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Study on the Effect of gypsum and Natural Fertilizer on the growth of young plantation in dry zone area

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Abstract

Salt-affected soils are present in Dry zone areas in significant quantity. This experiment was conducted to assess the effectiveness of compost with gypsum for reclamation and its efficiency. A saline-sodic field having pH - 9.02, EC 1.17 (dS m /1) and SAR 2.69 (mmol /l) and texture Sandy Loam. For this purpose, the treatment comprises T1, (gypsum + natural fertilizer) -1Kg/ tree, T2 (gypsum + natural fertilizer)- 2Kg/ tree, T3 (gypsum + natural fertilizer) -3Kg/ tree) and T4 (control) were applied in young plantation in Yenangyaung greening complex zone area which of six promising tree species and total 216 tree seedling. Soil samples were collected from each treatment after the application of fertilizer and analyzed for soil fertility status and plant height. The results showed that pH, EC, and SAR of the leachate samples were decreased with increasing level of gypsum and natural fertilizer and also improved soil fertility and growth condition of saline sodic soil.

Keywords: *Sodic soil, Gypsum, natural fertilizer, dry zone, soil fertility, plant height*

အပူပိုင်းဒေသ သက်ငယ်စိုက်ခင်းတွင် ဂျစ်ပဆန်နှင့် သဘာဝမြေဩဇာထည့်သွင်းခြင်းဖြင့် အပင်ကြီးထွားမှုအား နှိုင်းယှဉ်လေ့လာခြင်း

ဆွေဆွေထွန်း၊ လက်ထောက်သုတေသနအရာရှိ

စာတမ်းအကျဉ်း

အပူပိုင်းဒေသတွင် ဆားပေါက်မြေနေရာများအား သိသာစွာများပြားလျက်ရှိကြောင်း တွေ့ရှိရပါသည်။ ဆားပေါက်မြေအားမြေဆီလွှာပြုပြင်ပေးရန်အတွက် ဂျစ်ပဆန်နှင့် သဘာဝမြေဩဇာထည့်သွင်းခြင်း၏ အကျိုးသက်ရောက်မှုကိုသိရှိရန် လက်တွေ့စမ်းသပ် ဆောင်ရွက်ခဲ့ပါသည်။ ဆားပေါက်မြေတွင် မြေချဉ်ငန်ဓါတ်- ၉.၀၂၊ ဆားငန်ဓါတ် ၁.၁၇၊ ဆိုဒီယမ်ကပ်ငြိမှု အချိုးပမာဏ ၂.၆၉နှင့် သဲဆန်သောမြေ အခြေအနေရှိကြောင်း တွေ့ရှိရ ပါသည်။ ရေနံချောင်းမြို့၊ အထူး စိမ်းလမ်း စိုပြည်ရေး ဧရိယာအတွင်း သစ်မျိုး (၆) မျိုးဖြင့် တည်ထောင်ထားရှိသည့် သက်ငယ်စိုက်ခင်းတွင် စမ်းသပ်ချက် များဖြစ်သည့် စမ်းသပ်ချက်-၁-စိုက်ပင်တစ်ပင်လျှင် (ဂျစ်ပဆန် + သဘာဝမြေဩဇာ) - ၁ ကီလိုဂရမ်၊ ၊ စမ်းသပ်ချက်- ၂-(ဂျစ်ပဆန် + သဘာဝမြေဩဇာ)-၂ ကီလိုဂရမ်၊ စမ်းသပ်ချက်-၃ (ဂျစ်ပဆန် + သဘာဝ မြေဩဇာ) - ၃ ကီလိုဂရမ်နှင့် စမ်းသပ်ချက်-၄ (ထိန်းချုပ်ကွက်/မြေဩဇာ မကျွေးခြင်း)ဖြင့် အပင်အရေအတွက် စုစုပေါင်း ၂၁၆ပင်အား မြေဩဇာများ ထည့်သွင်းခဲ့ပါသည်။ မြေဩဇာများ ထည့်သွင်းပြီးနောက် စမ်းသပ်ချက် အသီးသီးမှ မြေနမူနာများ ကောက်ယူ၍ မြေဆီဩဇာ အခြေအနေအား ဓါတ်ခွဲစမ်းသပ်ခြင်းနှင့် အပင်အမြင့် တိုင်းတာတွက်ချက်စစ်ဆေးခဲ့ပါသည်။ စမ်းသပ်တွေ့ရှိချက်များအရ ဂျစ်ပဆန်နှင့်သဘာဝမြေဩဇာ တိုးမြင့်ထည့်သွင်းခြင်းသည် မြေချဉ် ငန်ဓါတ်၊ ဆားငန်ဓါတ်နှင့် ဆိုဒီယမ်ကပ်ငြိမှု အချိုးပမာဏ လျော့ချနိုင်၍ မြေဆီ ဩဇာအခြေအနေနှင့် အပင်အမြင့်ကြီးထွားနှုန်း ကောင်းမွန်ကြောင်းတွေ့ရှိရပါသည်။

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Study on the Effect of gypsum and natural fertilizer on the growth of young plantation in dry zone area

1. Introduction

Nowadays, climate change is recognized as one of the biggest problems the world is facing, posing a potential threat to the environment and almost all aspects of human life. Consequently, afforestation and reforestation have become integral components of climate change mitigation strategies worldwide. (Kyriaki Psistaki et.al,2024)

The government of Myanmar established the Dry Zone Greening 5-year Plan, including a plan to plant trees in about 40,000 ha from FY2001 to FY2005. The target of the overall plan was to plant trees in an area of about 210,000 ha in the Central Dry Zone in the 30 years from 2000 to 2030. However, afforestation efforts in the Central Dry Zone had only been made in the areas where tree planting was relatively easy, and, in the areas with harsh environment where afforestation was more urgently required, only small-scale experimental afforestation had been conducted. (Jun Totsukawa,2013)

For greening landscape, some part of areas received salinity due to soil recommendation results, it has become very important to explore the possibilities of increasing tree growth of(saline) lands for sustainable forest management. Therefore, additional new studies about soil reclamation can contribute important information to help solve these problems

The management of salt-affected soils is mainly focused on decreasing soil salinity by leaching the affiliated ions out of the soil using materials such as gypsum and high-quality water [2] and the application of organic materials as a soil amendment. (Ghulam Sarwar et.al,2011)

The applications of composts and gypsum have been reported to positively affect the soil properties and the present investigations have addressed the combined effect of compost and gypsum on the saline- sodic soils under semi-arid conditions.(Megahed M.Ameret.al,2023)

Therefore, use of gypsum in combination with natural fertilizer may provide good strategy for improving soil chemical properties and fertility status of saline sodic soil. Keeping in view the situation of low organic matter status and huge amount of salt-affected soils in Dry Zone area, the present study was undertaken to evaluate the usefulness of compost and gypsum on soil chemical properties and fertility status of saline-sodic soil.

2. Objective

(a) To evaluate the combined effect of gypsum and natural fertilizer on some soil properties the growth performance of tree species

(b) To provide technical information for the establishment of young plantation in saline-alkali land in arid and semi-arid regions

3. Literature Review

Soil degradation, which can be caused by salinity and sodicity, is considered as an environmental problem with severe adverse effects on agricultural productivity, particularly in arid and semiarid regions (Qadir et al., 2006). It is considered the most critical environmental stress which can negatively affect plant growth and the metabolism process (Rodriguez-Navarro and Rubio, 2006). Salinity usually appears in the arid and semi-arid areas where the evaporation process is higher than the total precipitation (Qadir et al., 2006). It was reported that groundwater is a permanent source of soil salinization that causes poor productivity in the irrigated areas. (Moukhtar et al. ,2003)

The chemical remediation is one of these reclamation strategies (Sharma and Minhas, 2005). The application of Ca amendments can improve different properties of soil and act as soil modifiers that can prevent development of sodicity which is directly related to plant growth, crop productivity and crop yields (Wong et al., 2009; Chintala et al., 2010). Specific chemical amendments such as calcium chloride ($CaCl2·2H2O$) and gypsum ($CaSO4·2H2O$) can be used as direct source for Ca2+ cation; however gypsum is normally available and relatively cheap. Gypsum plays a significant role in the reclamation of saline-sodic soils by providing a Ca2+ cation to replace the exchangeable Na+ from the colloid's cation exchange positions and leaching it out from the root zone (Sharma and Minhas, 2005, Mohamed et al,. 2011).

Soil salinity management interventions usually vary from place to place depending on the type of soil salinity, the availability of the materials and awareness on soil salinity management practices. Gypsum has become an efficient to reclaim sodic soils (Fisher and Madeline, 2011). The study indicated that, application of gypsum increases concentration of Ca2+ in soil solution to substitute the adsorbed sodium, hence overcome the dispersion effects of Na+ and improve the soil structure in the dispersed soils.

Organic material amendments like application of compost increases soil CO2 concentrations and releases H+ when it dissolves in water. The released H+ enhances CaCO3 dissolution and liberates more calcium for sodium exchange (Ghafoor et al., 2008). The addition of compost in to salt affected soil has been successful in improving soil properties of sodic soils (Islam et al., 2017).

Use of gypsum with organic material like water hyacinth compost and rice straw compost showed that integrated use of these treatments was more efficient in decreasing the ECe, pH, SAR, and ESP of clay saline-sodic soils as compared to their individual use. Rice straw compost was more effective in diminishing EC, pH, SAR and ESP than water hyacinth compost (Mikanova et al., 2012; Shaaban et al., 2013; Abdel- Fattah 2012). The most efficient and economical methods for reclamation of salt affected soil is addition of Ca2+ source which change the ionic composition of soil solution and replace the Na from exchange site which is leached down out of soil profile (Ghafoor et al., 2008).

4. Materials and methods

4.1 Study Area

An afforestation site with saline-sodic soil properties was designated for this study and is located in he Magway region (20°28′N, 94°55′E) as a greening zone complex area by the Dry Zone greening Department. The climate in the study area is characterized by an average annual temperature of 27°C, average humidity of 65%, and annual rainfall ranging from 720 mm 860 mm, based on data from the local Meteorological Station.

4.2 Experimental Design and treatments

The study was conducted during two successive seasons of 2024 and 2025 at Yenangyaung Greening area. The plantation was established in 2024 with the original spacing of 3m x 3m. From the results of the earlier trials and experience in the region, six promising plant species, Dahat-*Tectona hamiltoniana* Wall , Pe cherry -*Gliricidia Sepium* (Jacq.)Walp, Phyuat Seit -*Holoptelea integrifolia* (Roxb.), Mezali-*Senna siamea* (Lam.), Sha-*Senegalia catechu* (L.f), Tamar-*Azadirachta indica* (A.Juss) were chosen for the experiment. The study area was considered a regional replicate (plots) with a complete block design of four treatments for each species. The treatment comprised T1 ((gypsum +natural fertilizer -1Kg/ tree, (T2 gypsum + natural fertilizer 2Kg/ tree, T3 (gypsum + natural fertilizer -3Kg/ tree)and T4 (no fertilizer /control,) were applied. Each experimental plot contained 54 plants, and a total of (216) plants were fertilized with buffer zones between plots. Application time and different ratios are shown in the following.

Treatment/tree	2024 year	2025 year
	Gypsum + natural fertilizer	Gypsum + natural fertilizer
T1-1Kg	400 g	600g
T2-2Kg	800g	1200g
T3-3Kg	1400g	1600g
T4-control		

4.3 Soil sampling and Analysis

A soil sample was conducted before and after application. Composite soil samples from each study site were randomly collected to a depth of 50cm in each treatment. About 0.5-kg sub-sample was air-dried, sieved through a 2-mm mesh for physical and chemical analyses. The particle-size distribution was determined by using the pipette method. The soil pH was determined using a pH meter in a 1:2.5 soil: water suspension. Soil organic matter (OM) was determined by loss on ignition at 900 ◦C. Soil total nitrogen (TN) was measured by the semi-micro Kjeldahl method, and available phosphorus (Ava.P) was measured by the ultraviolet spectro - photometer method. Extractable potassium was assessed with double-acid extracting solution by using Atomic Absorption Spectrophotometer A saline-sodic field having pH – 9.02, EC e 1.17 (dS/ m) and SAR 2.69 (mmol/ L) and texture Sandy loam

4.3 Height measurement

Tree height was measured in December 2024 and December 2025.

4.4 Data Analysis

Data on soil properties and height of tree species were analyzed using the Analysis of Variance (ANOVA) test. Where test results were significant, the Tukey test method was used for mean comparison at a 5% probability level. All statistical analyses were con ducted with SPSS 18.0.

5. Result

5.1 The effect of soil amendments on soil properties

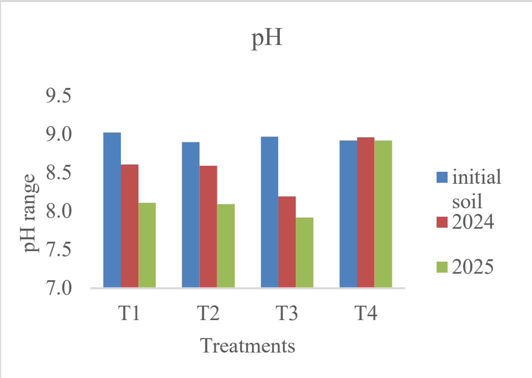
The results of this study demonstrate a significant effect of the combined gypsum and natural fertilizer treatments on improving soil conditions. (Appendix I&II)

5.1.1 Soil pH and Sodium Absorption Ratio (SAR)

In 2024 and 2025, all of the improvement treatments decreased soil pH compared to the control, with reductions ranging from 0.031 to 0.78 in 2024 and 0.81 to 1.08 in 2025 (Table 1); these differences between treatments were all statistically significant. Additionally, all of the treatments reduced SAR in the soil compared with the control. Specifically, in 2024, the SAR values for the T1, T2 and T3 treatments decreased by 2.92%, 11.3% and 11.42% respectively, compared to the control treatment. In 2025, the SAR values for T1, T2 and T3 treatments decreased by 8.4%, 17.99%, and 26.55% respectively, compared with the control treatment. This analysis highlights that T3 treatment was the most effective in reducing soil pH and SAR (figure1) in saline-alkali soil.

Treatment	pH range			SAR (mmmol/L)			EC (DSm^{-1})		
	Initial	Final	Decrease rate	Inital	Final	%decrease	Initial	Final	Decrease rate
T1	9.02	8.11	0.91	32.65	20.43	8.41	1.16	0.77	0.39
T2	8.9	8.09	0.81	27.0	20.29	17.99	1.16	0.55	0.61
T3	8.97	7.89	1.08	20.5	18.13	26.55	1.14	0.32	0.82
T4	8.96	8.89	0.04	35.0	29.98	5.02	1.17	0.97	0.20

Table 1. Effect of different treatments on pH, SAR and EC



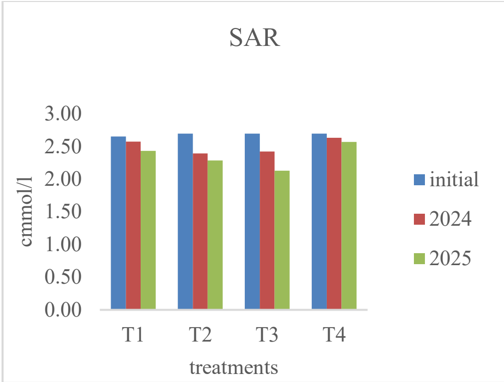


Figure 1. Effect of different treatments on soil pH range and SAR value

5.1.2 Electrical Conductivity (EC)

The results of various treatments on the EC of the soil after reclamation are shown in Figure 8. The EC decreased significantly with treated per year. The treated soils showed numerical values of 0.45(DSm^{-1}) in 2024 yr and 0.82 (DSm^{-1}) in 2025yr, respectively (Fig. 2). The EC value of 0.20 (DSm^{-1}) was obtained in the control soil (without gypsum and natural fertilizer).

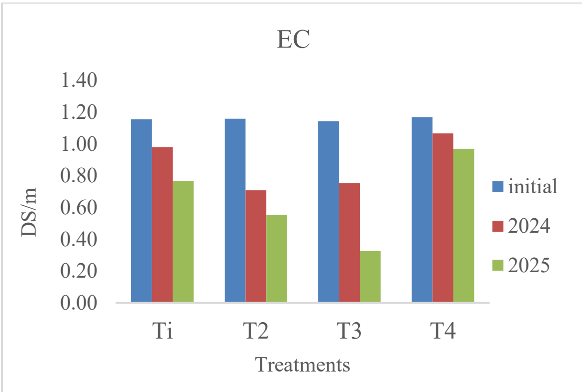


Figure 2. Effect of different treatments on soil EC value in 0-50 cm soil depth

5.1.3 Soil Nutrients

The amended treatments increased soil organic matter (OM) and Total nitrogen (TN) content within two-year periods (Figure3). Each treatment showed a gradual increase in organic matter and total nitrogen (TN), with the T3 yielding the highest increase and the control yielding the lowest increase. The T3 treatment showed a significant increase of 23% in organic matter and 20% in TN compared with the control treatment in 2024.The T2 treatment achieved a substantial increase of 16% in organic matter and 16% in TN, whereas the T1 treatment showed an increase of 10% in organic matter and 5% in TN. Similar trends have already observed in 2025.

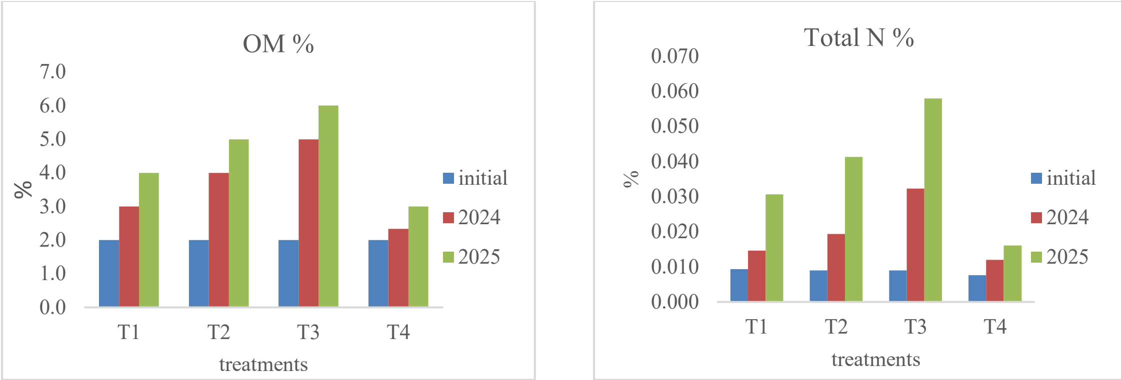


Figure 3. Effect of different treatments on soil OM % and Total N % in 0-50 cm soil depth

In 2024, the extractable potassium (Ext. K) levels in each treatment were significantly higher than in the control treatment, with the differences observed being statistically significant ($P < 0.05$). In 2025 potassium in each treatment was significantly elevated compared with the control group, with statistically significant differences between treatments (Figures 4). T3 treatment showed the most significant enhancement among all of the treatments, with improvements in the following sequence: T3<T2<T1<T4. Compared to the control, T1, T2, and T3 treatment showed increase in Ext. K content of 2.5%, 3.76% and 5.63%, respectively.

The available phosphorus ranged from 0.00008% to 0.00012% (Figure4). The available phosphorus was not significantly different in all treatments a in 2024 and 2025.

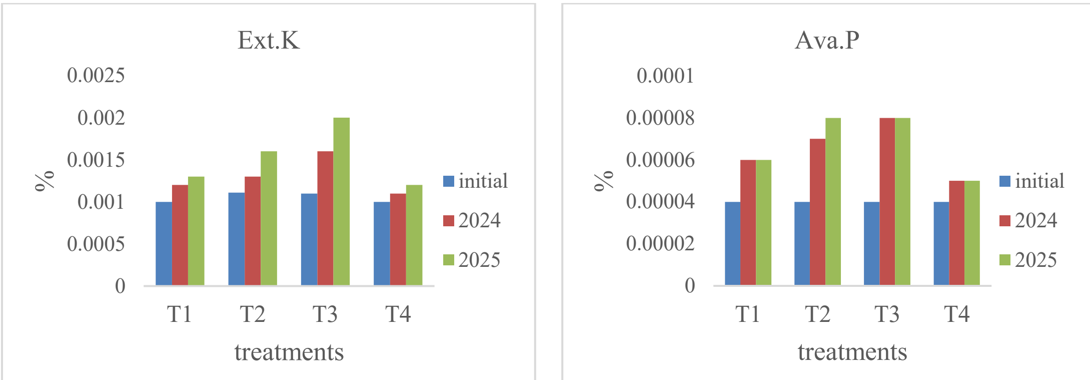


Figure 3. Effect of different treatments on soil ext. K %and Ava. P%% in 0-50 soil depth

5.2. The effect of soil amendments on Tree growth

The mean height growth of tree species and the analysis of variance for the one-year-old (Dec 2024) and two years old (Dec 2025) species were shown in Figure 5. The combined application of Gypsum and natural fertilizer increase of tree growth within two years experimental duration, but it was highly significant within species and year.

Height of tree species ranged from77cm to 300 cm in all of the treatment, with the T3 treatment showing the largest increase, at 13.3% higher than control in 2024. Similarly, the average height for each treatment increased from 127cm to 486 cm1in 2025, with the T3 treatment being the highest, increasing by 20.6% compared to the control treatment (Figure5).

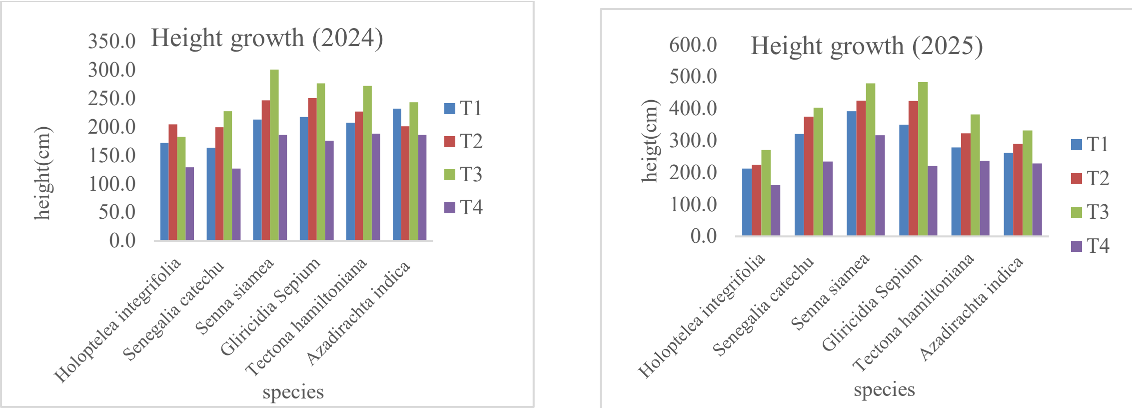


Figure 5. Effect of different treatments on height growth of tree species in 2024yr and 2025yr

The ranking order of tree growth across treatments was T3>T2>T1>T4. The per cent increase in height of Pe cherry -*Gliricidia Sepium*, Mezali-*Senna siamea*, Sha-*Senegalia catechu*, Dahat-*Tectona hamiltoniana*, Phyuat Seit -*Holoptelea integrifolia* ,Tamar-*Azadirachta indica* under gypsum +natural fertilizer treatment over control were 16.5%, 15.3%, 12.9%,11.55%,6.8% and 6.1%.

6. Discussion

6.1 Soil fertility status

Some of the difficulties of establishing forest species in extremely hostile places have been overcome with greater effort in land preparation, with nursery propagation of young trees, and in other silvicultural practices. In these conditions, afforestation is hardly an economic proposition, since timber yield is insufficient to pay off the heavy investment required. Such tree plantings, nevertheless, may fulfill many of the ecosystem services while providing shelterbelts and windbreaks to protect against soil erosion, provide wildlife habitat, and to provide recreational grounds to meet the increasing demands for outdoor recreation. These efforts afford the opportunity to integrate grazing and forestry, while still increasing the carrying capacity of the land. Singh and Garg (2007) claimed that species diversity and productivity significantly increased the soil amelioration process in sodic waste land in Lucknow, India. (Megahed M. Ame et al., 2023)

During plantation trials in the region, the first problem encountered on an ecological basis is that of the species choice. For the plantation establishment, it is a common practice to resort to species known as pioneer or preparatory, i.e. easily established indigenous trees, able to rapidly cover the ground and to prepare it suitably for more demanding species. In this respect, drought tolerant species have been used extensively in afforestation practices, shelterbelts and windbreaks in this study.

The result of the present investigation entitled gypsum and natural fertilizer effects in a semi-arid region of green complex area observed that different applications of gypsum and natural fertilizer reduced soil pH, SAR and EC at study periods.

pH of the initial soil was 9.02 and on reclamation with gypsum and natural fertilizer, the pH significantly reduced up to 7.89. The impact of amendments in decreasing soil pH significantly from the control could be observed at all levels of application. The significant reduction in pH due to the dissolution of CaSO4 2H2O in the submerged condition as there was replacement of Na+ from the soil exchange complex by Ca2+ supplied by the amendments. Similar findings highlighting the reduction of soil pH due to application of conventional gypsum was also reported by Ashenafi Worku Daba,2016.

Addition of organic matter in saline sodic soils would help to chelate Ca2+ and decrease soil pH leading to increase in solubility of CaCO3 (Ghafoor et al., 2008; Zia-ur-Rehman et al., 2016). Wong et al (2009) determined that addition of organic materials increased soil microbial biomass while added gypsum decrease pH. Our results are supported by previous findings that application of gypsum with organic and inorganic amendments decreased the soil salinity and sodicity indicators (Nan et al., 2016; Qadir et al., 2017).

Decrease in EC from the initial value was registered by the application of gypsum and natural fertilizer at all levels. The increased reduction in EC with increasing levels was clearly attributed to the removal of soluble salts during the reclamation process especially ponding and surface leaching. Sharma et al., (1991) and Ilyas et al., (1997) reported a similar change in EC. The reason similar to that of reduction of soil pH could be thought of for the reduction in EC. Moreover, a significant reduction in the sodium absorption ratio (SAR) was observed for all treatments involving their combined applications. This indicates that these treatments effectively mitigated soil sodicity by decreasing the relative proportion of sodium ions in the soil solution, thereby improving soil health and potentially enhancing growth conditions. The increasing application rate of gypsum and compost 3Kg/tree shows a greater effect on saline-alkali soil amelioration.

Proper reclamation practice must ensure that salts are concentrated outside the root zone. Yılmaz (2001) estimated that to leach out 80% or more of soluble salts, the water requirement for application should be at least two times the soil depth. In the current study, two years after treatments, SAR, and EC values were still below the target level (below 10). In our study, 50 cm of water was used to wash the amendments through the soil profile. This amount of water was 40% lower than the quantity Taş and Öztürk (2011) used and 57% lower than that used by Yılmaz (2001).

Soil nutrients play a crucial role in soil fertility and are integral to the overall structure of farmland soil (Wang et al., 2015). In this study, both the desulfurization gypsum and organic material treatments significantly increased organic matter and TN contents in both years compared with the control treatment, which can be attributed to the synergistic effect of desulfurized gypsum and organic material, which stimulated tree canopy growth, increased root biomass and stubble, and reduced trade nitrogen leaching. Application of desulfurized gypsum and natural fertilizer -3Kg/tree can more effectively increase soil nutrients.

The data showed that tree establishment and development enhanced soil content of exchangeable K+. These trends increased significantly with increasing plantation age. These findings suggest that elevated soil nutrient levels can substantially promote plant growth. The increase in soil nutrient contents and the promotion of plant growth after applying gypsum combined with a new soil ameliorant have also been demonstrated in field studies (Liu 2015)

In India, Singh et al. (2012) evaluated the ecological restoration of degraded sodic lands through afforestation in a Typic Halaquept: pH = 9–10.5, EC = 1–4.19 dS m–1, ESP = 45–75%. They concluded that Acacia spp., Albizia spp., Populus spp. and mixed forest growth played important roles in restoring sodic lands. Soil pH, EC, Na and ESP values decreased significantly in both afforestation and long-term cropping systems. (Oktay Yildiz1, et.al,2017).

6.2 The effectiveness of soil amendments on Growth of Tree Species

The data indicated that better height growth of tree species with different compost and gypsum combinations proved effective and efficient for decreasing soil pH, EC and SAR. In the first step, plant height and tillering improved due to reduction of harmful elements through soil amelioration. The uptake of elements such as Na^+ decreased while the concentration of K increased to adjust Na and K ratio favorable for the plant growth. Eventually, the height growth increased significantly in the treatments that proved more effective for soil reclamation. The most effective treatment was the T3. Thus, combination of gypsum and organic amendments was successful to increase height growths over control.

The utilization of desulfurized gypsum and organic materials has been found to enhance soil organic matter, TN and ext. K levels, potentially fostering the growth of tree species. Numerous studies have shown that organic materials can effectively supply plants with significant quantities of accessible nutrients (Wang et al., 2023). Organic materials both reduce water permeability and facilitate the absorption of filtered nutrients.

These results may be due to the significant and effective role of gypsum and organic materials improving the physical and chemical properties of the soil, which led to an increase in the ability of the plant to absorb water and nutrients and thus increased the rate of Metabolism and the chlorophyll and proline contents. (Megahed M.Amer,etal.,2023)

Growth of tree species were influenced remarkably with T3 -3Kg/tree proved more superior over other treatments

A plausible reason for improved tree growth may be that the soil properties are amended by addition of gypsum as it removed excessive Na+ out of the root zone (Muhammad and Khattak, 2011) and accelerated the reclamation process (Abdel-Fattah, 2012) by leaching the soluble salts and decreasing the salinity as well as sodicity.

The ranking order of height of across treatments was Pe cherry -*Gliricidia Sepium*, Mezali-*Senna siamea* > Sha-*Senegalia catechu* > Dahat-*Tectona hamiltoniana* > Phyuat Seit -*Holoptelea integrifolia* >Tamar-*Azadirachta indica*.

the growth performance of tree species suggests that these species should be good candidates to consider using in afforestation projects to reclaim these degraded arid lands.

7. **Conclusion and Recommendation**

This study investigated the impact of gypsum and natural fertilizer as soil amendments on enhancing saline-alkali soil quality. Long-term experimental data from 2024 to 2025 revealed that the combined application of gypsum and natural fertilizer effectively lowered soil pH and sodium absorption ratio and EC, whereas increasing organic matter, Total N and Ext. K contents in saline-alkali soil. The increasing application rate of gypsum and natural fertilizer 3Kg/tree was found to be the most effective strategy. By employing gypsum and natural fertilizer, soil salinity issues can be addressed while simultaneously significantly increasing soil nutrients, improving soil quality, and enhancing height growth of tree species.

This study suggests that natural fertilizer can be used as an effective and eco-friendly soil amendment for saline-alkali soil improvement, and its combination with gypsum provides superior effects on saline-alkali soil improvement and tree growth. Hopefully, the results from this study will be utilized for future follow-up studies in the region, will contribute to the interpretation of long-term study results, and also contribute to potential beneficial silvicultural applications.

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Appendix1

ANOVA for pH

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	20.013[a]	11	1.819	193.160	.000	2124.764	1.000
Intercept	7955.205	1	7955.205	8.446E5	.000	844613.678	1.000
year	10.106	2	5.053	536.459	.000	1072.918	1.000
treatment	5.803	3	1.934	205.362	.000	616.086	1.000
year * treatment	4.104	6	.684	72.627	.000	435.760	1.000
Error	.904	96	.009				
Total	7976.122	108					
Corrected Total	20.917	107					

Multiple Comparisons for treatments in soil pH

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	T1	T2	.0522	.02641	.051	-.0002	.1047
		T3	.2956*	.02641	.000	.2431	.3480
		T4	-.3533*	.02641	.000	-.4058	-.3009
	T2	T1	-.0522	.02641	.051	-.1047	.0002
		T3	.2433*	.02641	.000	.1909	.2958
		T4	-.4056*	.02641	.000	-.4580	-.3531
	T3	T1	-.2956*	.02641	.000	-.3480	-.2431
		T2	-.2433*	.02641	.000	-.2958	-.1909
		T4	-.6489*	.02641	.000	-.7013	-.5965
	T4	T1	.3533*	.02641	.000	.3009	.4058
		T2	.4056*	.02641	.000	.3531	.4580
		T3	.6489*	.02641	.000	.5965	.7013

Appendix1-a

ANOVA for SAR

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	3.363[a]	11	.306	42.204	.000	464.240	1.000
Intercept	684.080	1	684.080	9.443E4	.000	94434.302	1.000
year	2.023	2	1.011	139.621	.000	279.242	1.000
treatment	.768	3	.256	35.340	.000	106.021	1.000
year * treatment	.572	6	.095	13.163	.000	78.976	1.000
Error	.695	96	.007				
Total	688.139	108					
Corrected Total	4.058	107					

Multiple Comparisons for treatments in SAR

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	T1	T2	.0956*	.02316	.000	.0496	.1415
		T3	.1359*	.02316	.000	.0899	.1819
		T4	-.0807*	.02316	.001	-.1267	-.0348
	T2	T1	-.0956*	.02316	.000	-.1415	-.0496
		T3	.0404	.02316	.085	-.0056	.0864
		T4	-.1763*	.02316	.000	-.2223	-.1303
	T3	T1	-.1359*	.02316	.000	-.1819	-.0899
		T2	-.0404	.02316	.085	-.0864	.0056
		T4	-.2167*	.02316	.000	-.2626	-.1707
	T4	T1	.0807*	.02316	.001	.0348	.1267
		T2	.1763*	.02316	.000	.1303	.2223
		T3	.2167*	.02316	.000	.1707	.2626

Appendix1-c

ANOVA for EC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.487[a]	11	.681	38.479	.000
Intercept	86.939	1	86.939	4.915E3	.000
year	4.613	2	2.306	130.391	.000
treatment	1.729	3	.576	32.591	.000
year * treatment	1.145	6	.191	10.786	.000
Error	1.698	96	.018		
Total	96.124	108			
Corrected Total	9.185	107			

Multiple Comparisons for treatments in EC value

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
\LSD	T1	T2	.1614*	.03620	.000	.0895	.2332
		T3	.2224*	.03620	.000	.1506	.2943
		T4	-.0961*	.03620	.009	-.1679	-.0242
	T2	T1	-.1614*	.03620	.000	-.2332	-.0895
		T3	.0611	.03620	.095	-.0108	.1329
		T4	-.2574*	.03620	.000	-.3293	-.1856
	T3	T1	-.2224*	.03620	.000	-.2943	-.1506
		T2	-.0611	.03620	.095	-.1329	.0108
		T4	-.3185*	.03620	.000	-.3904	-.2467
	T4	T4	T1	.03620	.009	.0242	
		T2	.2574*	.03620	.000	.1856	.3293
		T3	.3185*	.03620	.000	.2467	.3904

Appendix1-d

ANOVA for OM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	176.667[a]	11	16.061	256.970	.000	2826.667	1.000
Intercept	1281.333	1	1281.333	2.050E4	.000	20501.333	1.000
year	92.167	2	46.083	737.333	.000	1474.667	1.000
treatment	68.667	3	22.889	366.222	.000	1098.667	1.000
year * treatment	15.833	6	2.639	42.222	.000	253.333	1.000
Error	6.000	96	.062				
Total	1464.000	108					
Corrected Total	182.667	107					

Multiple Comparisons for treatments in OM

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	T1	T2	-.7778*	.06804	.000	-.9128	-.6427
		T3	-1.5556*	.06804	.000	-1.6906	-1.4205
		T4	.5556*	.06804	.000	.4205	.6906
	T2	T1	.7778*	.06804	.000	.6427	.9128
		T3	-.7778*	.06804	.000	-.9128	-.6427
		T4	1.3333*	.06804	.000	1.1983	1.4684
	T3	T1	1.5556*	.06804	.000	1.4205	1.6906
		T2	.7778*	.06804	.000	.6427	.9128
		T4	2.1111*	.06804	.000	1.9761	2.2462
	T4	T1	-.5556*	.06804	.000	-.6906	-.4205
		T2	-1.3333*	.06804	.000	-1.4684	-1.1983
		T3	-2.1111*	.06804	.000	-2.2462	-1.9761

Appendix1-e

ANOVA of TN

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	8.828E-6[a]	11	8.025E-7	43.336	.000	476.695	1.000
Intercept	.000	1	.000	9.758E3	.000	9758.045	1.000
year	3.969E-6	2	1.985E-6	107.165	.000	214.330	1.000
treatment	3.566E-6	3	1.189E-6	64.192	.000	192.575	1.000
year * treatment	1.292E-6	6	2.154E-7	11.632	.000	69.790	1.000
Error	1.778E-6	96	1.852E-8				
Total	.000	108					
Corrected Total	1.061E-5	107					

Multiple Comparisons for treatments in TN

						95% Confidence Interval	
	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
LSD	T1	T2	-.0062311*	.00103803	.000	-.0082916	-.0041706
		T3	-.0159200*	.00103803	.000	-.0179805	-.0138595
		T4	.0063244*	.00103803	.000	.0042640	.0083849
	T2	T1	.0062311*	.00103803	.000	.0041706	.0082916
		T3	-.0096889*	.00103803	.000	-.0117494	-.0076284
		T4	.0125556*	.00103803	.000	.0104951	.0146160
	T3	T1	.0159200*	.00103803	.000	.0138595	.0179805
		T2	.0096889*	.00103803	.000	.0076284	.0117494
		T4	.0222444*	.00103803	.000	.0201840	.0243049
	T4	T1	-.0063244*	.00103803	.000	-.0083849	-.0042640
		T2	-.0125556*	.00103803	.000	-.0146160	-.0104951
		T3	-.0222444*	.00103803	.000	-.0243049	-.0201840

Appendix1-h

ANOVA of ext.K

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	.023[a]	11	.002	146.015	.000	1606.168	1.000
Intercept	.053	1	.053	3.657E3	.000	3656.561	1.000
year	.013	2	.006	432.709	.000	865.419	1.000
treatment	.007	3	.002	166.837	.000	500.510	1.000
year * treatment	.003	6	.001	40.040	.000	240.239	1.000
Error	.001	96	1.455E-5				
Total	.078	108					
Corrected Total	.025	107					

Multiple Comparisons for treatments in ext.K

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	T1	T2	-.000170*	.0000370	.000	-.000244	-.000097
		T3	-.000404*	.0000370	.000	-.000477	-.000330
		T4	.000067	.0000370	.075	-.000007	.000140
	T2	T1	.000170*	.0000370	.000	.000097	.000244
		T3	-.000233*	.0000370	.000	-.000307	-.000160
		T4	.000237*	.0000370	.000	.000164	.000311
	T3	T1	.000404*	.0000370	.000	.000330	.000477
		T2	.000233*	.0000370	.000	.000160	.000307
		T4	.000470*	.0000370	.000	.000397	.000544
	T4	T1	-.000067	.0000370	.075	-.000140	.000007
		T2	-.000237*	.0000370	.000	-.000311	-.000164
		T3	-.000470*	.0000370	.000	-.000544	-.000397

Appendix II-a

ANOVA for *Gliricidia Sepium*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	1.593E6[a]	11	144834.076	363.210	.000	.977	3995.308	1.000
Intercept	6119383.785	1	6119383.785	1.535E4	.000	.994	15345.976	1.000
treatment	299852.734	3	99950.911	250.653	.000	.887	751.960	1.000
year	1177393.564	2	588696.782	1.476E3	.000	.969	2952.626	1.000
treatment * year	115928.542	6	19321.424	48.454	.000	.752	290.722	1.000
Error	38281.099	96	398.761					
Total	7750839.724	108						
Corrected Total	1631455.939	107						

Multiple Comparisons of the average height of *Gliricidia Sepium*

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	T1	T2	-40.41422*	5.434877	.000	-51.20237	-29.62608
		T3	-75.89896*	5.434877	.000	-86.68711	-65.11082
		T4	65.92711*	5.434877	.000	55.13897	76.71526
	T2	T1	40.41422*	5.434877	.000	29.62608	51.20237
		T3	-35.48474*	5.434877	.000	-46.27289	-24.69660
		T4	106.34133*	5.434877	.000	95.55319	117.12948
	T3	T1	75.89896*	5.434877	.000	65.11082	86.68711
		T2	35.48474*	5.434877	.000	24.69660	46.27289
		T4	141.82607*	5.434877	.000	131.03793	152.61422
	T4	T1	-65.92711*	5.434877	.000	-76.71526	-55.13897
		T2	-106.34133*	5.434877	.000	-117.12948	-95.55319
		T3	-141.82607*	5.434877	.000	-152.61422	-131.03793

Appendix II-b

ANOVA for *Senegalia catechu*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	1.246E6[a]	11	113299.968	1.648E3	.000	18127.258	1.000
Intercept	4484725.683	1	4484725.683	6.523E4	.000	65229.722	1.000
treatment	183263.455	3	61087.818	888.514	.000	2665.542	1.000
year	1027757.863	2	513878.932	7.474E3	.000	14948.598	1.000
treatment * year	35278.329	6	5879.721	85.520	.000	513.118	1.000
Error	6600.268	96	68.753				
Total	5737625.599	108					
Corrected Total	1252899.916	107					

Multiple Comparisons of the average height of *Senegalia catechu*

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	T1	T2	-35.22133*	2.256723	.000	-39.70089	-30.74177
		T3	-62.29600*	2.256723	.000	-66.77556	-57.81644
		T4	47.79431*	2.256723	.000	43.31475	52.27387
	T2	T1	35.22133*	2.256723	.000	30.74177	39.70089
		T3	-27.07467*	2.256723	.000	-31.55423	-22.59511
		T4	83.01564*	2.256723	.000	78.53608	87.49520
	T3	T1	62.29600*	2.256723	.000	57.81644	66.77556
		T2	27.07467*	2.256723	.000	22.59511	31.55423
		T4	110.09031*	2.256723	.000	105.61075	114.56987
	T4	T1	-47.79431*	2.256723	.000	-52.27387	-43.31475
		T2	-83.01564*	2.256723	.000	-87.49520	-78.53608
		T3	-110.09031*	2.256723	.000	-114.56987	-105.61075

Appendix II-c

ANOVA for *Senna siamea*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	1.758E6[a]	11	159783.772	2.541E3	.000	.997	27945.722	1.000
Intercept	6803577.898	1	6803577.898	1.082E5	.000	.999	108175.110	1.000
treatment	205459.846	3	68486.615	1.089E3	.000	.971	3266.758	1.000
year	1534532.550	2	767266.275	1.220E4	.000	.996	24398.666	1.000
treatment * year	17629.095	6	2938.183	46.716	.000	.745	280.298	1.000
Error	6037.835	96	62.894					
Total	8567237.224	108						
Corrected Total	1763659.326	107						

Multiple Comparisons of the average height of *Senna siamea*

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	T1	T2	-27.58489*	2.158431	.000	-31.86934	-23.30044
		T3	-75.29689*	2.158431	.000	-79.58134	-71.01244
		T4	44.92978*	2.158431	.000	40.64533	49.21423
	T2	T1	27.58489*	2.158431	.000	23.30044	31.86934
		T3	-47.71200*	2.158431	.000	-51.99645	-43.42755
		T4	72.51467*	2.158431	.000	68.23022	76.79912
	T3	T1	75.29689*	2.158431	.000	71.01244	79.58134
		T2	47.71200*	2.158431	.000	43.42755	51.99645
		T4	120.22667*	2.158431	.000	115.94222	124.51112
	T4	T1	-44.92978*	2.158431	.000	-49.21423	-40.64533
		T2	-72.51467*	2.158431	.000	-76.79912	-68.23022
		T3	-120.22667*	2.158431	.000	-124.51112	-115.94222

Appendix II-d

ANOVA for *Tectona hamiltoniana*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	1.319E6[a]	11	119943.055	267.477	.000	2942.248	1.000
Intercept	4588396.426	1	4588396.426	1.023E4	.000	10232.280	1.000
treatment	264842.062	3	88280.687	196.869	.000	590.607	1.000
year	925639.821	2	462819.910	1.032E3	.000	2064.208	1.000
treatment * year	128891.725	6	21481.954	47.905	.000	287.433	1.000
Error	43048.670	96	448.424				
Total	5950818.704	108					
Corrected Total	1362422.278	107					

a. R Squared = .968 (Adjusted R Squared = .965)

b. Computed using alpha = .05

Multiple Comparisons of the average height of *Tectona hamiltoniana*

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	T1	T2	-29.31556*	4.275204	.000	-37.80177	-20.82934
		T3	-71.44711*	4.275204	.000	-79.93332	-62.96090
		T4	28.86865*	4.275204	.000	20.38244	37.35486
	T2	T1	29.31556*	4.275204	.000	20.82934	37.80177
		T3	-42.13156*	4.275204	.000	-50.61777	-33.64534
		T4	58.18421*	4.275204	.000	49.69800	66.67042
	T3	T1	71.44711*	4.275204	.000	62.96090	79.93332
		T2	42.13156*	4.275204	.000	33.64534	50.61777
		T4	100.31576*	4.275204	.000	91.82955	108.80197
	T4	T1	-28.86865*	4.275204	.000	-37.35486	-20.38244
		T2	-58.18421*	4.275204	.000	-66.67042	-49.69800
		T3	-100.31576*	4.275204	.000	-108.80197	-91.82955

Appendix II-e

ANOVA for *Azadirachta indica*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	1.046E6[a]	11	95075.992	518.238	.000	5700.622	1.000
Intercept	3312780.386	1	3312780.386	1.806E4	.000	18057.238	1.000
treatment	291044.057	3	97014.686	528.806	.000	1586.417	1.000
year	632192.852	2	316096.426	1.723E3	.000	3445.944	1.000
treatment * year	122599.002	6	20433.167	111.377	.000	668.260	1.000
Error	17612.157	96	183.460				
Total	4376228.455	108					
Corrected Total	1063448.069	107					

Multiple Comparisons of the average height of *Azadirachta indica*

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	T1	T2	-27.85215*	5.763382	.000	-39.29237	-16.41193
		T3	-97.86904*	5.763382	.000	-109.30926	-86.42882
		T4	37.45271*	5.763382	.000	26.01249	48.89293
	T2	T1	27.85215*	5.763382	.000	16.41193	39.29237
		T3	-70.01689*	5.763382	.000	-81.45711	-58.57667
		T4	65.30486*	5.763382	.000	53.86464	76.74508
	T3	T1	97.86904*	5.763382	.000	86.42882	109.30926
		T2	70.01689*	5.763382	.000	58.57667	81.45711
		T4	135.32175*	5.763382	.000	123.88153	146.76197
	T4	T1	-37.45271*	5.763382	.000	-48.89293	-26.01249
		T2	-65.30486*	5.763382	.000	-76.74508	-53.86464
		T3	-135.32175*	5.763382	.000	-146.76197	-123.88153

Appendix II-f

ANOVA for *Holoptelea integrifolia*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	1.046E6[a]	11	95075.992	518.238	.000	5700.622	1.000
Intercept	3312780.386	1	3312780.386	1.806E4	.000	18057.238	1.000
treatment	291044.057	3	97014.686	528.806	.000	1586.417	1.000
year	632192.852	2	316096.426	1.723E3	.000	3445.944	1.000
treatment * year	122599.002	6	20433.167	111.377	.000	668.260	1.000
Error	17612.157	96	183.460				
Total	4376228.455	108					
Corrected Total	1063448.069	107					

Multiple Comparisons of *Holoptelea integrifolia*

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
LSD	T1	T2	-41.84293*	3.686411	.000	-49.16040	-34.52546
		T3	-112.22427*	3.686411	.000	-119.54174	-104.90680
		T4	24.77159*	3.686411	.000	17.45412	32.08905
	T2	T1	41.84293*	3.686411	.000	34.52546	49.16040
		T3	-70.38133*	3.686411	.000	-77.69880	-63.06386
		T4	66.61452*	3.686411	.000	59.29705	73.93199
	T3	T1	112.22427*	3.686411	.000	104.90680	119.54174
		T2	70.38133*	3.686411	.000	63.06386	77.69880
		T4	136.99585*	3.686411	.000	129.67838	144.31332
	T4	T1	-24.77159*	3.686411	.000	-32.08905	-17.45412
		T2	-66.61452*	3.686411	.000	-73.93199	-59.29705
		T3	-136.99585*	3.686411	.000	-144.31332	-129.67838