Comparison of saturated hydraulic conductivity under the reclaimed conditions of salt affected soil

ABSTRACT

Solving the soil problems that affect negatively on growth of plants and reduce the soil permeability is necessary for the study site, Thein Gone Village in Yamethin Township, Myanmar. The objectives of this study are; to identify the soil whether it is salt-affected or not and to investigate the proper reclamation method with different rates of amendments by comparing the saturated conductivity (K_s). Bothcomposite (disturbed) and core (undisturbed) soil samplings were collected at three profiles (0 - 60 cm soil depth) during March, 2023. Some soil properties such as texture, bulk density (g cm^{-3}), moisture content (%), ECe (electrical conductivity, saturated extract; mS cm^{-1}), pH (1:5 water), SAR (sodium absorption ratio) and pH and EC of leaching water were measured. Firstly, the study site was problematic with high pH due to Na^+ distribution of underground water although there was some application of gypsum for a decade. Also, low permeability (K_s< $1x10^{-8}$ cm s^{-1}) was another problem there. To leach the salt (EC < 1 mS cm^{-1} in leachate), 1500 cm^3 of water was necessary for one core (98.21 cm^3 soil volume). It was relatively high amount for using the quality-water. For reclamation methods, gypsum 5 t ha^{-1}, sulphur 1 t ha^{-1}, and cow-dung manure 20 t ha^{-1} gave the minimum (-log K_s) value among different rates of each amendment. The less the -log K_s, the more permeable the soil becomes. Among different amendments, gypsum 5 t ha^{-1} showed the fastest saturated hydraulic conductivity. Moreover, it is necessary to drain out the leachate to prevent the formation of saline -sodic soil.

Keywords: saturated hydraulic conductivity, reclamation, salt-affected soil

1. INTRODUCTION

Saturated hydraulic conductivity (K_s) is one of the soil quality indicators and measuring it is useful to identify whether the soil is salt affected or not. Moreover, it can be regarded as a crucial aspect of soil that controls its capacity to transfer water under saturated conditions[1]. In soil-plant-water relations and processes, decisions on water conservation, irrigation systems, fertilizer application, drainage, solute mitigation, and plant growth, estimation of K_s performs as one of the desirable measurements[2]. $K_s$is typically determined by using easy-to-complete field and laboratory procedures [3].

The hydraulic conductivity is generally constant in saturated soil with a stable structure and in porous media like sandstone. In sandy soil, it ranges from approximately 10^{-2} to 10^{-3} cm s^{-1}, whereas in clayey soil, it is between 10^{-4} and 10^{-7}cm s^{-1}.[4] noted that soil texture and structure could have an impact on hydraulic conductivity. Hydraulic conductivity varies with soil type in several cases due to a variety of chemical, physical, and biological compositions and phenomena [5]. Salt concentration or composition in the water solution can also alter the hydraulic conductivity of the soil [6].

Nowadays, many soils in the world become problematic as a result of various natural disasters and intensive farming methods. Among these, salt-affected soils (saline, saline-sodic, and sodic) are brought on by an excessive accumulation of soluble salts with different compositions, concentrations, and saturations of the soil exchange complex by sodium, which alters the soil's permeability and hinders healthy root development [7]; [8]. Excess salts harm developing plants and cause thepoor physical soil conditions. Low rainfall, saline or sodic subsoil exposure from erosion, parent soil material, high salt irrigation water uses, prolonged use of certain fertilizers, poor drainage are some of the potential causes of salt affected soils Therefore, the negative effect on growth of plants is the result of reduced permeability of the soil to both water and air that in turn restricts root development, establishment, growth and final yield of crops [9].

Salts affected soil can be reclaimed by leaching salts out of the root zone through good quality irrigation water or by heavy rainfall, by creating good surface and internal drainage in which using tile drains and open ditches in the fields to increase drainage and to remove some of the salts, by breaking the compacted layers that occur near or at the soil surface and by applying organic matters (cow dung manures, poultry manures, green manures, farm yard manure, crop residue and compost) and chemical amendments (gypsum,lime, sulphuric acid, sulphur, hydrochloric acid and nitric acid etc.)[10]; [11].

Currently, Myanmar faces soils with problems of approximately 1 million hectares (7.8%) of all cultivable land. Although most of these problem soils are currently under cultivation, salty and alkaline soils make up approximately 68.75% (660,000ha) of the total area of problem soils. Therefore, salt affected soils becomes the most common issue to solve in [12].Thein Gone Village, Yamethin Township, Mandalay Division, Myanmar, has 14.57 ha as a problematic soil. According to local administrative reports, this soil can be utilized as low land for paddy growing in the rainy season only. However, utilization of these soils returnsuneconomical values for the cultivation of crops without adopting proper reclamation measures. Therefore, this study was conducted with the following objectives –(1) To identify the soil whether it is salt-affected or not and (2) To investigate the proper reclamation method with different rates of amendments by comparing the saturated conductivity (K_s). In this study, comparing saturated hydraulic conductivity under reclaimed condition of salt affected soils will fill the lack of scientific facts related to soil properties and will inform the soil status for current and long-term impact.

2. MATERIAL AND METHODS

2.1 Site Description and Land Use History

The study site was located at Thein Gone Village,Yamethin Township, Mandalay Division, Myanmar. It is situated at 20.45 °N latitude and 96.17 ºE longitude and the elevation of 431.10 m above the sea level. According to the local meteorological reports, average monthly minimum and maximum temperature of the study area were 13.80°C and 34.40ºC for the study year and the average rainfall was 5.84 mm per day during the wet season. There is no rainfall in the hot season.Farmer response of the land use history of the study site was shown in table 1.

Table 1 Land use history of the study site

Location	Land use	Remark
Theingon village Yemethin Township,	Uncultivable	Past 60 years

Mandalay Division, Myanmar	Cultivable	Past 30 years (Rainy season only)
	Cultivable	Past 10 years (rainy season) (farmer-based application-gypsum 124 - 350 kg ha^{-1})
	Cultivable	Current (rainy season)

2.2 Soil and Water Samplings and their Analyses

Both composite (disturbed) and undisturbed cores soil samples were collected at three profiles from 0-20 cm, 20-40 cm and 40-60 cm depths, respectively. Before analyzing, all composite soil samples were air-dried at room temperature for further physical and chemical soil analyses and undisturbed cores were measured for bulk density and saturated hydraulic conductivity. Water sample in the well at the nearest filed were also collected. Soil and water sampling time was in 26th and 27thMarch,2023.

2.3 Soil, water and leachate analyses

Soil, water and leachate analyses were carried out at the laboratory of the Department of Soil and Water Science, Yezin Agricultural University. This study was performed with three steps to identify the soil problems, to calculate the leaching requirement and to reclaim the soil problems.

Firstly, in the identification of soil problem, the following parameter such as soil texture, soil bulk density, saturated hydraulic conductivity, soil pH, electrical conductivity of saturation extract (Ece), sodium adsorption ratio (SAR), soil organic matter and water quality of pH and EC were studied. Soil texture was classified by using sedimentation method[13]. Soil bulk density (BD) was determined with core sampler method[14]. Measurements of saturated hydraulic conductivity (K_s) of soils were based on the direct application of Darcy's equation (constant head method) to a saturated soil column of uniform cross-sectional area [15]. Soil pH was measured in a 1:5 soil water solution by a pH meter [16]. Soil electrical conductivity of saturation extract (ECe) was measured with an EC meter (CD 4307 SD)[17]. Sodium adsorption ratio (SAR) was determined by flame method using atomic absorption spectrophotometer (AAS) [18]. Soil organic carbon was determined by the method of Heanes wet oxidation. The percentage of organic carbon (C_{org}) in a soil is multiplied by 1.724 to obtain the percentage of soil organic matter (SOM). Well water quality was measured by using water quality meter (WQC-24). pH of leachate was measured withpH meter (AS 800). EC of leachate was measured with EC meter (CD 4307 SD).

In the second step, leaching requirement (LR) was calculated by constructing the curve of the relationship between cumulative leaching amount and EC values. This study was started with five frequencies of leaching water at 7 days interval using 500, 750, 1000, 1250, 1500 cm^3, respectively. To wash salt, 0.4 µS cm^{-1}of deionized water was used.

In the third experiment for the reclamation of soil problem, comparison of saturated soil hydraulic conductivity under different rates of amendments used such as gypsum, sulphur and cow dung manure were carried out. Each study had four treatments and these were assigned as completely randomized design with three replications. In the gypsum treatment, differentrates of 0 t ha^{-1}, 5 t ha^{-1}, 10 t ha^{-1} and 15 t ha^{-1} were used. In sulphur treatment, different rates of sulphur 0 t ha^{-1}, 1 t ha^{-1}, 2 t ha^{-1} and 3 t ha^{-1} were used. In cow dung manure treatment, different rates of cow dung 0 t $ha^{-1,}$ 10 t ha^{-1}, 20 t ha^{-1} and 30 t ha^{-1} were used.

2.5 Statistical analysis

All collected data were analyzed by using the statistical software program (statisix version 8.0). Oneway ANOVA for CRD was constructed to test at $P < 0.05$. All means were compared by using LSD test at 5% level.

3. RESULTS AND DISCUSSION

3.1 Identification of the study soil whether it is salt affected or not

Table 2: Some soil characteristics of the study site

No.	Soil Characteristics	Soil Depth		
		0-20 cm	**20-40 cm**	**40-60 cm**
1	Texture	Sandy loam	Clay loam	Clay loam
2	Bulk density (g cm^{-3})	1.41 ± 0.16	1.63 ± 0.11	1.53 ± 0.07
3	ECe ($mScm^{-1}$)	2.63 ± 0.06	1.90 ± 0.08	2.11 ± 0.04
4	pH (1:5 water)	8.58 ± 0.05	8.88 ± 0.41	8.65 ± 0.08
5	SAR	3.49 ± 0.04	3.93 ± 0.02	3.79 ± 0.10
6	K_s (cm s^{-1})	1 x 10^{-6}	1x 10^{-8}	1X10-8
7	SOM (%)	0.98±0.08	0.26±0.09	0.14±0.07

After ± values are standard deviation.

SAR means sodium adsorption ratio using the equation of $SAR = \sqrt{\frac{(Ca2+ +Mg\ 2+)}{Na+}}$

K_s means saturated hydraulic conductivity.

SOM means soil organic matter.

Some measured soil characters were shown in table 2 and 3. Two textural classification was observed at three soil depths. Bulk density at 20-40 cm soil depth was the maximum. It meant that the plough layer was forming because of rice cultivation.Soil organic matter content was decreased in order from top to bottom of the soil profile. However, organic matter contents were too low there. According to table 2, it could be recognized that three soil depths of the

Tables 3: Exchangeable soil Na^+, Ca^{2+} and Mg^{2+} contents of the study site

Soil Properties (Sodium Absorption Ratio)	Depth		
	0-20 cm	**20-40 cm**	**40-60 cm**

Exchangable Na (meqL^{-1})	22.10	22.60	22.30
Exchangable Ca (meqL^{-1})	70.93	54.07	52.80
Exchangable Mg(meqL^{-1})	9.9	11.30	12.27

study site had pH of >8.5, ECe of around 2 mS cm^{-1} and SAR of > 3. It indicated that the soil with high pH, slightly saline and slightly sodic. Throughout the soil column, exchangeable Na^+ was equally distributed and amount of exchangeable Ca^{2+} was the greatest at the surface (table 3). It was the sign of salt affected soil with high pH [19]. Well water quality near the study site during the hot season also showed with high EC and pH (table 4). The reason of high Na^+ amount therewas evaporation from ground water (table 4) and high Ca^{2+} amount was the application of gypsum for a decade by native farmers (table 1). In table (2), K_s was varied from 10^{-6} to 10^{-8} cm s^{-1}. So, the soil was low permeable. In sodium affected soils, the soil permeability was usually poor. In addition, the soil texture and bulk density of upper layer (0-20 cm) and lower layers (20-40 cm and 40-60 cm) were completely different. Textural differentiations and high bulk density made the soil permeability poor. Likely, Waskom et al (2012) reported that many sensitive crops such as some vegetables and ornamentals showed symptoms and reduced yields at ECs of 2 - 4 mS cm^{-1}. In addition, many soils would begin to have reduced infiltration and increased crusting at SAR levels well below 13.

Table 4: Characteristics of well water quality near the study site

No.	Water Quality	Value
1	Oxidation Reduction Potential, ORP (mv)	550.33
2	Dissolved Oxygen, DO (mg/L)	47.46
3	Electrical Conductivity, CON (mScm^{-1})	3.81
4	Turbidity, TURD (NTU)	10.53
5	Temperature, TEMP (°C)	27.3
6	pH	8.77

3.2 Calculation of leaching amount

To calculate the leaching amount for reclaiming this problem soil, the relationship between cumulative amount of leached water (cm^3) and the electrical conductivity (EC) value (mS cm^{-1}) of the drained water was calibrated in figure 1. The use of leached water quality was 0.4 μS cm^{-1}). In the drained water, water quality was reduced from 1.2 mS cm^{-1} to less than 0.8 mS cm^{-1} when 500- 1500 cm^3 of deionized water was used for leaching the salts. At the amount of 750 cm^3 leaching water, EC value showed the lowest and after that, EC values became

higher. It was due to water soluble Na^+ and reduced Ca^{2+} and Mg^{2+} made the poor soil structure [20]. At 1500 cm^3 of leached water, the electrical conductivity (EC) value was stable. Therefore, leaching volume of 1500 cm^3 of deionized water was used for reclaiming this problem soil using different rates of amendments such as gypsum, sulphur and cow dung manure and for comparing K_s. Actually, this use amount of quality water is relatively high.

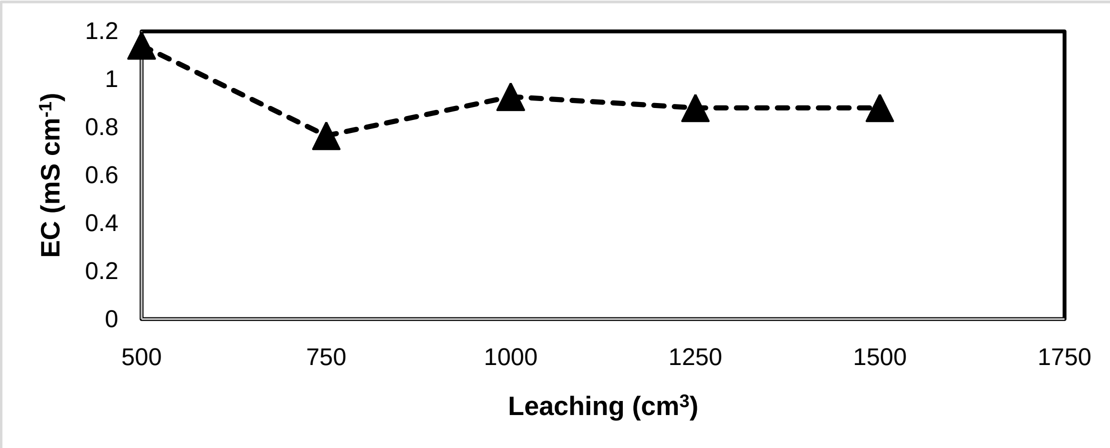

Figure 1. Relationship between cumulative leaching amount (cm^3) and EC (mS cm^{-1}) of drained water

3.3 Reclamation of the problem soil

3.3.1 Effects of different rates of gypsum on saturated hydraulic conductivity (K_s)

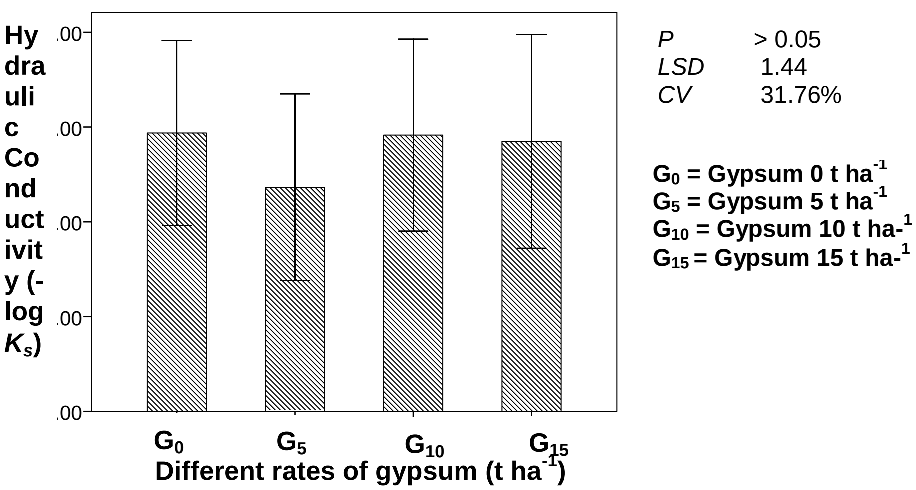

Figure 2. Effects of different rates of gypsum application on saturated hydraulic conductivity (-log Ks) of high pH soil

Mean comparisons of K_s under different rates of gypsum application were shown in figure 1. Decreasing in -log K_s means the soil become more permeable. Statistically, there was no significantly difference among the treatments. However, there was numerically decreased in - log K_s. When different rate of gypsum 5 t ha^{-1}, 10 t $ha^{-1}$and 15 t ha^{-1} were applied with 1500 cm^3 of deionized water for salt leaching, K_s in G_5 was faster than other treatments. It indicated that the soil became more permeable at - log K_s value between 4 and 5. The reason of G_5 showing the more permeable than G_{10} and G_{15} was that exchangeable calcium in G_5 could balance with exchangeable sodium in soil. Permeability of G_5 was about 100 times greater than that of no addition. Therefore, gypsum 5 t ha^{-1} should be used when using gypsum for solving this problem soil.

3.3.2 Effects of different rates of sulfur on saturated hydraulic conductivity (K_s)

Effects of different rates of sulphurapplication on K_s were shown in figure 3. There was no statistically difference among the treatments. However, numerically decrease in - log $K_s$occurred at1 t $ha^{-1}$of sulphur application. It was nearly 100 times reduce in - log K_s when compared to control treatment. Similarly,1 t ha^{-1}sulphur application gave the more permeability than other treatments because of the balancing effect of anions SO_4^{2-} in the soil-water solution.Therefore,sulphur 1 t ha^{-1} should be used when using sulphurfor solving the problem soil.

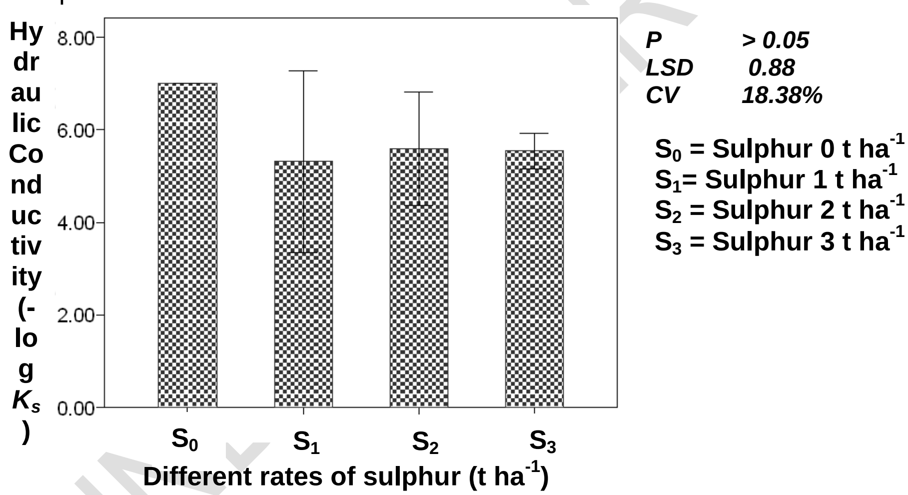

Figure 3. Effects of different rates of sulphur application on saturated hydraulic conductivity (-log K_s) of high pH soil

3.3.3Effects of different rates of cow dung manure application on saturated hydraulic conductivity (K_s)

Effects of different rates of cow dung manure on - log K_s were described in figure (4). Statistically, there was no significant effects on - log K_s among the treatments. However, there was a numerically decrease in - log K_s due to the application of cow dung manure. In comparison of - log K_s, CD_{20} treatment (20 t ha^{-1}) gave the minimum value and it showed the soil as the faster permeability than other treatments. Permeability of CD_{20} was about 10 times greater than that of CD_{30} treatment (30 t ha^{-1}). Therefore, cow dung manure 20 t ha^{-1} should be used when using cow dung manure for solving this problem soil. Addition of organic residues on K_s varied with soil texture, structure and there were some changes in hydraulic characteristics on salt-affected [21].

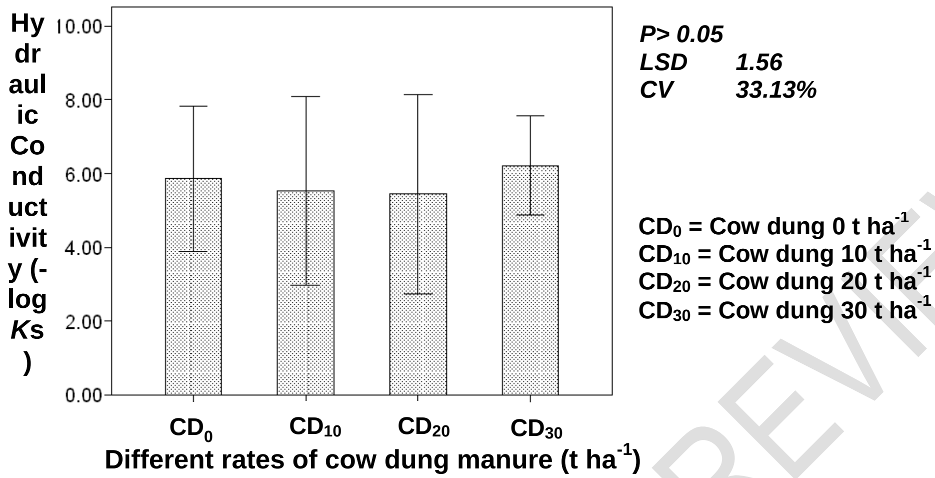

Figure 4. Effects of different rates of cow dung manure application on saturated hydraulic conductivity (-log K_s) of high pH soil

3.3.4 Comparison of Saturated hydraulic conductivity (K_s) using different amendments

Based on the three above experiments, it was found that among different amendment applications, gypsum 5 t ha^{-1} gave the best permeability (the fastest saturated hydraulic conductivity) (in figure 5). Permeability of G_5 was about 10 times greater than that of S_1 and CD_{20} treatments and it was also about 100 times greater than that of no addition. Therefore, the study site could be reclaimed using gypsum 5 t ha^{-1} with quality water to leach out the salt and it is necessary to drain out. Here, it could be expected that application of cow dung manure on - log K_s had less effect than other amendments (figure 2 and 3).

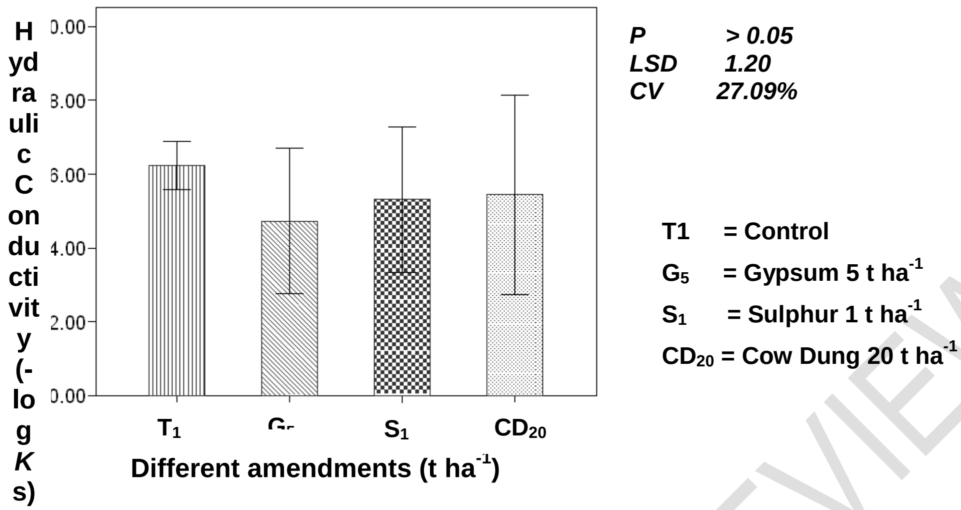

Figure 5. Effects of saturated hydraulic conductivity (-log *K*s) among different amendments of high pH soil

4. CONCLUSION

The study site faces with high soil pH problem due to Na^+ distribution in the ground water as well as application of gypsum there. To reduce the EC value in the drained water (<1 mS cm^{-1}), leaching requirement was $1500cm^3$ per core. Among different rates of gypsum application, 5 t ha^{-1} gave the fastest rate of saturated hydraulic conductivity. Among different rates of sulphur application, 1 t ha^{-1} gave the fastest rate of saturated hydraulic conductivity. Among different rates of cow dung manure application, 20 t ha^{-1} also showed the fastest rate of saturated hydraulic conductivity. Among different amendment applications, gypsum 5 t ha^{-1}favoured the soil becomes more permeable that was about 100 times greater than that of no addition.

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