Addressing the restoration of degraded land in Europe using waste materials. A schist quarry in Greece

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Abstract
The extreme land degradation caused by quarrying leaves bare, ugly expanses, with very little topsoil remaining. Post mining restoration is very important for environmentally sustainable development. For effective, sustainable regeneration of such degraded sites the addition of organic matter is desirable. Waste disposal in Greece is a serious and increasingly acute problem, and initiatives such as the use of compost made from urban waste in land restoration are essential. The paper describes an experiment on the restoration of a schist quarry. *Pinus halepensis* Mill. were pocket planted and three different compost rates were applied in order to examine the effect of the addition of organic matter on tree establishment and development. Tree height, main stem diameter and branching were measured soon after planting, and are being followed at regular time intervals. Results to date show positive interaction between growth rates and compost amendment.
Keywords: Restoration; Quarry; Compost; Wastes; Pine trees.

1. INTRODUCTION

The extraction of mineral materials for many different industrial and construction purposes is widespread in Greece. There were 743 active quarries (including those lying idle for up to 2 years) serving different branches of mining in the year 2002 [1].
Surface mining and extraction activities cause intense changes to the landscape and result in the destruction of vegetation and soil, the alteration of relief, the imbalance of ecological conditions and changes in the natural landscape, beyond damage and nuisance in the wider area [2]. The scale and impacts of quarrying are generally more severe than other kinds of disturbance and the number of bare, ugly expanses virtually devoid of topsoil has increased rapidly over the last 50 years [3].
Although exploitation of the mining wealth of a country is a modern economic and social necessity, the finite nature of mineral deposits makes it a temporary landuse. The growing emphasis on sustainability means that the granting of planning permission for a new mine in many parts of the world nowadays requires the prior setting of landuse goals, which have a major influence on mining operations and waste disposal [4]. Sustainability may be taken to imply restoration of the land surface to maintain the land use options of future generations [5]. In practice, restoration usually aims to create the conditions under which the pre-existing plant and animal organisms may be reintroduced in the short or long term, resulting in a stable ecosystem that is able to support the pre-selected landuse [6]. For mining operations in Greece that take place in forested areas, restoration is synonymous with reforestation, but may include certain small scale projects beneficial to the public that are allowed by national law. Restoration of such sites ideally aims to create a self-sustaining ecosystem similar to that in the surrounding areas, which may be integrated into the cultural and economic activities of the wider region. In mountainous areas of Greece, these activities will often

include grazing, and restoration planning must take into account the detrimental effects this may have on the restored ecosystem, which must be capable of maintaining itself in the long term.
The majority of open mining sites contain large areas of stony waste, which usually present problems in one or more of their chemical and physical characteristics. A lack of fine material often leads to low water holding capacity, while flat areas may have been compacted by the use of heavy machinery. Available phosphorus and potassium are frequently inadequate, and nitrogen content is typically low because of the lack of organic material. Such conditions adversely affect the viability of revegetation in both the short and long term without ameliorative intervention. Incorporation of organic matter into waste rock generally promotes plant growth [7]. Considerable attention has been paid over the years to revegetation of mining spoil with the aid of sewage sludge, ash, limestone and/or other amendments [8]. The use of compost as an amendment is increasing for soil restoration in degraded Mediterranean areas. Indeed, it has been shown that such amendments increase soil fertility, plant biomass, plant nutrient uptake and plant cover [9]. However, there are only a few in situ studies on the use of Mediterranean trees for restoration [10].
It is economically and environmentally desirable that the organic matter used in restoration originates from materials that would otherwise be wasted and create a burden on the environment through their disposal. Waste disposal in Greece is a serious and increasingly acute problem, and initiatives such as the use of compost in land restoration, which support recent efforts to compost urban solid wastes and through this plant nutrient recycling, are essential.
Pinus halepensis is a drought – tolerant, fast growing conifer that grows from sea level to 1700 m. Summer temperatures averaging 20-25^{o}C accompanied by 3-month drought are typical in its (current) natural range is characterized by its inability to tolerate water logging and it is generally considered to be exceedingly tolerant to frost, depending on the microclimatic conditions, to nutrient – poor soils and to salt spray [11]. Bjugstad [12], reports that limited growth of tree seedlings should be attributed to the lack of nutrients, while drying out is very likely to be connected to factors such as the compaction of soil, long-term low rainfall and the limited presence of fine soil material (< 20%).
The main objective of this research is to demonstrate the restoration of a schist quarry site with the effective use of compost produced from municipal waste, green waste and digested sewage sludge.

2. MATERIALS AND METHODS

2.1 Site description

The experimental site is a schist quarry located in the mountainous area of Parnitha near Athens and is exploited by the TITAN Cement Company S.A. [13]. The climate is typical Mediterranean with mean annual rainfall exceeding 650 mm. The well-forested area surrounding the site has fairly poor, dry soil and is characterised by forests of the endemic Greek fir *Abies cephalonica* Loud., temperate coniferous forests (mainly *Pinus halepensis* Mill.), sclerophyllous scrub/maquis, mountain grassland, rocky cliffs, springs and streams [14].

2.2 Experimental design

Three different areas within the quarry were selected representing three different topographies. These are a compacted, flat area with seasonal water logging, a gently sloping, land formed area, and artificially created mounds of overburden rock material formed on the flat area. The experimental reclamation test plots were established in November 2005 and they were fenced for protection from animal grazing. The dimensions of the flat and sloping experimental sites are 24 m x 12 m each, while 18 mounds of approximately 6 m x 3 m and 1 m height were formed in an area of approximately twice the size. Three compost:schist treatments of 0:3 (C0), 1:2 (C1) and 2:1 (C2) by volume were used, with six replicates in each experimental site in a completely randomized design, in order to examine the effect of the addition of organic matter on the establishment of pine trees (*Pinus halepensis* Mill.) on the infertile schist material (Table 1). Pine trees (*Pinus halepensis* Mill.), 4 per replicate, were pocket planted with the ball of their nursing soil in a volume of 3 L of schist or schist:compost mixture and were watered (5 L per plant). There was no additional watering during the growth period. Tree height, main stem diameter and branching were recorded following planting. These measurements are being repeated at six-monthly intervals. The availability of nutrients and other soil physicochemical parameters are also being studied and will be related to plant growth. Two hypotheses will be tested: that compaction and water logging reduce pine establishment and growth and that nutrient addition through the application of compost is favorable to the establishment and growth of pines on schist waste.

2.3 The compost

The compost used was provided by the Association of Communities and Municipalities in the Attica Region (ACMAR) and is produced in its recycling plant. The compost is the final product of the aerobic degradation process of the homogenized organic fraction of municipal wastes, green wastes and treated sewage sludge [15].

2.4 The seedlings

The tree seedlings (*Pinus halepensis* Mill.) planted, were one year old in clayey soil balls and were produced at TITAN's nursery in the region of Elefsina. Their height ranged from 16 to 19 cm and their main stem diameter from 2.4 to 3.2 cm. The date of planting was 19th and 20th January 2006 respectively for the mounds and the slope and 5th April 2006 for the flat. Planting on the slope and mounds was followed immediately by severe winter conditions accompanied by snow, which prevented planting of the flat area for several weeks. These conditions killed several seedlings on the sites already planted (10 on the mounds and 11 on the slope) and these seedlings were replaced when the flat site was planted approximately 10 weeks later. The intervening period is assumed to be of no significance as far as growth of the seedlings is concerned and for this reason time zero for all the sites is taken to be the same (the date of the spring planting). The initial plant deaths on the mounds and slope were not taken into account.

3. RESULTS AND DISCUSSION

3.1 Soil analysis

Schist material and compost used were analyzed for the physicochemical properties (Table 1).

Table 1. Physicochemical analyses of parent schist material and of compost after planting.

Parameter	Schist	Compost
Moisture Content (%)	5.8	40.7
Organic Matter (%)[1]	0.7	32.6
Organic Carbon (%)	0.4	18.9
Saturation Percentage (%)	12.6	70
E.C. (mS cm^{-1})	2.9	21.7
Salts (%)	0.04	1.94
pH	7.51	6.99
$CaCO_3$ (%)	0.5	22.7
Total Nitrogen (%)[2]	0.04	1.59
Available P (mg kg^{-1})[3]	0.28	96.2
K (meq $100g^{-1}$)[4]	0.10	17.9
Ca (%)[5]	0.08	0.92
Mg (%)[5]	0.03	0.12

[1] Walkley – Black method
[2] Kjeldahl method
[3] Olsen method
[4] Flame photometer determination
[5] Atomic absorption determination

The low values of all nutrients in the schist material indicate the desirability of compost amendment for the successful establishment of healthy tree growth.

3.2 Tree survival

Results to date show that tree survival and plant establishment were markedly better on the sloping area and the mounds than on the flat site. Table 2 gives the percentage of trees surviving on each site during the first year of the experiment (2006).

Table 2. Percentage survival of trees (*Pinus halepensis* Mill.), during the first year after planting.

	Experimental Sites		
Treatment	**Flat**	**Slope**	**Mounds**
C0	87.5	91.7	100
C1	83.3	91.7	100
C2	54.2	100	100

The small number of seedling deaths on the sloping site is likely to be a consequence of the severe weather conditions immediately after planting. Only the most severely damaged seedlings that had completely dried out were replaced in April after the snow had melted, although some other trees had been substantially damaged. The cause of the seedling deaths on the flat site is not at present clear, although the higher rate of compost application would appear to be a factor. There may be small variations in the spatial distribution of compaction and waterlogging over the site that have an effect on plant survival.

3.3 Tree growth

The results for the three parameters selected to depict growth rate are shown in Figure 1. All are representative of the development of the seedlings, but the plant height and main stem diameter are more sensitive indicators of this than the number of secondary branches.

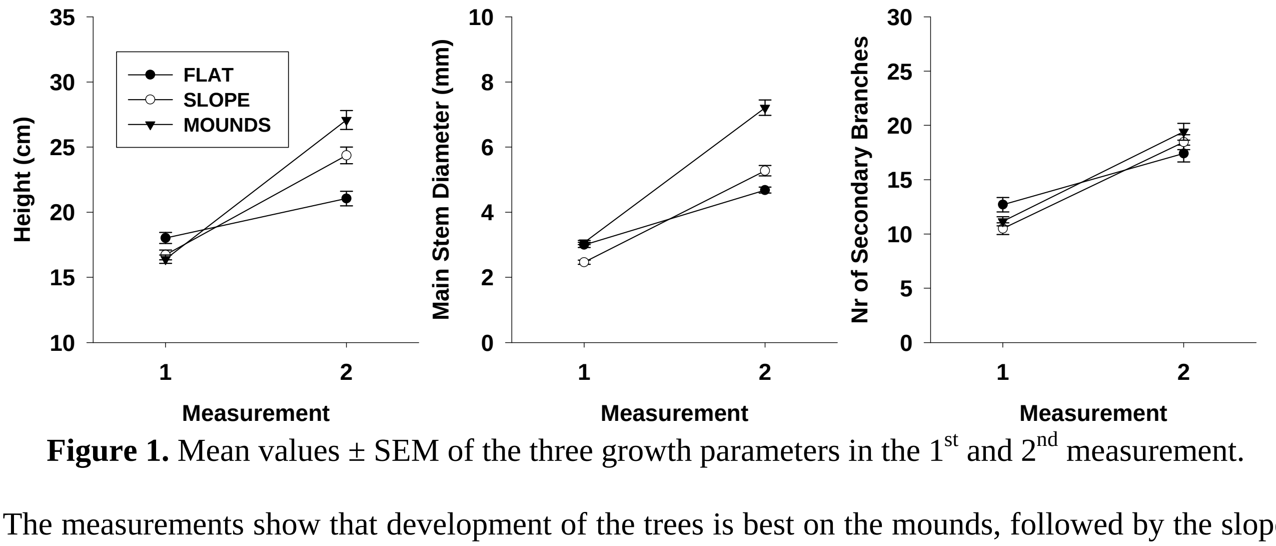

Figure 1. Mean values ± SEM of the three growth parameters in the 1st and 2nd measurement.

The measurements show that development of the trees is best on the mounds, followed by the slope and lastly the flat site. The sloping site has a north-west aspect and is susceptible to strong winds, while the mounds in the flat area of the quarry are more sheltered, and compaction and water logging affect the flat site.

A clear outcome of the first year's monitoring is that addition of compost at planting resulted in a greater average increase in height, main stem diameter and number of secondary branches than the increase observed in the trees with no compost amendment. This is shown in Figure 2, in which the mean percentage increase of each growth parameter for the different sites and treatments are compared. This trend is clear for the slope and mounds for all three parameters, but for the flat topography only the lower compost dose shows a slightly higher rate of growth.

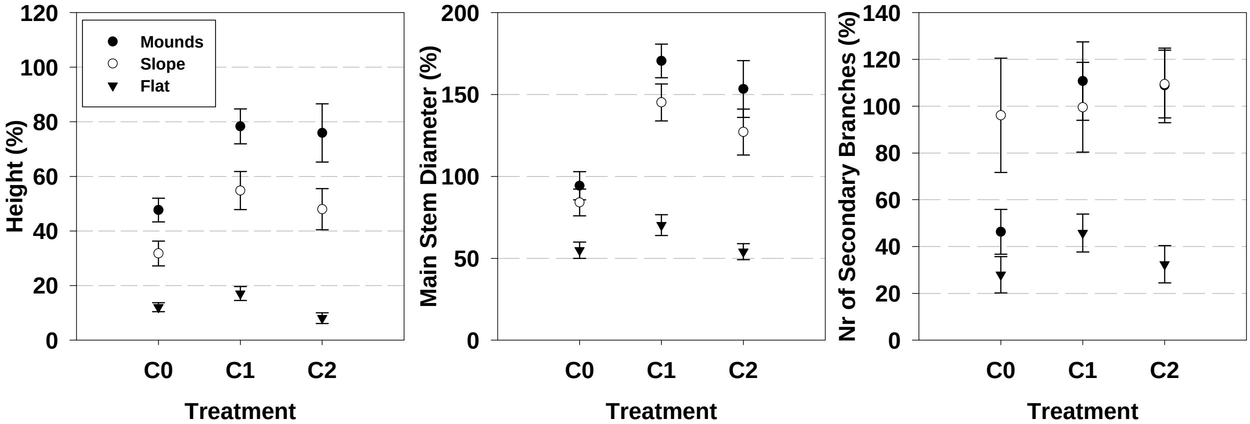

Figure 2. Growth rates ± SEM of the measured parameters per treatment and experimental site.

An analysis of variance revealed that there is a significant difference between the growth rates calculated for the pairs of treatments C0-C1 ($P<0.05$) for the sloping site, and C0-C1 ($P<0.05$) and C0-C2 ($P<0.01$) for the mounds (Table 3). The differences between the effects of C1 and C2 treatments in plant growth were not significant during the first year. In addition, the picture for the flat site is rather confused because of the lower number of surviving pines treated with the higher compost rate and the limited measurements taken to date.

Table 3. Analysis of variance between the treatments applied per experimental site, concerning height growth rates.

Treatment	Flat			Slope			Mounds		
per site	C_0	C_1	C_2	C_0	C_1	C_2	C_0	C_1	C_2
C_0	-	n.s.	n.s.	-	*	n.s.	-	**	*
C_1		-	**		-	n.s.		-	n.s.
C_2			-			-			-

* P < 0.05
** P < 0.01
n.s. no significant difference

The same results as those presented in Table 3 result from the analysis of the stem diameter and number of branches for the three treatments (not presented here). Further measurements are required for definite conclusions to be reached regarding the effects of compost addition on tree development for the three different sites.

4. CONCLUSIONS

The present experiment shows that compost addition during the planting of *Pinus halepensis* Mill. seedlings for the restoration of a disused schist quarry enforced seedling development on the sloping and mound sites, with increased tree height, stem diameter and side branching. On the flat site, which is compacted and prone to water logging, tree survival was lower and the effect of compost amendment less clear. Future monitoring of the sites is expected to clarify which of the two rates of compost addition is more favourable to tree development and to establish whether planting trees directly on the flat without the formation of mounds is a realistic option for restoration.

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