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Influence of Charcoal, Manure and Fertilizer Soil Amendment on Growth of *Grevillea robusta* Nursery Seedlings

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil amendment is vital especially in tree nurseries that are located away from the forest areas. Grevillea robusta seedlings are high nutrient demanders. An experiment was set up for a period of 8 months in 2021 at Egerton University, Njoro, Kenya to determine the effect of soil amendment on the early growth of Grevillea nursery seedlings. The experimental design was a CRD with 12 treatments replicated 3 times. The soil amendments included; manure, charcoal and artificial fertilizer combined with agricultural soil as well as their other combinations while forest soil was used as a check. The pot size was 9 by 12 cm in width and length respectively. Routine weeding and watering was done during the experimental period. The data was analyzed using SAS statistical package and the significance differences between means were separated using LSD at $P \leq 0.05$. The results showed that forest soil and agricultural soil gave significantly ($P \leq 0.05$) the

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highest survival (84 and 81%) respectively compared with charcoal + manure + fertilizer combination (37%) which was the least. On the other hand, Forest soil had significantly ($P \leq 0.05$) the highest height (14.6cm) compared to all the other variables. Similarly, forest soil showed the highest root collar diameter (4.5 mm) which was significantly different from all the other variables measured except agricultural soil alone, agricultural soil + manure + fertilizer and agricultural soil + charcoal + manure which were similar. On the other hand, charcoal alone showed the highest root: shoot ratio (3.2), as well as root biomass which were significantly ($P \leq 0.05$) higher compared with agricultural soil + manure and charcoal + fertilizer. In conclusion, forest soil was superior in supporting the growth of both shoot, foliage and root collar diameter of grevillea seedlings. On the other hand, charcoal showed higher root to shoot ratio as well as root biomass. Forest soil is therefore recommended to be used in raising Grevillea nursery seedlings in areas nearby the forest. However, for areas located far away from the forest, a mixture of agricultural soil + manure + fertilizer or charcoal is recommended. Further research is recommended on using the same soil mixtures on other tree species which are less demanding in nutrient uptake.

Keywords: Grevillea; nursery seedlings; soil amendments; growth.

1. INTRODUCTION

Seedling production nurseries are vital in meeting the increasing demand for *Grevillea robusta* seedlings in agroforestry systems in farmlands. Earlier works by Jemmimah [1,2] showed that over 50% of smallholder seedlings planted were from tree nurseries in close proximity to the farmlands. Previous studies showed that large scale nurseries have an edge over many smallholder nurseries in terms of seedlings performance based on quality seed [3]. However, smallholder tree farmers have been documented in several studies to face challenges in availability of quality planting materials which in turn, affect the quality of the tree seedlings established [4,5]. Kenya Forestry Research Institute has the mandate to supply high quality tree seed in Kenya and beyond [6].

Choosing the right growing media is critical in early seedlings performance. However, several studies have shown that several materials can be used as a growing media, but the final choice is based on the ability of the media to sustain plant growth [7]. On the other hand, more recent studies by [8,9] documented that majority of the smallholder farmers lack adequate knowledge on the effects of various soil mixture composition on the seedling growth performance.

Growing nursery media is of major concern to agroforesters since this is where most variation in seedling performance occurs [10,11]. The variations in nursery growing media emerge from the different soil types and their amendments [12,13]. The influence of the growing media on the performance of commercial tree species is an important factor since it forms the basis of adjustments to tree nursery practices depending on the demands of the species raised [14,15].

On the other hand, organic matter content of soil, which is a very important component, influence the physical condition, water holding capacity and the temperature of the soil, especially the soil bacteria processes, which in turn affect the availability of nutrients for plant growth [16]. It further reduces adverse effect of excessive alkalinity, acidity and over-fertilization [17]. The cation exchange capacity (CEC) of the soil is increased, enabling the soil to hold more plant nutrient for a longer period. The organic matter produces organic acid which reduce the amount of aluminum ions, further decreasing their ability to fix the phosphates, hence making P available for root development [18]. Recent studies documented by several authors [19,20,21,22] showed that synthetic fertilizer combined with manure and also lime especially in acidic soils, increases soil fertility and crop yields compared with sole chemical fertilizer.

Manure possesses enormous potentials which eventually lead to enhancement of soil fertility for luxuriant plant growth. Enhancement of soil fertility is the key to the production of high quality seedlings required for plantation establishment [23].

Similarly, charcoal waste has been used in soil amendment and earlier work by Siregar [24] stated that charcoal can improve the physical, chemical and nutritional nature of the soil inducing better plant growth and development. Charcoal has very low N, but high P and K. Soil nutrient status is one important growth factor that affects assimilation ability, which is a vital determinant for growth and survival of seedlings. In addition to assimilation, respiration is a critical determinant of net carbon gain in seedlings [24].

Woody plants growing on Alfisols and Ultisols under kiln charcoal were reported to have better seed germination (30 % increase), shoot heights (24 %), and biomass production (13 %) [25]. Related studies working with sugi trees (*Cryptomeria japonica*) on clay loam soils, and five years of charcoal application at the rate of 0.5 Mg ha^{-1} , reported the heights of sugi trees increased by a factor of 1.26– 1.35 while the biomass production increased by a factor of 2.31–2.36 [26]. Other works by Ishii and Kadoya [27] also reported that the fresh weight of the root, shoot and the whole tree, one year after replanting, increased in response to charcoal application at the rate of 2 % (w/w). However, root dry weight was not significantly affected by the charcoal application. The probable reason for the lack of root growth response to this charcoal addition was due to the sufficient soil fertility level.

Charcoal application significantly influenced soil pH, C organic, N, P, K, C/N, exchangeable bases, CEC, BS, Al, and H, hence improving the fertility of highly weathered tropical soils [24,28]. Charcoal application also led to the reduction in acidic cations and the increased in basic cations, and in turn, resulted in an increase in soil pH [29]. This further increased the exchangeable bases (Ca, Mg, K, and Na). Consequently, the base saturation also increased and becoming three to four fold higher after charcoal application.

Charcoal addition to soil at the rate up to 20 % also increased organic C and total N. The trend of organic C and total N increased as the rate of charcoal application increased [30]. Equally, potential P considerably increased as charcoal was added to the soils at the rate of 10 %. These data are apparent since charcoal contains some amounts of elemental C, N, P, and others [24].

Limited studies have previously focused on growing medium for Grevillea tree species and its early growth performance whose smallholder farmers' preference was observed to be high in agroforestry systems within the Kenyan highlands [31,32]. On the other hand, recent studies by Kipkemboi, et al. [33,34] showed that higher concentration was done on large scale nurseries with less attention on smallholder tree nurseries, which are the majority and also the growing media variation.

This present study sought to analyze the effect of different soil amendments on early growth performance of *Grevillea robusta* nursery seedlings. The specific objectives were i) to determine the effect of varying soil amendments on survival, height and foliage growth ii) to determine the effects varying soil amendments on root growth. This will provide the best soil amendment that can be recommended for raising *Grevillea* seedlings in the nursery especially in the farmlands, since it is a heavy nutrient demander.

2. MATERIALS AND METHODS

2.1 Study Site Description

The study was conducted at Agroforestry tree nursery, Egerton University, Njoro, Kenya, within the eastern Mau water-catchment. The study site lies on a latitude 0°22'11.0"S, Longitude 35°55'58.0"E and an altitude of 2,238 m. The area falls in agro ecological zone Lower Highland 3. The experimental site receives mean annual rainfall of 1200 mm while the distribution of rain is bimodal with long rains between April and August and short rains between October and December. The temperatures lie between 10.2 and 22.0°C [35] while the soils are mollic andosols [36] with relatively high levels of phosphorus.

2.2 Experimental Design

The experiment was laid down in a complete randomized design (CRD) with 12 treatments replicated 3 times giving a total of 36 experimental units. Each unit consisted of 10 seedlings raised in polythene pots of 9 by 12 cm in width and length respectively. The treatments were as follows; Forest soil, agricultural soil, manure, charcoal, artificial fertilizer and other amendment combinations. The experiment was set up for a period of 8 months from October 2020 to May 2021 at Egerton University, Njoro, Kenya. Forest soil was used as a check since it is preferred in raising tree seedlings in forest nurseries [37]. Forest was collected from the indigenous forest near the nursery site while the agricultural soil was also attained within the cultivated area at 30 cm depth. Routine weeding and watering was done during the growth period. The soil combinations were in the ratio 2: 1 for agricultural soil + manure and agricultural soil + charcoal. However, other combinations of charcoal + manure were in the ratio 1:1. On the other hand, artificial fertilizer in form of

Table 1. Nutrient composition of the soil amendments used

Nutrient content	Manure	Agricultural soil	Forest soil
Nitrogen %	1.86	0.93	1.05
Phosphorus %	0.25	0.21	0.15
Potassium %	1.29	0.96	0.89
Calcium %	1.62	2.02	1.42
Magnesium %	0.4	0.56	0.25
Iron mg/kg	807	1285	1085
Copper mg/kg	8.33	15	15
Manganese mg/kg	41.7	40	25
Zinc mg/kg	21.7	13.3	16.7

Source: [37]

Table 2. Some important chemical properties of charcoal

Chemical properties	Values
pH (H_2O)	8
C – Organic, %	55
N – Kjeldahl, %	0.1
C/N ratio	131
P – available (Bray, P_2O_5), ppm	69
K – available (Morgan, K_2O), ppm	133
Ca (1 N NH4Oac, pH 7.0 extraction), me/100 g	28
Mg (1 N NH4Oac, pH 7.0 extraction), me/ 100 g	8
Na (1 N NH4Oac, pH 7.0 extraction), me/100 g	2
Total (1 N NH4Oac, pH 7.0 extraction), me/100 g	55
CEC (1 N NH4Oac, pH 7.0 extraction), me/100 g	19

Source: [24]

Diammonium phosphate (DAP) combinations were applied in small quantities of 10g per pot.

The nutrient composition of soils and manure (Table 1) and chemical composition of charcoal (Table 2) are indicated.

2.3 Data Analysis

Analysis of variance (ANOVA) model was used to test differences of treatment means using SAS statistical package [38] while the significantly different means were separated by using Least Significance Difference (LSD) at $p \leq 0.05$ [39].

3. RESULTS AND DISCUSSION

3.1 Effect of Soil Amendment on Survival, Shoot and Foliage Growth of Grevillea Nursery Seedlings

Forest soil and agricultural soil gave significantly ($P \leq 0.05$) the highest survival (84 and 81%) respectively compared with charcoal (55%), agricultural soil + fertilizer (40%), agricultural soil + charcoal + fertilizer (51%) as well as charcoal + manure + fertilizer (37%) which was the lowest as shown in Table 3.

The current results corroborate with recent work by Owino, et al. [37] which showed that forest soil gave highest survival as well as height in both Grevillea and cypress nursery seedlings. Other recent works by Owino, et al. [37] stated that Grevillea survival in the field was 57% under high rainfall conditions.

Fertilizer mixtures gave relatively low survival and this could have been due to the high amounts applied (10g per pot) which led to scorching effect on the young seedlings. This can be further explained by low osmotic pressure brought up by the higher concentration of salts outside the root cell membrane, such that water will not move across the membrane [40]. Instead water may even leave the root system in an attempt to equalize the concentration of salts in the soil. When there is a low osmotic pressure, the fertilizer is working incorrectly and the plant may experience a fertilizer burn.

Table 3. Effect of soil amendments on survival, shoot and foliage growth of *Grevillea robusta* nursery seedlings

Treatment	Survival %	Height (cm)	No. of leaves	Leaf Length (cm)	Shoot Biomass (g)	Total Plant biomass (g)
1.For soil	84a	14.6a	13bcd	10.3a	3.6a	7.033a
2.Agric soil	81a	11.4b	12d	6.9b	1.8bcd	4.100bc
3.Char	55bc	8.7d	12cd	5.0cd	1.2cd	5.167bc
4.Agric soil+ Man	62ab	11.0bc	15ab	6.5bc	1.8bcd	3.867bc
5.Agric soil+ Fert	40bc	10.0bcd	13bcd	5.9bcd	2.0bc	5.233abc
6. Agric soil+ Man+Fert	40bc	11.7b	12d	5.9bcd	2.1b	5.200bc
7.Agric soil+Char	62ab	10.2bcd	12d	6.3bcd	2.0bc	4.933bc
8.Agric soil+ char+man	62ab	12.2b	16a	6.5bc	2.2b	4.800bc
9. Agric soil+ char+fert	51bc	11.8b	16a	6.4bcd	2.2b	5.467ab
10.Char+Fert	62ab	8.9cd	13bcd	4.3bcd	1.6bcd	3.633c
11.Char+Man	62ab	8.8cd	14abc	3.8d	1.1d	4.133bc
12.Char+ man+Fert	37c	10.0bcd	16a	5.2bcd	1.8bcd	4.633bc
P≤0.05	0.05	0.05	0.05	0.05	0.05	0.05
LSD	22.1	2.3	2.0	2.6	0.8	1.8
% CV	22.4	12.7	8.7	25.9	24.9	22.0

Note: Values within a column followed by same letter (s) are not significant at p ≤ 0.05. Key: For soil= forest soil, Agric soil =Agricultural soil, Char: Charcoal, Man= Manure and Fert= Fertilizer

On the other hand, Forest soil had significantly (P ≤ 0.05) the highest height (14.6 cm) compared to all the other variables. These findings corroborates with recent studies by Owino, et al. [37,41] working on ideal soil mixtures for Grevillea and Cypress seedlings. Similarly, the lowest height was showed by charcoal (8.7cm), which was significantly different from all the other variables except most of the charcoal combinations. The current findings disagrees with earlier work by Kishimoto and Sugiura [26] who reported that charcoal increased height and biomass of trees

The highest number of leaves were showed by; agricultural soil + charcoal + manure (16), agricultural soil + charcoal + fertilizer (16), and charcoal + manure + fertilizer (16) which were significantly (P ≤ 0.05) different from all the other variables except agricultural soil + manure and charcoal + manure. Forest soil showed the highest leaf length (10.3cm) and shoot biomass (7.3g), which were significantly higher compared with all the other variables. However, the only exception was in total plant biomass where only agricultural soil + fertilizer (5.2g) showed similar trend compared with forest soil. Earlier studies by Owino, et al. [37,41] are also in tandem with the current studies which showed that forest soil increased total plant biomass of seedlings.

The current results are contradictory to earlier work by Siregar [24] that stated that the best charcoal amount is (10 – 20) % in mixture for better height, stem diameter, leaf and shoot biomass in tree seedlings. He further stated that higher amounts of charcoal have little effect on growth and this therefore agrees with the current study. Earlier works by Kishimoto and Sugiura [26,42] affirms that charcoal application at high rate may produce detrimental effects on crop growth. More recent work by Siregar [43] stated that excess charcoal in the soil adsorbs nutrients leading to stunted plant growth and this corroborates with the current studies, since relatively high levels of charcoal were used.

3.2 Effect of Soil Amendment on the Root Growth of *Grevillea robusta* Nursery Seedlings

Results showed that forest soil gave the highest root collar diameter (4.5 mm) which was significantly (P ≤ 0.05) different from all the other variables measured except agricultural soil alone, agricultural + manure + fertilizer and agricultural soil + charcoal + manure which were similar as indicated in Table 4. Forest soil has more balanced levels of NPK, and therefore able to support adequate growth of seedlings. These findings corroborates with other studies by Owino, et al. [37,41].

Table 4. Effect of soil amendments on root growth of *Grevillea robusta* nursery seedlings

Treatment	Root collar diameter (mm)	Root length (cm)	Root biomass (g)	Root to shoot ratio
1.For soil	4.5a	19.7	3.4ab	1.0c
2.Agric soil	4.1ab	18.3	2.3ab	1.3c
3.Char	2.6de	19.7	3.9a	3.2a
4.Agric soil+ Man	3.3bcd	19.2	2.1b	1.2c
5.Agric soil+ Fert	3.2bcd	16.8	3.2ab	1.8bc
6.Agric soil+Man+Fert	3.8ab	21.0	3.1ab	1.5c
7.Agric soil+Char	3.5bc	20.3	2.9ab	1.5c
8.Agric soil +char+man	3.9ab	20.3	2.6ab	1.2c
9.Agric soil+char+fert	3.4bcd	19.9	3.3ab	1.5c
10.Char+Fert	2.7cde	18.8	2.1b	1.4c
11.Char+Man	2.3e	21.6	3.0ab	3.0ab
12.Char+man+Fert	2.8cde	17.8	2.9ab	1.6c
$P \leq 0.05$	0.05	NS	0.05	0.05
LSD	0.9	4.9	1.7	1.3
% CV	16.4	15.0	34.9	44.0

Note: Values within a column followed by same letter (s) are not significant at $p \leq 0.05$. Key: For soil= forest soil, Agric soil =Agricultural soil, Char= Charcoal, Man= Manure and Fert= Fertilizer

Recent studies by Inoti and Ocholla [41] recommended that tree nurseries located far from forests can use a potting soil mixture of agricultural soil + manure in raising Grevillea seedlings since this gives similar growth performance with forest soil. The current study also agrees with these studies since manure mixtures were superior in supporting root growth.

On the other hand, charcoal alone showed the highest root: shoot ratio (3.2), which was significantly higher compared with agricultural soil + manure (2.1g) and charcoal + fertilizer (2.1g). This could be explained by the porous nature and high levels of P contained in the charcoal media as earlier reported by Siregar [24]. High P level favors the growth of root biomass, which in absence of N cannot increase vegetative plant growth. Earlier studies by Ishii and Kadoya [27] agrees with the current studies which showed that charcoal alone increased the fresh weight root biomass. Charcoal also ameliorates the soil through increasing P^H towards neutral, hence boosting the CEC of the soil [30,44].

According to the recent work reported by Owino, et al. [37], agricultural soil should be sourced from the well managed farms which are not exhausted through continuous cropping and subsequent nutrient mining, and probably from fallow land.

4. CONCLUSION AND RECOMMENDATIONS

Forest soil was superior in supporting the growth of both shoot, foliage and also root collar diameter of grevillea seedlings while, the least growth was shown by charcoal alone and also other charcoal combinations. On the other hand, charcoal is quite porous and might have allowed excessive nutrient leach ing from the media compromising overall seedling growth. Charcoal alone also resulted in higher root to shoot ratio and also root biomass. Forest soil has adequate nutrients and is therefore recommended for use in raising Grevillea seedlings since they are high nutrient demanders. However, further research is recommended on using the same soil mixtures on other tree species which are less demanding in nutrient uptake and also adding other mixtures with higher nitrogen levels. The best combination ratio of charcoal and manure needs to be investigated further especially for farmers located far away from the forest.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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