Research Article

Rejected Lime as Soil Conditioner for Growth of *Vigna radiata*: A Case Study from Mountainous Ranges of Dhofar Governorate, Oman

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Abstract | Rejected lime is a residual by product generated during the calcination of rejected limestone. In the present study, the aim is to utilize rejected lime as a soil conditioner and evaluate its effectiveness for the growth of the green gram (*Vigna radiata*) plant. The soil samples were collected from eastern (16.9931° N, 54.7028° E) and western (16.7118° N, 53.1857° E) mountainous ranges of Dhofar Governorate, Oman. Soil and rejected lime samples were evaluated for pH, electrical conductivity, particle size, moisture. In addition, the collected soil samples were mixed with various proportions of rejected lime (10 to 50% of rejected lime in soil-rejected lime mixture with fixed 5 g of soil) and tested for pH, electrical conductivity, and cation exchange capacity. An optimal combination of soil and rejected lime from each mountain was selected to grow the green gram plant for 28 days. The western mountainous range of Dhofar Governorate showed better growth with 4 plants, and length of the stem, root, and plant as 14.2, 2.1 and 16.3 cm, respectively. Thus, it is be concluded that rejected lime could be a potential soil conditioner for plant growth.

Received | February 17, 2023; **Accepted** | November 23, 2023; **Published** | December 06, 2023
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Citation | Zabanoot, A.A.M.M., A.W.A.S. Qatan, A.S.M. Hubais, K.H.M.B. Said and S. Sivamani. 2023. Rejected lime as soil conditioner for growth of *Vigna radiata*: A case study from mountainous ranges of Dhofar governorate, Oman. *Pakistan Journal of Agricultural Research,* 36(4): 304-310.
DOI | https://dx.doi.org/10.17582/journal.pjar/2023/36.4.304.310
Keywords | Rejected lime, Soil, CEC, pH, Electrical conductivity

Introduction

Agricultural sector has the good potential for expansion in Oman. In Oman, agriculture contributes about 2.51% to GDP during the fiscal year of 2019 (Hussein, 2011). Oman has five distinct agricultural regions, going roughly from north to south, include the Musandam Peninsula, the Al-Batinah coast, the valleys and the high plateau of the eastern region, the interior oases, and Dhofar mountains (Al-Kindi and Hird, 2020). Salalah city, capital of Dhofar Governorate in the Sultanate of Oman, is bound by Al-Qara mountains and low hills in the north, west and east, and the Arabian Sea in the south (Sana and Baawain, 2014). Al-Qara mountains, rich in rejected limestone, have two principal scarp directions – Wilayat of Dhalkut in the west and Wilayat of Mirbat in the east (Zerboni *et al*., 2020). Carmeuse Majan LLC (SFZ) is a rejected lime manufacturing company located in Raysut, Salalah, Oman. Rejected lime or rejected lime waste is a material generated during the calcination of rejected limestone. Chemically, rejected lime contains 70 to 80% of mixed CaO and MgO, and Al_2O_3, SiO_2, Fe_2O_3, K_2O, TiO_2, Na_2O, MnO and P_2O_5 being the rest (Toniolo *et al*., 2018). Limited literature is available on the utilization of rejected lime for engineering applications. A few scientific literatures are reported on the application of rejected lime waste in construction industries (Garg *et al*., 1996; BMTPC, 2021).

A soil amendment is any material added to a soil to improve its physical properties, such as water retention, permeability, water infiltration, drainage, aeration, and structure. The goal is to provide a better environment for roots (Noble, 2011). Soil amendments are of three types fertilizers, soil inoculants and soil conditioners. Fertilizers, organic or synthetic, are soil amending materials that provide essential macro-nutrients such as nitrogen, phosphorus, and potassium, and 72 micro-nutrients. Soil inoculants add biology to the soil to improve the soil food web using bacteria or fungi. Soil conditioners or soil enhancers alter the soil structure, that effect cation exchange capacity, soil pH, water holding capacity, or soil compaction (Schoebitz *et al*., 2013). The effect of soil conditioner on its fertility is determined through cation exchange capacity (CEC). CEC is a measure of how many cations can be retained on soil particle surfaces (Ramos *et al*., 2018). Negative charges on the surfaces of soil particles bind positively charged atoms or molecules (cations). However, it allows negatively charged particles to exchange with other positively charged particles in the surrounding soil water. It is one of the ways that solid materials in soil alter the chemistry of the soil. CEC affects many aspects of soil chemistry and is used as a measure of soil fertility, as it indicates the capacity of the soil to retain several nutrients (e.g., K^+, NH_4^+, Ca_2^+) in plant-available form. It also indicates the capacity to retain pollutant cations (e.g., Pb^{2+}) (Yener *et al*., 2012).

Green gram (*Vigna radiata*), belongs to the Fabaceae family, is an annual leguminous crop which is grown for its seeds, which are a high source of nutrients (Pandey *et al*., 2014). The crop is easy to cultivate and can grow up to a height of 30-120 cm, producing pods. Dried seeds are cooked or milled into flour, while the crop residues are used as fodder or in making green manure. Green gram plants thrive in a well-drained soil, rich in nutrients and with an optimum pH and temperature of 6.0-7.5 and 28-30°C, respectively. Extreme pH and temperature affect crop growth and development. Green gram plants are relatively drought tolerant and can give reasonable yield with an annual rainfall of between 350-650 mm. The monsoon season of Salalah (Khareef) is suitable for the growth of green gram plants (Anand *et al*., 2020).

For the first time, rejected lime is used as a soil conditioner for plant growth. Green gram plant is selected for growth studies as the climatic conditions of Dhofar Governorate is more suitable for its propagation. To the nest of authors knowledge, no literature is available for the utilization of rejected lime as a soil conditioner for the growth of green gram plant. Hence. The following objectives are framed from the research gaps: (i) To collect soil samples from eastern and western mountain ranges of Dhofar Governorate; (ii) To characterize soil samples and rejected lime for pH, electrical conductivity, particle size and moisture content; (iii) To mix soil samples and rejected lime in various proportions (0.55, 1.25, 2.14, 3.33 and 5 g of rejected lime in 5 g of soil to achieve 10-50% of rejected lime in mixture) and determined their CEC; and (iv) to observe plant growth by measuring the length of stem, root and plant for growth of green gram crop at optimized mass % of rejected lime in soil-rejected lime mixture.

Materials and Methods

Sample collection and storage

Soils from eastern and western mountainous ranges were collected in an air-tight container and transported to Biochemical Engineering Laboratory of University of Technology and Applied Sciences – Salalah (UTAS-SLL). Soil samples were collected by digging the surface to about 2 cm to get accurate experimental results. The samples were stored at 4 °C in air-tight container for further experiments. Rejected lime was kindly provided by Carmeuse Majan LLC (SFZ), Salalah. All the chemicals, reagents, equipments, instruments, and apparatus were used from the various laboratories of UTAS-SLL.

Experimental studies

Soil pH and electrical conductivity: Soil sample, sieved through 2 mm screen, was taken in 50 mL beaker. 1 g of soil sample was mixed with 10 mL of double distilled water. They were mixed well, and the supernatant was filtered by wire mesh. pH of the supernatant was measured by pH meter. Similarly, electrical conductivity of the supernatant was measured by electrical conductivity meter.

Particle size

A set of sieves were arranged with screen sizes in descending order and the pan or receiver was placed at the bottom. 10 g of sample was placed on the top screen. The samples were sieved in vibratory sieve shaker for 15 min. The sample collected in each sieve was weighed and the mass was noted down. But the mass of sample collected in each screen, average particle size was calculated from mass fraction.

Moisture content

An empty beaker (50 mL) was cleaned and dried. Mass of empty beaker was noted down. 10 g of sample, sieved through 2 mm screen. was taken in 50 mL beaker. Then, the beaker was placed in hot air oven at 105±2 °C to constant weight. Mass of beaker with sample was noted down. The moisture content was calculated based on the difference between mass of beaker with sample and mass of empty beaker.

Cation exchange capacity

Soil sample, sieved through 2 mm screen, was taken in 50 mL beaker. Soil samples collected from eastern and western mountain ranges of Dhofar Governorate was mixed with rejected lime in various proportions as shown in Table 1. CEC was calculated for each mixture and tabulated.

Table 1: *Mixed design of soil-rejected lime mixture for CEC calculation.*

Mass of soil (g)	Mass of rejected lime (g)	Mass % of rejected lime in the mixture
5	0	0
5	0.56	10
5	1.25	20
5	2.14	30
5	3.33	40
5	5	50

CEC was calculated using methylene blue test as follows: 2 g of sample was mixed with 20 mL of double distilled water. 0.028 N methylene blue solution was prepared by mixing 0.89 g of methylene blue in 100 mL of water to complete dissolution. Methylene blue solution was taken in burette. 0.5 mL of methylene blue solution was taken in a Petri dish. 0.5 mL of supernatant was taken using dropper and mixed with 0.5 mL of methylene blue solution. The mixture was dropped on a filter paper until end point is reached. If end point is not reached, again 0.5 mL of methyl blue was added to the supernatant and the procedure was repeated. The end point is the formation of light halo around the dark blue dot. CEC was calculated using the Equation 1:

$$Cation\ exchange\ capacity\ (CEC) = \frac{S\ x\ V_m\ x\ 1000}{W}\frac{meq}{kg} \quad ...(1)$$

Where, S is normality of methylene blue solution, geq/L or N, V_m is volume of methylene blue solution (mL) required to reach end point, W is weight of the soil (g) and 1000 is the conversion to convert g of soil to kg.

Plant growth studies

The used water bottles were collected irrespective of the brand and cut them to two pieces. The top part was discarded retaining the bottom part for plant growth studies. Two such bottles were taken, one for eastern mountainous range and the other for western mountainous range. Around 4 or 5 green gram seeds were added in each bottle to observe the plant growth. Plant growth was observed on 28^{th} day with intermittent observation once in 2 days. At the end of 28^{th} day, the length of stem, root and plant was measured using 30 cm linear scale.

Results and Discussion

Characterization of samples

Figure 1 shows the pH of soil samples collected from eastern and western mountain ranges of Dhofar Governorate and rejected lime. Soil sample collected from eastern mountain range is slightly basic than the soil sample collected from western mountain range. Hence, pH of eastern mountain range soil is more than that of western mountain range. Normally, region with more rainfall has acidic soil (Cusack and Turner, 2020). During Khareef season, the average rainfall of western mountain range is more than that of eastern mountain range. So, the soil in western mountain range may be more acidic than that of eastern mountain range. As rejected lime is an alkaline material, pH of rejected lime is high at 12.5.

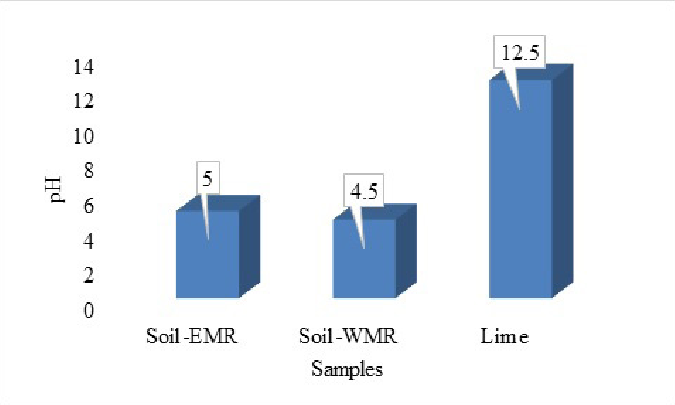

Figure 1: *pH of samples (Soil-EMR: Soil sample collected from eastern mountain range of Dhofar Governorate; Soil-WMR: Soil sample collected from western mountain range; Lime: Rejected lime).*

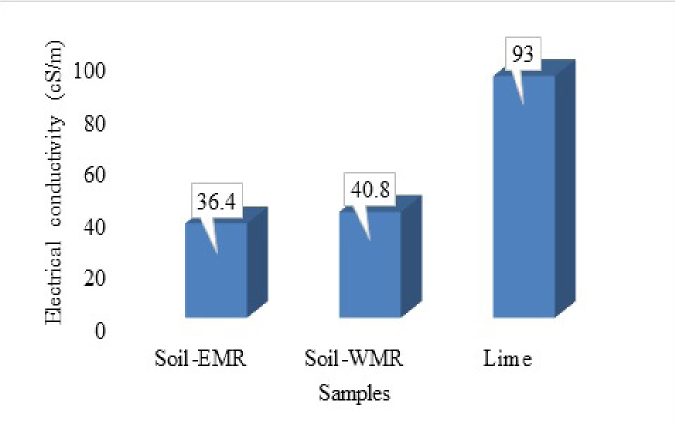

Figure 2: *Electrical conductivity of samples (Soil-EMR: Soil sample collected from eastern mountain range of Dhofar Governorate; Soil-WMR: Soil sample collected from western mountain range; Lime: Rejected lime).*

Table 2: *Effect of electrical conductivity on soil salinity.*

Electrical conductivity (cS/m)	Salinity of soil
0-20	Non-saline
21-40	Very slightly saline
41-80	Slightly saline
81-160	Moderately saline
>160	Strongly saline

Figure 2 shows the electrical conductivity of soil samples collected from eastern and western mountain ranges of Dhofar Governorate and rejected lime. Table 2 shows the effect of electrical conductivity on salinity of soil. Electrical conductivity of soil measures the concentration of salts carried away by electric current (Kim *et al*., 2010). Even though electrical conductivity is not a direct measurement of soil properties, but indirectly affects physical and chemical properties of soil including salt concentration, organic matter, cation exchange capacity, nutrients and minerals, fertility, water holding capacity, crop yield, etc. (Liu *et al*., 2017). In non-saline soils where electrical conductivity is less than 20 cS/m, soil moisture could be used as a measure of soil properties (Bezzar and Ghomari, 2013). High saline soils affect the soil biology as most of the microorganisms cannot tolerate high salt concentration, and only halophiles grow in high saline soils. It is also an indicator of soil health if electrical conductivity is less than 160 cS/m. Soil in eastern and western mountain ranges exhibited that they are very slightly saline to slightly saline, which means that the soil health is good. As rejected lime is an alkaline material, electrical conductivity of rejected lime is high at 93 cS/m. But, since rejected lime falls under moderately saline and soil is very slightly saline, they could be mixed to get slightly saline mixture.

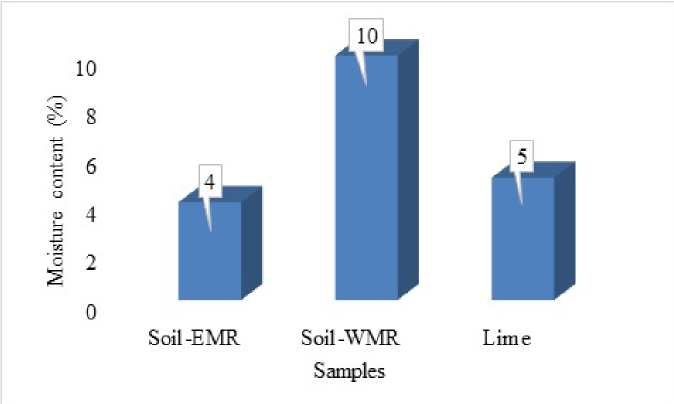

Figure 3: *Moisture content of samples (Soil-EMR: Soil sample collected from eastern mountain range of Dhofar Governorate; Soil-WMR: Soil sample collected from western mountain range; Lime: Rejected lime).*

Figure 3 shows the soil moisture content of soil samples collected from eastern and western mountain ranges of Dhofar Governorate and rejected lime. Soil sample collected from eastern mountain range has less moisture than the soil sample collected from western mountain range. Soil moisture is a measure of soil dynamics and affected by precipitation, surface temperature etc. (Su *et al*., 2014). During Khareef season, since the average rainfall of western mountain range is more than that of eastern mountain range, moisture content is more in western mountain range than that of eastern mountain range. As rejected lime is disposed as a landfill in the Dhofar municipality designated area, the moisture content of rejected lime may be affected by the environment.

Figure 4 shows the particle size of soil samples collected from eastern and western mountain ranges of Dhofar Governorate and rejected lime. Table 3 shows the effect of particle size on category of soil.

Soil moisture measures its heterogeneity and fertility (Hu *et al*., 2011). Soil moisture also affects its physical and chemical properties (Scholl *et al*., 2014). Soil in eastern and western mountain ranges exhibited that they are medium shaped soil. The particle size of rejected lime is medium at 0.5 mm.

Table 3: *Effect of particle size on soil category.*

Particle size (mm)	Soil category
< 0.002	Clay
0.002-0.05	Silt
0.06-0.10	Very fine
0.11-0.25	Fine
0.26-0.5	Medium
0.51-1	Coarse
1.01-2	Very coarse

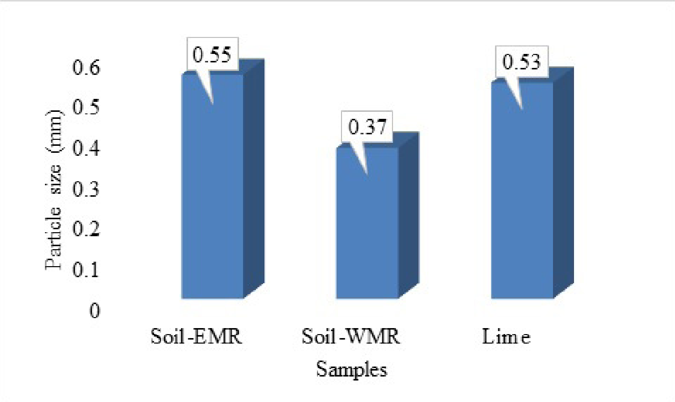

Figure 4: *Particle size of samples (Soil-EMR: Soil sample collected from eastern mountain range of Dhofar Governorate; Soil-WMR: Soil sample collected from western mountain range; Lime: Rejected lime).*

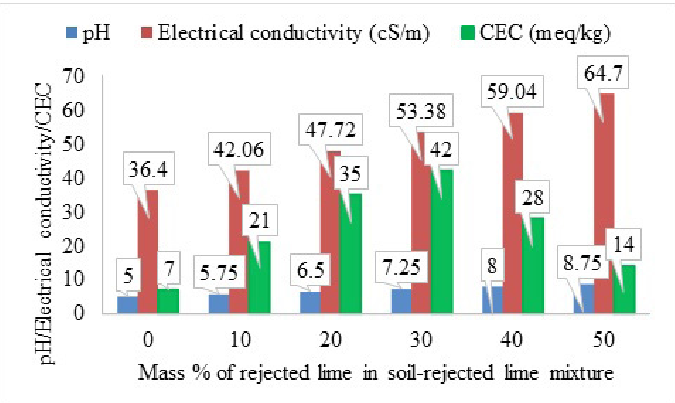

Figure 5: *Effect of mass % of rejected lime in soil-rejected lime mixture on pH, electrical conductivity, and CEC of samples for eastern mountain range of Dhofar Governorate.*

Figure 5 shows the effect of mass % of rejected lime in soil-rejected lime mixture on pH, electrical conductivity, and CEC of samples for eastern mountain range of Dhofar Governorate. As the mass % of rejected lime increases, pH increases due to its alkalinity and electrical conductivity also increases due to increase in salt concentration. But CEC increased from 7 to 42 meq/kg when mass % of rejected lime increased from 0 to 30%. Further increase in mass % of rejected lime to 50% decreases CEC to 14 meq/kg. CEC exhibited its maximum value of 42 meq/kg at pH of 7.25 and electrical conductivity of 53.38 cS/m. Rejected lime induce changes in soil pH, electrical conductivity, and CEC with the effectiveness and magnitude of changes closely related to the physical and chemical properties of soil (Hailegnaw *et al*., 2019).

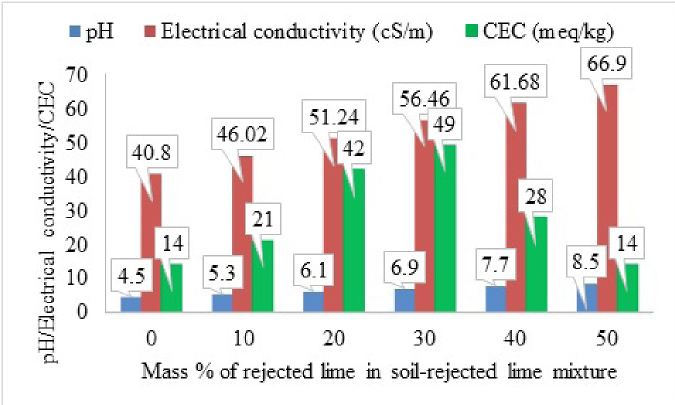

Figure 6: *Effect of mass % of rejected lime in soil-rejected lime mixture on pH, electrical conductivity, and CEC of samples for western mountain range of Dhofar Governorate.*

Figure 6 shows the effect of mass % of rejected lime in soil-rejected lime mixture on pH, electrical conductivity, and CEC of samples for western mountain range of Dhofar Governorate. As the mass % of rejected lime increases, pH increases due to its basicity and electrical conductivity also increases due to increase in concentration of minerals. But CEC increased from 14 to 49 meq/kg when mass % of rejected lime increased from 0 to 30%. Further increase in mass % of rejected lime to 50% decreases CEC to 14 meq/kg. CEC exhibited its maximum value of 49 meq/kg at pH of 6.9 and electrical conductivity of 56.46 cS/m.

Table 4 shows the effect of CEC on number of plants, length of stem, root, and plant for both mountain ranges of Dhofar Governorate. Even though 30% by mass is the optimum for rejected lime in soil-rejected lime mixture for eastern and western mountain ranges of Dhofar Governorate. But CEC differs for both eastern and western mountain ranges at 42 and 49, respectively. It could be clearly correlated that soil with high CEC exhibited better plant growth, which is also evident from Figure 7.

Table 4: *Effect of CEC on number of plants, length of stem, root, and plant for both mountain ranges of Dhofar Governorate.*

Location	Mass % of rejected lime in the mixture	CEC (meq/kg)	Length of stem (cm)	Length of root (cm)	Length of plant (cm)	Number of plants
Soil-EMR	30	42	13	1.4	14.4	3
Soil-WMR	30	49	14.2	2.1	16.3	4

(a) (b)

Figure 7: *Micrographs of growth of green gram plant at optimized mass % of rejected lime in soil-rejected lime mixture.*

Conclusions and Recommendations

This work aimed to study the applicability of rejected lime as a soil conditioner for growth of green gram plant. The soil samples were collected from eastern (16.9931° N, 54.7028° E) and western (16.7118° N, 53.1857° E) mountainous ranges of Dhofar Governorate, Oman. Soil and rejected lime samples were evaluated for pH, electrical conductivity, particle size, moisture. In addition, the collected soil samples were mixed with various proportions of rejected lime (10 to 50% of rejected lime in soil-rejected lime mixture with fixed 5 g of soil) and tested for pH, electrical conductivity, and cation exchange capacity. An optimal combination of soil and rejected lime from each mountain was selected to grow the green gram plant for 28 days. The western mountainous range of Dhofar Governorate showed better growth with 4 plants, and length of the stem, root, and plant as 14.2, 2.1 and 16.3 cm, respectively. Thus, rejected lime could be a potential soil conditioner for plant growth.

Acknowledgement

We would like to acknowledge the support from the University of Technology and Applied Sciences, Salalah, Oman and Carmeuse Majan, Salalah, Oman for research.

Novelty Statement

This study investigates the potential of rejected lime as a soil conditioner for green gram cultivation in Dhofar Governorate, utilizing a novel approach of mixing it with local soil at various proportions to optimize growth.

Author's Contribution

Amna Ali Mohammed Makoof Zabanoot: Wrote abstract, Methodology, Data collection.
Al Wafaa Ahmed Suhail Qatan: Wrote Results and discussion, Data collection.
Amal Salim Mahad Hubais: Wrote Conclusion, Data collection, References.
Khadijah Hamid Musallam Bait Said: Wrote introduction, Data collection.
Selvaraju Sivamani: Conceived the idea, Technical Input at every step, Overall Management of the article.

Conflict of interest

The authors have declared no conflict of interest.

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