table 3). The minimum decrease in soil ECe was recorded in the control soil (treated with neither of the treatments) while the greater decrease in soil ECe over the control was recorded in the soil treated by combined application of 100% GR and leaching. The result showed that application of gypsum at rate 100% GR combining with leaching and alone significantly affected soil Ec. Ec showed a decreasing trend from 2.69 mmhos/ cm to 0.75 mmhos/cm as the levels of gypsum requirement was increasing from 50% to 100% combining with leaching (Table 3). The effect of leaching alone did not significantly affect ($p<0.05$) the levels of Ec compare to l00% GR alone. Treatment with gypsum followed by leaching is far more effective in reducing Ec than is without gypsum. This result was supported by [12] who conclude that the decrease might be the result of gypsum addition. The reduction of EC may probably be due to leaching of soluble salts into the deeper layers of the profile. Gypsum provides calcium ions for the replacement of exchangeable sodium and for the formation of a more desirable calcium-sodium ratio in the soil, and reduces the dispersion and puddling which is usually associated with alkali soils.

3.3.3. Effect of Treatments on Soil Basic Cations (Na^+, Ca^{++} and Mg^{++})

Sodium concentration was relatively very high (18.76 cmol (+) kg^{-1}) and highly significantly different ($p<0.05$) for the control treatment as compared with both 100% GR combined with leaching (11.37 cmol (+) kg^{-1}) and 100% GR (13.13 cmol (+) kg^{-1}) alone treatments. It was very low (11.37 cmol (+) kg^{-1}) at treatment received 100% GR combined with leaching (Table 3). The effect of leaching alone did not significantly affect ($p<0.05$) the levels of Na^+ compare to application of l00% GR both alone and supported by leaching. These results led to the conclusion that gypsum is a good source of Ca^{++} that replaced Na^+ on the exchange complex, which in turn leached out with water. This result was supported by [12] who noted that gypsum was effective in lowering the chemical parameters that might be due to substitution of exchangeable Na by Ca that produced more soluble salts (NaCl, or Na_2SO_4) and was leached by the irrigation water. Similar studies by different authors also indicated that the increase in Ca^{++} occurred due to direct application of gypsum [4]. This Ca^{++} replaced Na^+ on exchange sites that was leached down during continuous irrigation so that there was net increase in Ca content and very high decrease in the amount of Na from the soil solution [8].

Calcium concentration varied negatively with the sodium concentration in the soil (Table 3). It was very low at the control treatment (12.13 cmol (+) kg^{-1}) where no gypsum and leaching were applied. Significantly, higher values (20.98 cmol (+) kg^{-1}) and (19.65 cmol (+) kg^{-1}) were recorded at the treatments received 100% GR plus leaching and gypsum alone respectively compare to other treatments (Table 3). The effect of gypsum and leaching was not significant for the levels of magnesium concentration. But, magnesium contents in soil were higher as a result of gypsum and leaching application compared with the control.

3.3.4. Effect of Treatments on ESP and Sodium Adsorption Ratio (SAR)

The amount of salts remaining in soil samples after onion harvesting i.e. the corresponding leaching process with gypsum treatments are presented in Table 3. The results revealed that ESP decreased with leaching water and was related to the rate of amendments. Exchangeable sodium percentage was highly significantly different ($p<0.05$) among the treatments. ESP was very high at the control treatment (43%) where there was no application of Gypsum and leaching treatments. ESP value showed a decreasing trend from 25.5-13% as the level of Gypsum requirement increases from 50% to 100% (Table 3) combined with leaching. Gypsum accompanied by leaching were more effective in reducing ESP when compared with leaching alone Table 3. The SAR takes the same trend as that of the ESP. The SAR value showed decrease which ranged between 13.6 and 10.9. Significantly, greater decrease in SAR (10.9) was recorded at the treatments received 100% GR plus leaching Table 3. Soil receiving gypsum at higher rate removes the greatest amount of Na^+ from the soil columns and causes a substantial decrease in EC and SAR [15]. Noticeable effect of leaching on the SAR was higher with gypsum treatments and lower with leaching alone. This might be due to gypsum application, which is good source of Ca^{+2} that replaced Na^+ and Na^+ leached down below crop root by leaching water. The result also supported by [11] who concluded that the reduction in SAR may be the result of increased Ca^{++} + Mg^{++} that help displace Na^+ from the soil exchange site.

Table 4. *Effect of gypsum and leaching on the economic benefit of onion production.*

Treatments	Mean yield in ku/ha	Input cost /ha (Birr)	Labor costs /ha (Birr)	Total cost/ha (Birr)	Market price of Onion/ku (Birr)	Total revenue /ha In Birr	Net income/ ha in Birr	benefit /cost ratio
Control	249.13	85000	83905	168905	2000	498260	329355	2.95
50% GR and Leaching	305.09	88600	88554	177154	2000	610180	433026	3.44
75% GR and Leaching	307.7	88703	88704	177407	2000	615400	437993	3.47
100% GR and Leaching	326.34	88860	88862	177722	2000	652680	474958	3.67
100% GR alone	310.15	88865	88865	177730	2000	620300	442570	3.49
Leaching alone	298.72	85710	85715	171425	2000	597440	426015	3.49

4. Economic Analysis

The economic analysis was done to select the most economically important soil salinity amendments that were evaluated using onion production as test crop. The study demonstrated that it is profitable and viable with reference to net income and benefit-cost ratio. As indicated in (Table 4), the highest total cost of gypsum and leaching was 177730 ETH Birr ha^{-1} was recorded for the application of 100% GR rate. The cheapest cost of production 168905 ETH Birr ha^{-1} was recorded on the control one. The maximum gypsum rate earns the maximum cost of production. However the greater profit from the yield was from 100% GR rate. The total revenue obtained was also directly proportional to the onion yield; in that, the maximum 652680 ETH Birr ha^{-1} was found when 100% GR was applied along with leaching and the minimum 498260 ETH Birr ha^{-1} was on the control experiment. The net income and benefit cost ratio showed also a positive relation to the onion yield and total revenue; (i.e maximum and minimum net income was 474958 and 329355 ETH Birr ha^{-1} and maximum and minimum benefit cost ratio were 3.67 and 2.95 respectively). The net benefit showed an increasing trend as the level of gypsum application was increasing from 50% GR to 100% GR. Similar studies by [22, 2] reported that gypsum amendment is the most economical amendment used on sodic soils.

5. Conclusions and Recommendations

The effects of leaching and gypsum treatments on the reclamation of sodic soil in the mid rift Valley of East shoa zone of Oromia region were followed by soil analysis and by measuring yields of onion. The productivity of this sodic soil can be raised from low productivity to reasonable levels by treatment with large quantities of gypsum along with leaching application. On all gypsum-treated plots onion yield increments were seen. The yield showed an increasing trend as the level of gypsum application was increasing from 50% GR to 100% GR. The lower yield of onion obtained from plots untreated and the highest was obtained from plots treated with gypsum and leaching and is attributable to the removal of excess salinity by leaching. Application of gypsum combined with leaching enhanced reclamation process and caused more decreases in EC, pH, SAR, and ESP compared with control. The efficiency of treatments in reducing exchangeable Na and increasing exchangeable Ca increased significantly with increasing applied rate of gypsum from 50% to 100% GR along with leaching. In general 100% GR rate and leaching are recommended to make farmers benefited from the reclamation of sodic soil. The calculated result also confirmed that the largest net farm income and benefit cost ratio was obtained from this treatment combination.

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