مجلة جامعة تشرين للبحوث والدراسات العلمية _ سلسلة العلوم البيولوجية المجلد (38) العدد (6) 2016
Tishreen University Journal for Research and Scientific Studies - Biological Sciences Series Vol. (38) No. (6) 2016

Effects of Sewage Sludge Application on Dry Biomass and Wood Volume of *Eucalyptus Camaldulensis* Plantation in Fedio (Lattakia)

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(Received 4 / 9 / 2016. Accepted 19 / 12 /2016)

□ ABSTRACT □

This study was carried out during 2013 – 2015 and aimed to assess the effects of applying dry sewage sludge on dry biomass production and wood volume of *Eucalyptus camaldulensis* plantation established on sandy soil in Fedio plantation-Lattakia at April - 2013.

Four experimental treatments were compared at age 22 months: SS1 (sewage sludge 3 kg/tree), SS2 (sewage sludge 6 kg/tree), MF (mineral fertilizer), and C (no fertilizer applications). Aboveground dry biomass production and wood volume in the SS1 treatment were about 107.60 t/ ha and 121.13 m^3/harespectively, MF treatment (87.52 t/ha, 96.98 m^3/ha) and SS2 treatment (91.12 t/ha, 103.42 m^3/ha)and higher than in the control treatment (43.89 t/ha, 51.32 m^3/ha).

Key words; sewage sludge, *Eucalyptus camaldulensis*, biomass, dry biomass, wood volume.

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أثر تطبيق حمأة الصرف الصحي على الكتلة الحيوية الجافة والمخزون الخشبي لمشجر للأوكاليبتوس المنقاري في فديو (اللاذقية)

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(تاريخ الإيداع 4 / 9 / 2016. قبل للنشر في 19 / 12 / 2016)

☐ ملخّص ☐

أجريت هذه الدراسة خلال عامي 2013 – 2015، وقد هدفت إلى تقييم الآثار الناتجة عن تطبيق حمأة الصرف الصحي الجافة على إنتاجية الكتلة الحيوية الجافةوالمخزون الخشبي في مشجر للأوكاليبتوس المنقاري تم إنشاؤه على تربة رملية في مزرعة فديو (اللاذقية) في نيسان 2013.

قمنا بمقارنة أربع معاملات تجريبية عند عمر 22 شهراً وهي: SS1 (حمأة صرف صحي3 كغ/غرسة)، SS2 (حمأة صرف صحي6 كغ/ غرسة)، MF (سماد معدني)، C (دون إضافة سماد أو حمأة). حيث بلغت إنتاجية الكتلة الحيوية الجافة فوق سطح الأرض والمخزون الخشبي في المعاملة SS1 حوالي107.60 طن/ الهكتار و121.13 م^3/ الهكتارعلى التوالي ومعاملة السماد المعدني (87.52 طن/الهكتار و 96.98 م^3/ الهكتار) ومعاملة SS2 (91.12 طن/الهكتار و103.42 م^3/ الهكتار)، وكانت أعلى مقارنة مع معاملة الشاهد (43.89 طن/ الهكتار و 51.32 م^3/ الهكتار)،.

الكلمات المفتاحية: حمأة الصرف الصحي، الأوكاليبتوس المنقاري، الكتلة الحيوية، الكتلة الحيوية الجافة، المخزون الخشبي.

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Introduction:

Sewage sludge resulting from the treatment of municipal wastewater is rich in organic matterand huge amount of sewage sludge (known as biosolids) is produced,(about 25-40kg/person/year) [1]. The chemical composition of sewage sludge depends on the source from which it has been generated, such as industrial or residential facilities and the processes used in sewage treatment stations. The raped increase of population, urban planning and the industrial developments produces more accumulation of it. Additionally, it causes a great environmental problem because the derived risk from the presence of pathogens, heavy metals and organic pollutants [2, 3].

Several alternatives exist for disposing of the sludge produced in sewage treatment, such as dumping into sanitary landfills, incineration [4] but reuse of sewage sludge as a fertilizer or soil conditioner, especially in forest plantations, is considered one of the best recycling option from agriculture and environmental point of[5, 6]. Sewage sludge contains nutrients and essential micronutrients often lacking in forest soils [7]which improve soil structure[8], soil water holding capacity and cations exchange capacity[9, 10], reduce erosion [11], and increase the biological and enzymatic activity of soils [12, 13, 14], crop production and plants growth [15]. In addition, sewage sludge applications reduce the environmental pollution and the amounts of mineral fertilizers needed to sustain the productivity on infertile soils [16].

Risks associated with sludge application in forest plantations are lower than in agriculture, since Eucalyptus plantations are usually managed to produce fire wood, charcoal, boards, or pulp and paper, and the final product (wood biomass) is not incorporated into the human food chain. Moreover, environmental impacts of sewage sludge applications in forest plantations are usually much lower than in agriculture because the doses required to meet tree nutrient requirements are low [17]. Sludge applications are only required at the first year of the rotation (every 6 to 7 years), whereas doses of the same order were magnitude may be applied annually for agricultural crops. Forest plantations are usually located on low fertile sandy soils and a fast development of Eucalyptus roots makes it possible to take up the nutrients released during sludge decomposition [18].

Studies have been carried out worldwide from the early 1970s to assess the effectiveness of applying organic waste residues to forest areas [19]and the effects on tree growth. In particular, early investigations in the state of Washington (USA) have shown positive effects of sewage sludge applications on the development of conifer plantations [20, 21]. Slow and continuous nutrient releases into soil solutions during sewage sludge decomposition may be an advantage in comparison with mineral fertilizations, fitting better nutrient availability of stand requirements [22]. De Lira et al. [23] observed a significant increase in eucalyptus biomass production resulting from the application of sewage sludge, with a strong relationship between tree growth and the enhancement of nitrogen, phosphorus, and base cation contents within the upper soil layer. Sludge applications in fast growing plantation forests lead to a return within the ecosystem of nutrients exported at the harvest. The slow release of nutrients contained within the sludge makes it possible to restore soil nutrient stocks throughout the development cycle of forest plantations [24].Previous research suggests that the application of sewage sludge might significantly improve the economic performance offorest plantations due to increases in wood production [25]. Furthermore, reduces in disposal costs of sewage sludge associated with a reduce in mineral fertilization costs [26].

Eucalyptus species (Fam: *Myrtaceae*) naturally occur in all Australian mainland status [27]. They have been widely planted overseas in areas with Mediterranean climate such Syria. They are highly adapted to the local environmental conditions and grow very fast. These species are traditionally planted as windbreak, for shade and to supply wood for lumber, particle board and charcoal production [28].

The overall aim of the present work was to evaluate the effects of dry sewage sludge(**3** kg/tree, **6** kg/tree) on the growth of *Eucalyptus camaldulensis* plantation (biomass production and wood volume), under sandy soil conditions, at age 22 months.

Materials and Methods:

Study Area, Experimental Design, and Treatments

This study was conducted inthe Experimental areaof Fedio plantation, Tishreen University, Lattakia, Syria (35°29′ S, 35°52′ W, ca.2.5 kmeast of Mediterranean sea).The study area has aMediterranean climatewithmean annual precipitation of 1395 mm,mean temperature of 19.2°C (climate elements are for the period: 1980-2010) andhas an elevation of 35-40m above sea level with accessibility of groundwater at depth of10 meters.

The soil is sandy (table 1) with very small amounts of available nutrients and organic matter (table 2).

Table 1: soil Mechanical analysis of the experimental area before planting

Depth (cm)	Sand %	Clay %	Silt %
0 - 25	77.88	18.48	3.64
25 - 50	81.95	16.45	1.60

Table 2: Soil analysis of the experimental area before planting

Parameter	Depth (cm)		Parameter	Depth (cm)	
	0 - 25	25 - 50		0 - 25	25 - 50
Moisture %	2	2.1	CEC (meq/100g)	9.485	7.729
pH (1:2.5 soil:water)	7.1	7.25	Nitrogen (N) %	0.15	0.06
E.C (µs/cm)	80	67.5	Phosphorus (P) %	0.0032	0.0028
Organic matter %	1.28	0.87	Potassium (K) %	0.014	0.012

Eucalyptus camaldulensis was planted in April 2013 using a complete randomized design, with 4 treatments and 3 replicates per treatment. Each replicate had a total area of 28 m^2 (7 m × 4 m) and planting distance was (1 * $1m^2$).

The treatments (table 3) were defined as: C: (Control), MF: (Mineral Fertilization representative of the silviculture in commercial plantations), SS1: (addition of 3 kg/tree of dry SewageSludge), and SS2: (addition of 6 kg/tree of drySewageSludge) and these treatments were distributed using alottery systemin the experimental (figure 1).

Chemical and physical properties of the usedsewage sludge are shown in table (4). The nutrients were applied in the treatments through the dry sewage sludge in order to reach the total amount of nitrogen added in the mineral fertilization treatment.

Table 3: Nutrients added of the treatments through the soil of the experimental eucalyptus plantation

Treatments	Nutrients (kg/ha)			Dry sludge (tn/ha)
	N	P	K	
Control (C)	----	----	----	----
Mineral fertilization (MF)	300	200	200	----
Sludge 3 kg/tree (SS1)	----	----	----	30
Sludge 6 kg/tree (SS2)	----	----	----	60

Table 4: Chemical and physical analysis of dry sewage sludge applied in the experiment

Parameters	Value	Parameters	Value
Moisture %	7.1	Phosphorus (P) %	0.78
E.C µs	1746	Nitrogen (N) %	1.2
Organic matter %	25.7	Copper (Cu) ppm	338.9
Organic Carbon %	14.9	Cadmium (Cd) ppm	0.12
CECmeq/100g	52	Zink (Zn) ppm	469
C/N	12.4	Lead (Pb) ppm	52.3
Potassium (K) %	0.01	Nickel (Ni) ppm	30.5

The seedlings were planted after subsoiling (depth 40 cm). Mineral fertilizer and dry sewage sludge were applied manually on a 0.5 m-wide strip in the planting row (at the soil surface without incorporation) some days after planting.

Weed and ant control were undertaken before and after planting. Medium mortality rates occurred within the first days after sewage sludge application (especially in SS2 treatment) and all dead seedlings were replaced after 15 days of treatment establishment.

Measurements and Sampling

Diameters at breast height (dbh) of eucalyptus trees measured at age 22 months, the allometric relationships between dbh and each of biomass and wood volume was modeled. .16 trees covering all diameter classes were cut.

Biomass estimates were conducted for several aboveground tree parts: in particular, stem, branches and leaves. Studies of biomass estimation of fast growing tree species grown in short rotation cycles found that use of nondestructive ways to estimate tree weight needs only a single easily measured variable like diameter [29], which allows estimators to apply regression analysis.

Biomass equations depend on the diameter as a single variable have been used widely with high accuracies. The relation between tree dry weight (BM) and tree diameter is none linear and the common models is;

BM= a* dbh ^ b

Where a, b= regressions coefficients, dbh = tree diameter at breast height. The amount of biomass per unit area was computed in terms of (t/ha) of dry matter [30].

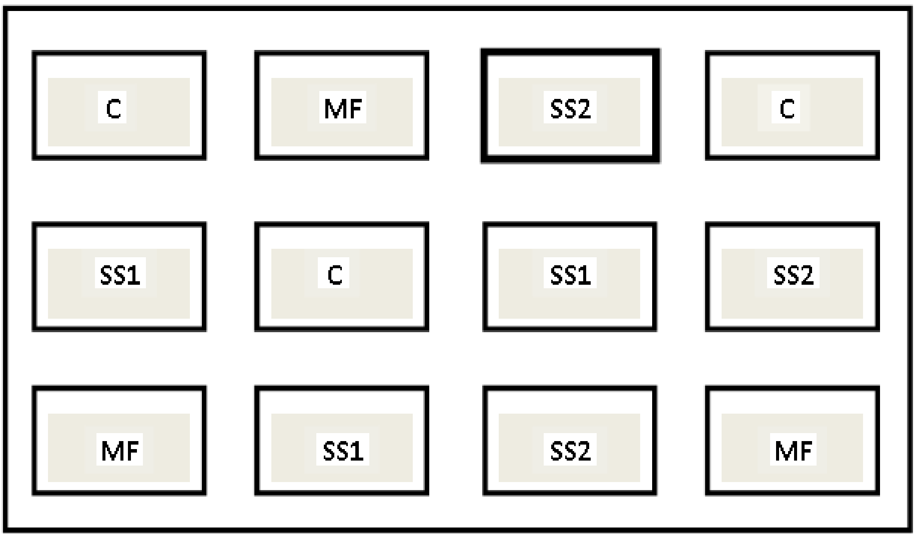

Figure 1: The design of exprememtal replicates

For wood volume estimation after tree fall, following measurements were conducted: dbh, total tree height and diameter at each one meter height (as one meter logs)..Using Smalian formula [29] the volume of each log was calculated as follows:

$$v = \frac{g_b + g_t}{2} \cdot l$$

where g: cross-sectional area m^2, b: base, t: top, l: log length m

The whole tree volume was estimated using the form:

$$V_t = v_1 + v_2 + v_3 + \dots \dots \dots v_n$$

Where:V_t, vn: volume of tree and volume of the log n.).Using nonlinear regression the relationship between dbh and tree volume was developed.

Data Analysis

The measurement variables of biomass production and wood volume averages were submitted to variance analysis (ANOVA) using least significant difference (L.S.D) at 5% confidence level. When p> 0.05 there are no significant differences while p< 0.05 significant differences are exist.

Results and Discussions:

Treatment establishment caused differences in tree mortality at the first days after planting, whilst (6 kg dry sludge per tree) application caused amortality of about 12%, maybe resulting from the addition of large amounts of nitrogen and organic matter [31],tree mortality in the other treatments was< 5%.

.DryBiomass Production;

.Aboveground Biomass (AGB);

Using power function the abovegroundbiomasswas estimated; $Y= 227.6x^{2.014}$with coefficient of determination R^2= 0.98 (figure 3).

Biomass accumulation at 22 months after planting was between 37.23 t/ha in C treatment and 114.53 t/ha in SS1 treatment (table 5). Average values of AGB were 107.60, 91.12, 87.52, 43.89t/ha in SS1, SS2, MF and C treatments, respectively (figure 4). Total biomass production recorded the higher significant value ($p< 0.05$) in SS1 treatment than in MF, SS2 and C treatment (table 6).

The high biomass production in SS1treatment may results from the initial seedling mortality. Even though dead seedlings were replanted 15 days after experiment establishment, large inter-tree competition led to a decrease in stand productivity in the SS2 treatment. A similar behavior has been demonstrated in other eucalypt plantations [32].

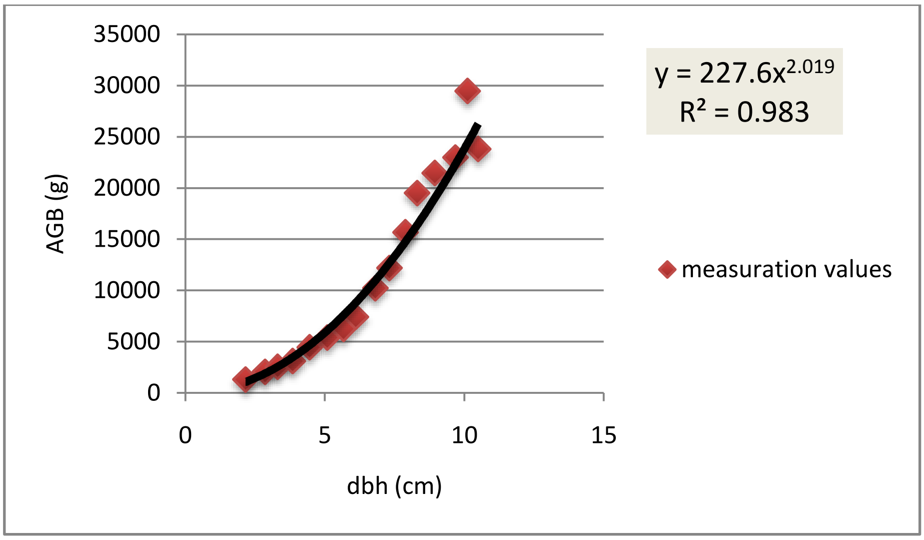

Figure 3: Relationship between total aboveground dry biomass and dbhof *Eucalyptus camaldulensis*

Table 5: Total aboveground biomass production (t/ha) at age 22 months

SS1	SS2	MF	C
107.49	87.36	89.82	45.07
114.53	101.91	77.48	37.23
100.78	84.08	95.26	49.35

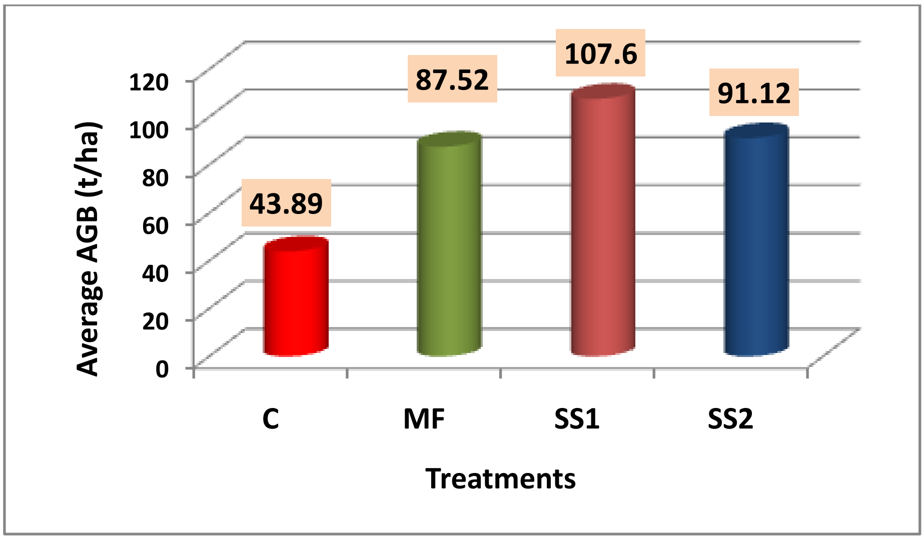

Figure (4): Average aboveground biomass production (t/ha)

The tree growth in SS1 replicates showed that sludge mineralization led to a sufficiently fast release of nutrients to meet the high tree requirements (in N and P in particular and organic matter) to establish the crown at the first two years after planting [33].

Table 6:ANOVA total aboveground biomass, comparison among treatments

Multiple Comparisons

Dependent Variable: DBM (t/ha)

LSD

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	MF	-43.63667-*	6.55891	.000	-58.7615-	-28.5118-
	SS1	-63.71667-*	6.55891	.000	-78.8415-	-48.5918-
	SS2	-47.23333-*	6.55891	.000	-62.3582-	-32.1085-
MF	C	43.63667*	6.55891	.000	28.5118	58.7615
	SS1	-20.08000-*	6.55891	.016	-35.2049-	-4.9551-
	SS2	-3.59667-	6.55891	.598	-18.7215-	11.5282
SS1	C	63.71667*	6.55891	.000	48.5918	78.8415
	MF	20.08000*	6.55891	.016	4.9551	35.2049
	SS2	16.48333*	6.55891	.036	1.3585	31.6082
SS2	C	47.23333*	6.55891	.000	32.1085	62.3582
	MF	3.59667	6.55891	.598	-11.5282-	18.7215
	SS1	-16.48333-*	6.55891	.036	-31.6082-	-1.3585-

*. The mean difference is significant at the 0.05 level.

Stem Biomass

Stemdry biomass equation was; $Y= 130.08x^{2.0716}$with $R^2= 0.98$ (figure 5).

Stem biomass production ranged between 23.26 t/ha in C treatment and 73.96 t/ha in SS1 treatment (table 7). Sewage sludge had significant effect on *Eucalyptus camaldulensis* growth represented as dry weights of different plant parts,Average values were69.36, 58.42, 54.63, 27.55t/ha in SS1, SS2, MF and C treatments, respectively (figure 6).

Stem biomass gave the higher significant value ($p<0.05$) in SS1 treatment than in SS2, MF and C treatments at 22 months after planting(table 8).

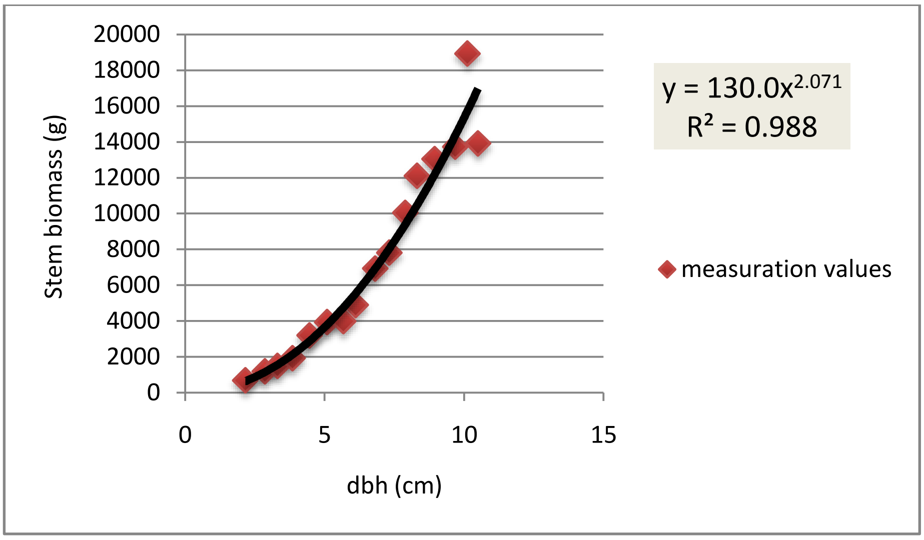

Figure 5:Relationship between stem dry biomass and dbh of Eucalyptus camadulensis

Table 7: Stem biomass production (t/ha) at 22 months after planting

SS1	SS2	MF	C
69.27	55.92	53.22	28.30
73.96	65.57	49.51	23.26
64.86	53.75	61.17	31.10

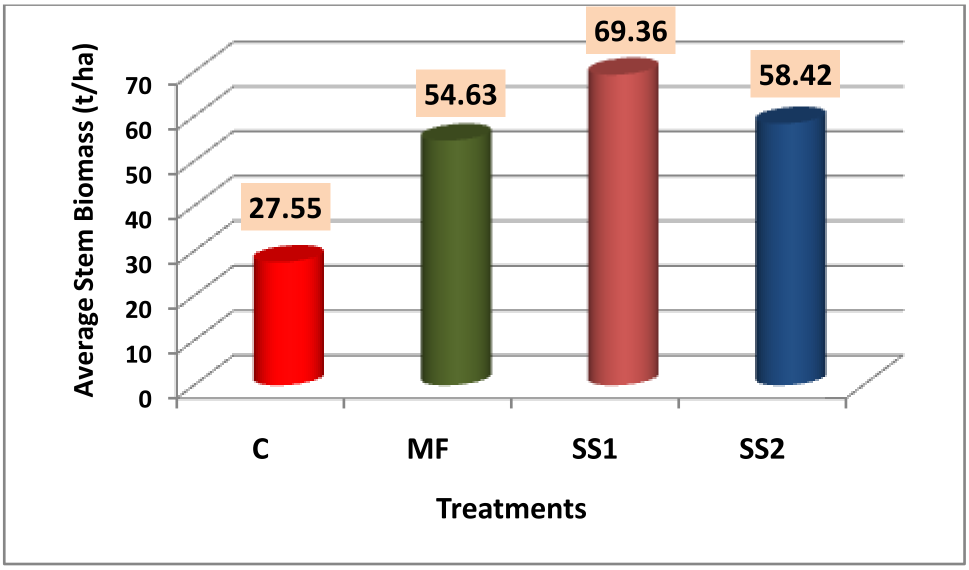

Figure (6): Average stem biomass production (t/ha)

Table 8: ANOVA stem biomass, comparison among treatments

Multiple Comparisons

Dependent Variable: DBM (t/ha)

LSD

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	MF	-27.08000-*	4.31222	.000	-37.0240-	-17.1360-
	SS1	-41.81000-*	4.31222	.000	-51.7540-	-31.8660-
	SS2	-30.86000-*	4.31222	.000	-40.8040-	-20.9160-
MF	C	27.08000*	4.31222	.000	17.1360	37.0240
	SS1	-14.73000-*	4.31222	.009	-24.6740-	-4.7860-
	SS2	-3.78000-	4.31222	.406	-13.7240-	6.1640
SS1	C	41.81000*	4.31222	.000	31.8660	51.7540
	MF	14.73000*	4.31222	.009	4.7860	24.6740
	SS2	10.95000*	4.31222	.035	1.0060	20.8940
SS2	C	30.86000*	4.31222	.000	20.9160	40.8040
	MF	3.78000	4.31222	.406	-6.1640-	13.7240
	SS1	-10.95000-*	4.31222	.035	-20.8940-	-1.0060-

*. The mean difference is significant at the 0.05 level.

Leaves and Branches Biomass

The form developed to calculate leaves and branchesdry biomass was:

$Y= 93.817x^{1.9548}$ with $R^2= 0.94$ (figure 7).

Biomass production was between 14.20 t/ha in C treatment and 42.20 t/ha in SS1 treatment (table 9). The greatest average value of leaves and branches biomass was recorded in SS1 treatment with 39.72 t/ha, whereas, the other treatments had values of 33.82, 31.72, 16.65 t/ha for SS2, MF and C , respectively (figure8).

Also table (10) showed that leaves and branches biomass was significantly higher ($p<0.05$) in SS1 treatment than in SS2, MF and C treatments.

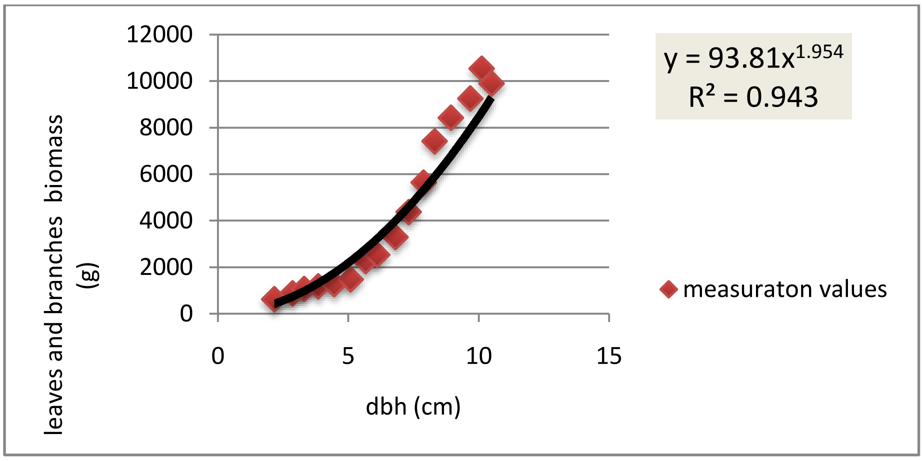

Figure 7: Relationship between Leaves and branches dry biomass and dbh of Eucalyptus camaldulensis

Table 9: Leaves and branches biomass production (t/ha) at age 22 months

SS1	SS2	MF	C
39.69	32.51	30.99	17.09
42.20	37.69	28.86	14.20
37.27	31.26	35.30	18.65

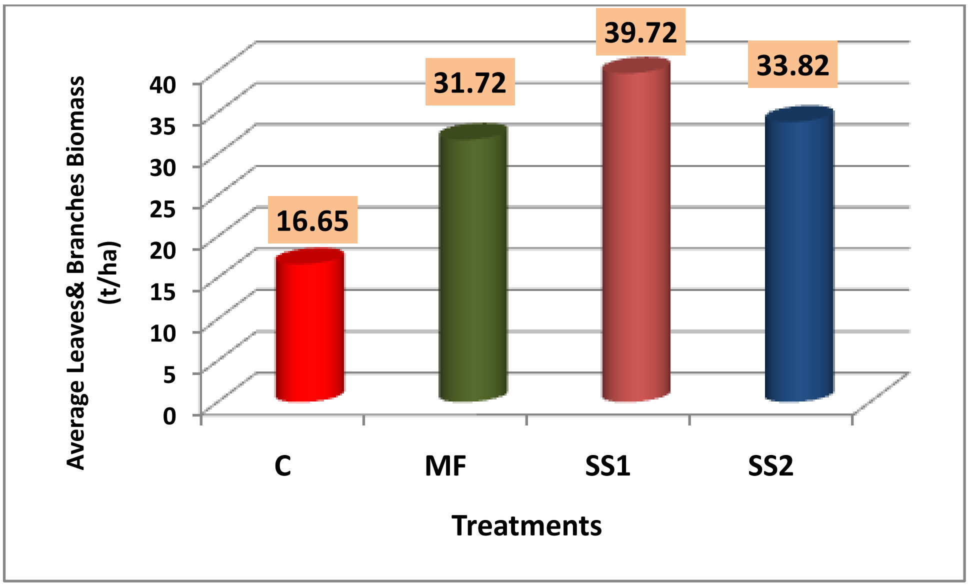

Figure (8): Average Leaves and branches biomass production (t/ha)

Table 10: ANOVA leaves and branches biomass, comparison among treatments

Multiple Comparisons

Dependent Variable: DBM (t/ha)

LSD

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	MF	-15.07000-*	2.36512	.000	-20.5240-	-9.6160-
	SS1	-23.07333-*	2.36512	.000	-28.5273-	-17.6194-
	SS2	-17.17333-*	2.36512	.000	-22.6273-	-11.7194-
MF	C	15.07000*	2.36512	.000	9.6160	20.5240
	SS1	-8.00333-*	2.36512	.010	-13.4573-	-2.5494-
	SS2	-2.10333-	2.36512	.400	-7.5573-	3.3506
SS1	C	23.07333*	2.36512	.000	17.6194	28.5273
	MF	8.00333*	2.36512	.010	2.5494	13.4573
	SS2	5.90000*	2.36512	.037	.4460	11.3540
SS2	C	17.17333*	2.36512	.000	11.7194	22.6273
	MF	2.10333	2.36512	.400	-3.3506-	7.5573
	SS1	-5.90000-*	2.36512	.037	-11.3540-	-.4460-

*. The mean difference is significant at the 0.05 level.

Wood Volume

Using power function the wood volume can be estimated

$Y= 0.0003x^{1.9307}$ $R^2= 0.98$ (figure 9).

Table (11)explains the wood volume values of all replicates at 22 months after planting. The average values were 121.13, 103.42, 96.98, 51.32 m^3/ha in SS1, SS2, MF and C treatments, respectively (figure10).

Wood volume was significantly high ($p<0.05$) in SS1 treatment in comparedwithSS2, MF treatments. and was about twice as high in SS2 and MF treatments than in the control treatment(table 12).

The higher wood volume in SS1 treatment than in SS2 treatment may result from the initial seedling mortality [32].

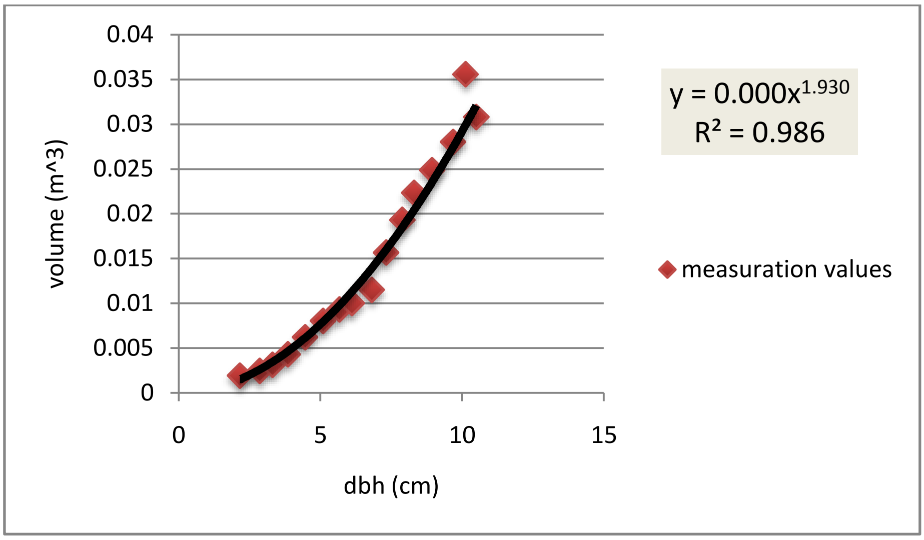

Figure 9:Relationship between volume and dbh of Eucalyptus camadulensis

Table 11: Wood volume (m^3/ha) at age 22 months

SS1	SS2	MF	C
121.05	99.45	94.81	52.70
128.60	115.03	88.32	43.86
113.73	95.79	107.82	57.40
121.13	103.42	96.98	51.32

The enhancing effect of sewage sludge on eucalyptus plant height and diameter may be due to abundant of organic matter as well as N and P elements. However, similar results were reported in Yost *et al.* (1987) on *Eucalyptus salign* [34], Androde and Mattizzo (2000) on *E. grandis* [35]and El- Baha (2001) on *E. camaldulensis* [36]..

Generally, plant growth is defined as an irreversible increase in volume. Growth is usually measured in terms of changes in fresh and dry weights of the living tissues over a particular period of time [37].

According to Stein (1997), most seedlings species grow faster in soil treated with sewage sludge; and some species respond dramatically, while others show only a slight response. Greater growth responses have been seen when seedlings have planted directly in soil already amended with large amounts of sewage sludge [38].

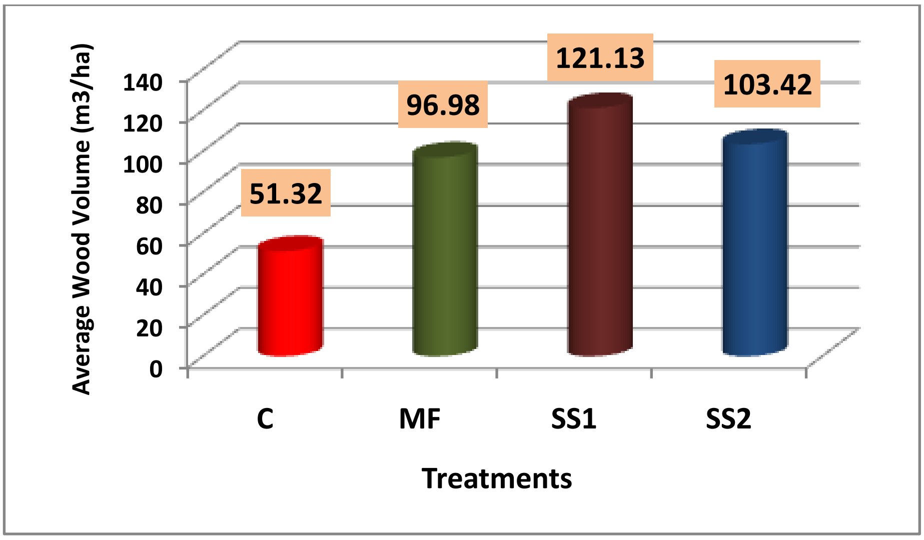

Figure (10): Average Wood volume (m^3/ha)

Table 12: ANOVA wood volume,comparison among treatments

Multiple Comparisons
Dependent Variable: V (m^3/ha)
LSD

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	MF	-45.66333-*	7.13600	.000	-62.1190-	-29.2077-
	SS1	-69.80667-*	7.13600	.000	-86.2623-	-53.3510-
	SS2	-52.10333-*	7.13600	.000	-68.5590-	-35.6477-
MF	C	45.66333*	7.13600	.000	29.2077	62.1190
	SS1	-24.14333-*	7.13600	.010	-40.5990-	-7.6877-
	SS2	-6.44000-	7.13600	.393	-22.8956-	10.0156
SS1	C	69.80667*	7.13600	.000	53.3510	86.2623
	MF	24.14333*	7.13600	.010	7.6877	40.5990
	SS2	17.70333*	7.13600	.038	1.2477	34.1590
SS2	C	52.10333*	7.13600	.000	35.6477	68.5590
	MF	6.44000	7.13600	.393	-10.0156-	22.8956
	SS1	-17.70333-*	7.13600	.038	-34.1590-	-1.2477-

*. The mean difference is significant at the 0.05 level.

4. Conclusions and Recommendations:

- In this experiment the application of dry sewage sludge in the planting rows was a large source of nutrients for eucalypt trees and significantly increased the dry biomass production of different tree parts and wood volume in comparison with the control treatment.
- this study shows that planting *Eucalyptus camaldulensis* in sandy soil with using sewage sludge as untraditional fertilizer may be a valuable option for the final disposal of this residue and a good chance to reduce or eliminate the risk of the environmental pollution resulted from sewage sludge, reducing considerably the requirements in mineral fertilizers.
- this experiment suggests that a minimum delay of one weekshouldbe respected between sewage sludge application and planting of eucalypt seedlings to avoid large mortality rates
- Complementary studies are necessary to assess other important environmental impacts of sludge application, in particular, the fate of heavy metals in soils and surface waters.

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