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Effect of Mulching and/or Watering on Soil Moisture for Growth and Survival of the Transplanted Tree Seedlings in Dry Period

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Abstract

Dry mulch, as soil moisture conservation techniques, is seldom practiced for growth and survival of transplanted tree seedlings in dry period in Eritrea. Field experiment was conducted at Halhale, Eritrea with Dry *Hyparrhenia rufa*, as a mulch, on a flat basin for growth and survival of seedlings of *Grevillea robusta* and *Acacia polyacantha subspecies Campylacantha* by involving four management practices: 1) mulching and watering basins (MW); 2) no-mulching but watering basins (NMW); 3) mulching but no-watering basins (MNW); 4) no-mulching and no-watering basins (NMNW). The experimental design was CRD with three replications. MW and NMW were watered 180 litters (20 litters/month) but MNW and NMNW were not watered at all. Parameters such as soil moisture content of the basin, early growth performance of seedling and survival rate of the seedlings were studied. The result indicated that there were statistically significant differences ($p < 0.05$) among the treatment for soil moisture content and early growth performance of the seedlings. The average volumetric water content (VWC%) on 0 - 20 cm soil depth at the end of dry period of MW, NMW, MNW, and NMNW were 10.08%, 7.7%, 6.3% and 3.9% respectively. Mean height increment of seedlings of *G. robusta* of MW (100 cm), NMW (83.3 cm), MNW (31.5 cm) and NMNW (9 cm) were recorded, while the mean height increments of seedlings of *A. polyacantha subsp. Campylacantha* of MW (48 cm), NMW (25 cm), MNW (4.5 cm) and NMNW (3 cm) were recorded. The mean survival rate of *G. robusta* was 91.8% of which the highest (100%) survival rate was recorded under MW, NMW and MNW, but the lowest (66.7%) was recorded by NMNW. All seedlings of *A. polyacanth subsp. Campylacantha* were survived, irrespective of the treatments. The study concluded that soil moisture content, early growth performance of seedlings, and survival rate of transplanted tree seedling was improved by application of mulch.

Keywords

Mulch, Soil Moisture, Intermittent Rainfall, Mean Height Increment, Survival Rate

1. Introduction

Capturing rainwater where it falls and storing it in the root zone is perhaps the most cost-effective means of increasing water availability for plants. One way of lengthening stored water in root zone is mulching the soil surface. The term mulching means different things to different people. It has been simply defined as "an application of a covering layer of material to the soil surface" [1] or any covering placed over the soil surface to modify soil physical properties, create favorable environments for root development and nutrient uptake, and reduce soil erosion and degradation [2]. Covering seems to be a key word in most definitions. Lal [3] defined mulch as a layer of dissimilar material separating the soil surface from the atmosphere. Mulch refers here to organic mulches and not to those derived from rock, plastic, or other inorganic materials in this study.

The list of materials used as mulches by traditional farmers is long. Cereal straw and stalks are perhaps the most commonly used mulches, but other examples are crop debris, sawdust, leaves, grass, maize stover, manure, weeds, reeds, spanish moss, gravel and various aquatic plants. Sand and stone mulch is extensively used in some dry areas of China [4]. In commercial agriculture, the list of materials used as mulches becomes longer and includes manufactured products such as various plastic materials, aluminum foil, asphalt paper, glass wool, and paper. Stones such as pebbles, chipped or crushed rock of varying sizes, shapes, and colors are commonly used as decorative mulches in the USA. Such mulches can reduce evaporation [5].

In drought-prone areas, dry mulches can significantly decrease evaporation of soil moisture, thus conserving moisture. Mulches are thus recommended for dry areas, although living green mulches can exacerbate drought problems in some cases [6]. Straw mulching has many advantages compared to no mulching. It dampens the influence of environmental factors on soil by increasing soil temperature and controlling diurnal/seasonal fluctuations in soil temperature [7] [8]. It also increases the soil biotic activity of earthworms [9] and other soil fauna and improves soil structure and quality [10] [11]. The purpose of this study was, however, solely to decrease the evaporation from soil surface and lengthen the availability of soil moisture for the seedling in dry period. Thus the mulch should relatively not depreciate during the research period to act as a cover and nor should change the soil through chemical reaction of the decay.

On transplanting, the basin should be well soaked with the rainfall that produces at least 20 liters of water around the basin of radius of 30 cm. After draining the water for one or two days, the seedlings should be planted. About 2 months in rainy season, the seedling will grow and develop its root system to extract water from deeper soil profile. Once the seedlings have started to grow again, about 2 months after planting, they should be watered once a month, with 20 to 40 liters of water throughout the dry season [12] and/or use other means of conserving soil moisture for the dry season.

In arid and semi-arid areas, tree cultivation frequently suffer with growth and survival due to insufficient soil moisture especially during seedling stages. Furthermore the seedling suffers much more of water scarcity during early seedling stage when the seedling passes through period of intermittent rainfall for the first time. This is one of the reasons why considerable failure is found at seedling stage in establishing tree plantation in dry areas. Therefore, application of water conservation techniques before/or during rainy season and mulching during dry period is essential for the seedling so that it will able to combat soil moisture deficit. Once the root system of the seedling develops (after one or two years), the plant could extract water from deeper soil profile in next periods of intermittent rainfall.

This study focused on performance evaluation of mulching and/ or watering for soil moisture conservation with respect to soil water storage for growth and survival of seedling during the first encounter of dry period (October 2017-June 2018) in the area. Mulching soil surface in dry period after catching rainwater in the preceding rainy season, is perhaps the most efficient means of increasing water availability for seedling. The seedlings used in this study were *G. robusta* and *A. polyacantha subsp. Campylacantha* brought from nearby nursery station; the former is exotic while the latter is indigenous tree. The general characteristics of *G. robusta* and *A*, *polyacantha subsp. Campylacantha* are as follows:

Grevillea robusta (Eng.: *Silky oak*) is an erect, single-stemmed tree typically reaching 20 - 30 m tall and 80 cm in stem diameter. The crown is conical and symmetrical with major branches spaced at intervals of about 1m and projecting upwards at an angle of 45˚. Bark on the trunk is dark grey and furrowed into a lace-like pattern [13]. *G. robusta* has gained popularity in warm temperate, subtropical and tropical highland regions of many countries originally as a shade tree for tea and coffee and now as an agroforestry tree for small farms [14]. In Eritrea, it has been introduced as an ornamental tree in Asmara, Mendefera and Sabur. The tree is widely planted and popular all over Africa [15].

Acacia polyacantha subsp. Campylacantha (*Eng.*: *Falcon*'*s-clazv acacia or hook thorn*; *Tigrigna language*: *Ghomoro*) is deciduous medium sized tree growing up to 20 m high. The crown light, spreading, flat and feathery and the branches are covered with numerous hooked paired prickles which have black tips. These prickles persist on older branches in the form of woody bosses. The upper branches are smooth or whitish and pale gray. Its gum is important for dying and tanning. This gum is very useful for making pottery [16]. In Eritrea, it is commonly found in wooded grassland, deciduous woodland, bush-land and riverine forests in the central highlands, like around Mai-tsebri, Hazemo plains, Mai-anyni, Elabered and in the south-western lowlands, in areas around Shambuko and Molki [15].

2. Materilals and Methods

2.1. Study Area

The study was conducted at Halhale Agricultural Research Center, located 33 km south of the capital, Asmara, Eritrea. It lies at an elevation of 1917 m a. s. level. It is located at 15˚03'38.141"N, 38˚48'47.828"E, with silt loam textural soil (**Table 1**), and favorable climate for growing indigenous and exotic trees and shrubs. It is categorized as one of the highland environments of the country.

Monthly mean of daily temperature maxima of the hottest month is in the range 29˚C - 32˚C and the lowest (coldest) month is around 25˚C. March, April and May are the highest mean maximum temperatures of the year. Monthly mean of daily temperature minima of the coolest month are 5˚C - 8˚C. The coolest mean minimum temperature recorded was in December 2007, which was −3.8˚C [17]. December and January are often associated with frost.

Rainfall regime of the Halhale, as many parts of the country, is bimodal, with the main (long) rainy season (summer or "kremti" rains) lasting from the end of June until mid-September, and more unreliable short rainy season (spring or "akeza" rains) with continually dry spells in them, lasting from the mid-March to late April or May [18]. A review of 18 years rainfall record at Halhle shows that 59 percentile of the short rainy season was in the range 30 - 75 mm; 41 percentile 75 - 120 mm; and 29 percentile 50 - 100 mm. It is not uncommon to have a few rains or rainless in short rainy season. There could be 0 - 20 rainy days in short rainy season. Short rainy season could include about 15% of the total annual rainfall [17]. The long rainy season falls from late June to mid-September; usually its peak reaches in August. The 82 percentile was in the range 300 - 700 mm; the 76 percentile 250 - 500 mm and the 59 percentile 400 - 750 mm. There were about 35 - 50 days of rains during the long rainy season. It is more reliable than the short rainy season [17].

2.2. Experimental Design

After the specific treatments were selected, the experiment was laid out in a complete randomized design (CRD) with three replications by using both *G. Robusta* and *A. polyacantha subsp. Campylacantha* seedlings as testing materials .The treatments include: 1) mulching and watering basins (MW); 2) No-mulching but watering basins (NMW); 3) mulching but no-watering basins (MNW) and 4) no-mulching and no-watering basins (NMNW) (**Table 2**). CRD design was involved for each species because there was no generally large variation among the experimental plots (basins).

The experiment was designed to evaluate the effect of mulching and/or watering on soil moisture for the early growth performances and survival of the transplanted seedlings. These treatments were compared with the usual and

Table 1. Analytical results of the soil sample of the basin.

Soil sample	*G. robusta*	*A. polyacantha*	Soil sample		*G. robusta*	*A. polyacantha*
Sand	33.3	29.6	N %		129.2	146.5
Silt	45.7	56.4	P (ppm)		1.9	3.9
Clay	21.3	13.9	Exchangeable cations Meq/100g of soil	N^+	0.56	0.27
Textural Class	Silt loam	silt loam		K^+	1.08	1.3
EC (ds/m) 1:5	0.08	0.08		Ca^{2+}	40.4	37.9
pH 1:5	7.08	6.78		Mg^{2+}	8.1	7.6
OM %	1.32	1.73	CEC Meq/100g of soil		50.14	47.07

Source: NARI, soil laboratory, Hahhale, 2017.

Table 2. Description of treatments.

Treatment	Specification and description of treatment	
MW	Mulching and watering	The effect of both watering and mulching on soil moisture
NMW	No-mulching but watering	The effect of watering alone on soil moisture
MNW	Mulching but no-watering	The effect of mulching alone on soil moisture
NMNW	No-mulching and no-watering	The effect of no-mulching and no watering on soil moisture

common practices of no-mulching and no watering. The research period in this study was the dry period of the area, lasting from early October 2017 (the termination of rainfall and start of dry season) to mid June 2018 (the commencement of long rainy season).

2.3. Experimental Field Layout

Each circular basin had a single seedling, with 30 cm ridge and 60 cm radius to conserve all in-situ rainfall during the rainy season. The seedlings were planted on July 8, 2017. The spacing between the two consecutive seedlings was 3 m × 3 m, in a staggered pattern. In the beginning of dry period, a second circumscribed (demarked) ridges of radius of 30 cm were constructed around the seedlings for the watered treatments (MW and NMW)) in order that the supplied limited water (20 litter/month) would concentrate around the seedling's roots.

Mature Dry *Hyparrhenia rufa* (in *Tigrigna language*: *Kanchag^{w}ual*) of 1.5 kg per a basin (1.13 m^2), as a mulch, were made to cover the surface uniformly at the early October with a thickness of 8 cm and were kept under the seedlings till mid-June. The amount of water supplied for one seedling was 180 liters for watered treatments (MW and NMW) but none for the un-watered treatments (NWM, NWNM).

2.4. Soil Moisture Measurement

Soil samples from the basins of the treatments were taken using tube auger from

0 - 20 cm, 20 - 40 cm, 40 - 60 cm soil layers at one month interval from early October (2017) to mid-June (2018). Soil sample was weighed on a digital balance, and then oven dried to a temperature of 105˚C till constant weight (one to two days) was observed. The gravimetric soil moisture content was determined using the following relationship as described by [19]:

$$\text{Soil moisture}(\%) = \frac{\text{Fresh weight in gm} - \text{Dry weight in gm}}{\text{Dry weight of soil in gm}} \times 100$$

The volumetric moisture content of each sample was determined by multiplying the gravimetric soil moisture results by their respective bulk densities. Soil moisture for the analysis of variance was taken from the upper soil profile (0 - 20 cm) before the beginning of rainy season (mid-June), because that month was the lowest determinant factor of soil moisture content that the seedlings would or would not be able to survive and reach the second rainy season.

2.5. Height Development of Seedlings

The heights of all seedlings were measured from the base of the plant to the base of the fully opened leaf in centimeter by tape measure. Height measurements were started in October and continue till June 2018, recording the increments monthly for nine months. Data for analysis of variance of height increments were taken from mid-June. The increment height of the seedling was the difference between final heights in June 2018 to initial height in October 2017.

2.6. Seedling Survival Rate

The total numbers of survived and dead seedlings throughout the dry period from the time of mulching and/or watering at the beginning of October 2017 to the beginning of rainy season (mid-June 2018) were recorded for all treatments for both species. Then the percentage of dead seedlings from the total number of seedlings at early application of mulching and/or watering per plot and treatments were calculated using the following formula:

$$\text{Survival rate}(\%) = \frac{\text{No of diedseedlings at the end of dry period}}{\text{Total seedlings at early application of mulching and or watering}} \times 100$$

2.7. Statistical Analysis

All the measured parameters under the various treatments were tested for significant differences using analysis of variance (ANOVA) for a CRD design; $p \leq 0.05$ was used as the critical limit for distinguishing the degree of variance between means. Treatments that show significant differences were subjected to mean comparison test, Least significant difference test (LSD) at 5% Probability level, which is suited for a planned pair comparison. Regression and correlation was carried out to determine the strength of relationships between months of the dry period to height increment of the species of the treatments. The parameters assessed included: soil moisture of the basin; height increments; survival and general characteristics of the seedlings during dry period.

3. Results and Discussion

3.1. Rainfall and Temperature, 2017/18

Total rainfall sums 482.7 mm after transplanting (July, 2017) the seedlings to the mid-June, 2018. There was no rain from October 2017 to March 2018. But rains appeared in April and May (combined 89.2 mm) of 2018. The mean maximum temperature was in the range 25.15˚C to 30˚C and the mean minimum temperature ranged 5˚C to 15.3˚C and monthly mean evaporation was 7.02 mm in the range 4.45 - 9.17 mm during the research period [17].

3.2. Effect of Mulching and/or Watering on Soil Moisture Content

The study indicated that there were statistically significant differences ($p < 0.05$) on mean soil moisture content among the treatments (**Table 3**). The LSD ($p < 0.05$) results for the three pair comparisons show that, except for MNW, the other mean soil moisture content of the treatments were significantly higher than that of NMNW (control) (**Table 3**). Mean Soil moisture content was significantly higher on MW (10.08%) followed by NMW (7.7%). It was lowest (3.9%) on NMNW (control), after MNW (6.3%). This means that mean soil moisture contents of MW (158%), NMW (97%), and MNW (61.5%) were greater (%) over NMNW (control) (**Table 3**). The Mean soil moisture content difference of MW to NMW or MNW to NMNW gave the amount of soil moisture conserved by mulching alone which might facilitate the seedlings to survive and grow more than the NMNW (control). Russell [20] reported that straw mulch can decrease the rate of evaporation by 35%.

Soil moisture variation for every 20 cm soil depth down to 60 cm was monitored every month during the research period. Mean soil moisture contents in all soil depths was highest in MW followed by NMW and then by MNW. It was lowest in NMNW (control) (**Figure 1**). The study was in line with that of [21] who indicated that mulched plots had higher soil moisture content than un-mulched ones. High moisture in mulch is also due to reduction in soil temperature. It is due to prevention of direct contact of solar radiation with the soil

Table 3. Mean soil moisture content as affected by mulching and/or watering on transplanted seedlings.

Treatment	Soil moisture content (%)			
	R1	RII	RIII	Mean
MW	8.12	9.24	12.88	10.08
NMW	6.58	8.2	8.3	7.7
MNW	6.4	6.1	6.3	6.3
NMNW (control)	2.8	4.9	3.9	3.9
	Mean			6.995
	LSD (5%)			2.7

Key: R = replication, LSD = least standard difference.

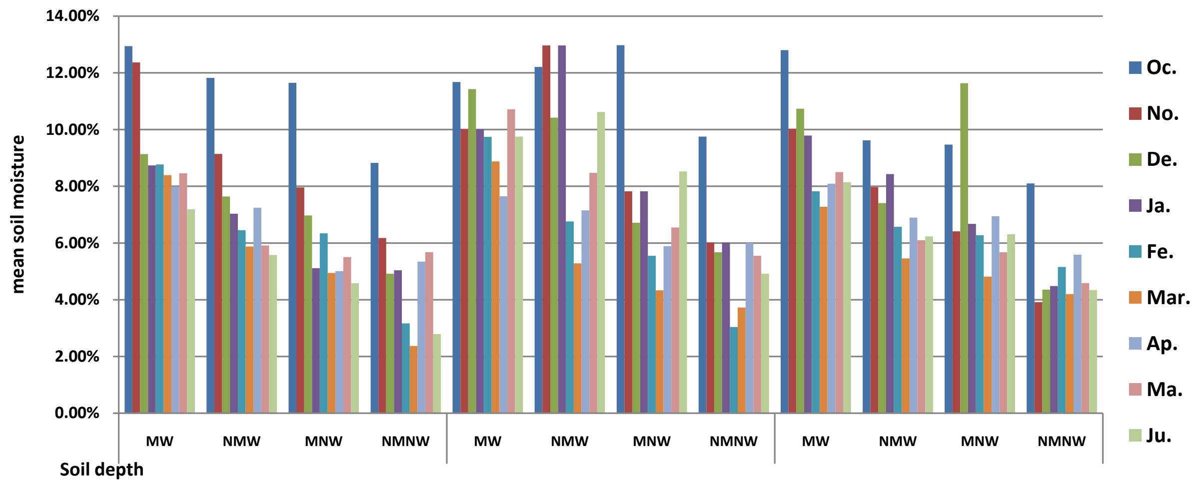

Figure 1. Mean soil moisture content (gravimetric) at different depths under different treatments during dry period.

by the mulches which reduced water loss into the atmosphere through evaporation. All these contributed to increase the soil moisture content and reduce moisture depletion.

Throughout the whole soil depth, mean soil moisture contents were mostly decreased steadily till early March and raised in April and May due to short rainy season, and Soil moisture variability tended to decrease with the increase of soil depth (Figure 1).

3.3. Effect of Mulching and/or Watering on Seedlings Growth Performances

Analysis of variance for seedling growth performances showed statistically significant differences ($p < 0.05$) among the treatments for both species (Table 4). The LSD (5% level) results for the three pair comparisons show that, except for MNW, the other treatments gave mean height increment that were significantly higher than that of NMNW (control). However, MW and NMW of *G. robusta* were statistically at par among each other but superior to the NMNW (control) For *G. robusta* seedlings, the highest mean increment values for plant height (100 cm) were achieved in MW, following by NMW with increment height (83.3 cm). The lowest (10.7 cm) was achieved by NMNW, after the MNW (31.5 cm). Similarly, for *A. polyecantha subsp. Campylacantha* seedlings, the highest mean increment values for plant height (48 cm) were achieved in MW; following by (NMW) with height (25 cm) increment. The lowest (3 cm) was achieved by NMNW after the MNW (4.5 cm) (Table 4).

The results of the study conducted on the seedling growth performances as affected by the mulching materials are in agreement with other similar research studies [22] [23] [24]. Those authors reported that mulching enhanced early growths of the transplanted seedlings through improving seedlings survival and enhancing root establishment of the seedlings as mulches provide improved soil moisture conservation, reduced soil temperature, reduced weed infestation and nutrient availability as a result of reduced leaching of nutrients.

Table 4. Height increment of transplanted seedling as affected by mulching and/or watering.

Treatment	Height increment (cm) *G. robusts*				Height increment (cm) *A. polyecantha*			
	R1	RII	RIII	Mean	R1	RII	RIII	Mean
MW	106	102	92	100	45	28	63	48
NMW	134	55	61	83.3	18	23	34	25
MNW	21	50	24	31.5	6	4	3	4.5
NMNW (control)	17	10	15	10.7	5	2	2	3
		Mean		56.4		Mean		19.5
		LSD (5%)		44.9		LSD (5%)		19.4

Key: R = replication, LSD = least standard difference.

3.4. Mulching and/or Watering Effect on Survival Rate

The analysis of variance showed that statistically significant different percentage of seedlings survival for *G. robusta* while not-significant different for *A. polyacanth subsp. Campylacantha* (Table 5). The grand mean survival rate of *G. robusta* was 91.8% of which the highest (100%) survival rate was recorded under MW, NMW and MNW, but the lowest (66.7%) was recorded by NMNW (control) (Table 5). All seedlings of *A. polyacanth subsp. Campylacantha* were survived and scored the highest (100%) irrespective of the treatments (Table 5). The result agrees with experiment outcomes of the study on oak species showed the significant effect of germination and seedling survival in relation to the pits with surface plantings using no mulch material [25].

Generally the seedlings of *G. robusta* were tolerant, vigor, preserving their natural beauty and color despite slight damages in their edge of leaves caused by frost in December. The seedlings of *A. polyacanth subsp. Campylacantha* shed their leaves in dry season, and grow fast as soon as the rains started to fall

3.5. Regression Correlation Analysis

Growth development constantly varies in increasing specific units for each unit change from October to June for both species among treatments and within treatment. For instance, mean height increment of *G. robusta* of MW increased from 12.003 to 23.995 cm (12 cm) and *A. polyacantha subsp. Campylacantha* from 6.931 to 12.4243 cm (5.5 cm) as month advances from November to December. It is possible to know the approximate mean height increment of the treatments or seedlings of two species by using the corresponding linear regression equation during the research period (Table 6).

The regression lines show that there were linear relationships across the research periods to the mean height increments of the seedlings (Table 6). Highest slope was for the MW, indicating the highest mean height increments and lowest slope was for NMNW, indicating lowest mean height increments within the

Table 5. Mean Survival rate of newly transplanted seedlings as affected by mulching and/or watering.

Treatment	Mean Survival rate (%) *G. robusts*				Mean Survival rate (%) *A.polyecantha*			
	R1	RII	RIII	Mean	R1	RII	RIII	Mean
MW	100	100	100	100	100	100	100	100
NMW	100	100	100	100	100	100	100	100
MNW	100	100	100	100	100	100	100	100
NMNW (control)	62.5	72.5	65.1	66.7	100	100	100	100
		G. mean		91.8		G. mean		100
		LSD (5%)		5		LSD (5%)		ns

Key: R = replication, LSD = least standard difference, ns = non-significant, G = grand.

Table 6. The estimated linear regression equations with their respective R value of the treatments.

Treatments.	*Height of G. robusta*	R^2	*Height of A. polycantha*	R^2
MW	$y = 11.992x - 11.981$	0.9786	$y = 5.4933x - 4.0556$	0.9846
NMW	$y = 10.022x - 5.9528$	0.9653	$y = 2.8567x - 4.6722$	0.9309
MNW	$y = 2.2333x + 4.0556$	0.6999	$y = 0.39x + 0.9722$	0.7483
NMNW	$y = 1.4317x + 1.5306$	0.8502	$y = 0.365x + 0.3194$	0.904

Note: Y is mean height increments and X was the month of research period (1 - 9 months).

research period which, in turn depends mainly on soil moisture and other favorable conditions resulted from mulching with/without watering of the basin.

4. Second Rainy Season

Supplying water to the seedlings was ceased and mulches were removed for all treatments when research ended to understand the growth rate during the long rainy season of 2018 (late June to mid-September). It was found that the growth rates at the end of rainy season of MNW (2) and NMNW (2.4) were greater than MW (0.63) and NMW (0.9) of *G. robusta.* Likewise the growth rate of *A. polyacantha subsp. Campylacantha* of NWM (1.39) and NWNM (1.12) was greater than WM (0.688) and WNM (0.473) (Figure 2). This result verifies that once the seedlings challenged to survive the first dry period, they can catch up in growth and potency with the other seedling favored in the previous dry season.

The mean annual Stem diameter (in cm) at ground level of the *G. robusta* of MW, NMW, NMW and NMNW were 2.4, 1.5, 1.1 and 0.7 cm respectively and the *A. polyacantha subsp. Campylacantha* seedling were of MW, NMW, NMW and NMNW 3.4, 2.2, 3.8, 2.9 cm respectively. The mean annual height increment (MAI) of *G. robusta* of MW, NMW, MNW and NMNW was 181.3 cm, 177.3 cm, 128 cm and 96 cm respectively. Mean annual increment (MAI) of the *A. polyacantha subsp. Campylacantha* of MW, NMW, MNW and NMNW, 96 cm, 46 cm, 88 cm and 63 cm respectively.

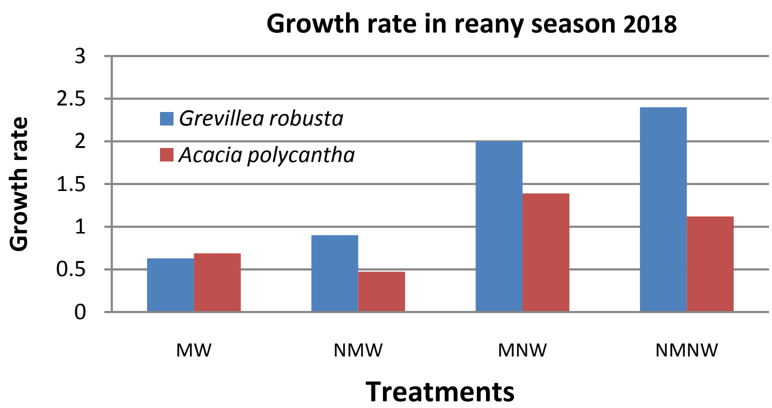

Figure 2. Growth rate during rainy season of seedlings.

5. Conclusions

Seedling stages are the most decisive period of tree cycle in which moisture conservation measures should be done for the growth and survival of tree plantation in arid and semi-arid area of Eritrea. Hence mulching can be one of the most beneficial practices tree-growers can use in dry period. Prior to mulching however, it is important to provide moisture conservation (harvesting) structures around the seedling in the rainy season.

Higher soil moisture through the application of mulching with/or a litter (20 liter/month) water exhibited vigor seedling growth performances, higher survival rate on early seedling stage of the two species during the research period. Even application of mulching alone (without watering) achieved success not only in growth development but also in carrying the seedlings on to the next rainfall than no mulching. Therefore, for tree growing farmers in arid and semi-arid, like Eritrea, where rainfall variability causes moisture stress, the use of grass as mulching material on newly transplanted seedlings during dry period is recommended.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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