Highlights

- CGW addition significantly increased SOC, SOM and soil nutrient levels.
- Final soil pH was highest under the control treatment
- CGW addition led to significantly greater *Alnus cordata* growth.
- *Alnus cordata* survival rate was highest under both CGW and earthworm addition.
- *Acer platanoides* growth and survival was negatively affected by soil drought conditions.

Effects of composted green waste on soil quality and tree growth on a reclaimed landfill site

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Abstract

The addition of composted green waste (CGW) into soil-forming materials during land reclamation can benefit tree growth by improvement of soil properties and provide an effective waste management solution. CGW addition may also assist the establishment of earthworm populations, which in turn aid soil development through their burrowing and feeding activities. An experiment was set up on a reclaimed landfill site, to measure the effects of CGW addition on soil physical and chemical quality and subsequently on the survival and growth of two tree species (*Acer platanoides* and *Alnus cordata*). A further objective was to measure the influence of earthworm (*Aporrectodea longa*) addition on the above. CGW addition led to significantly greater *A. cordata* growth (height and diameter) and increased survival rate. No benefits from CGW addition were observed on *A. platanoides* growth or survival, although this is likely due to soil drought conditions during establishment. CGW addition significantly increased levels of organic carbon and essential plant macro-nutrients in the reclaimed soil. Soil pH rose slightly across all treatments, with highest final pH under the control treatment. Earthworm inoculation, as used, was unsuccessful at increasing population density of *A. longa*. This experiment showed that CGW application can effectively improve tree establishment and soil quality on reclaimed landfill; however tree species selection is an important consideration, based on individual species tolerance and sensitivity to certain soil conditions. These findings will be informative to decisions on soil amendment and afforestation activities on similar reclaimed landfill sites.

Keywords

Acer platanoides; *Alnus cordata*; *Aporrectodea longa*; *Earthworm; Organic waste; Soil quality*.

1. Introduction

There is scientific and industry-based interest in improving the soil materials used in land reclamation for soft-end use projects, particularly through the addition of organic matter (OM) from waste streams such as composted green waste (CGW) [1–3]. Benefits of CGW in soil improvement include a source of plant nutrients such as slow-releasing nitrogen and high OM material input improving soil physical structure and water retention [3]. Despite availability of guidance regarding the amendment of soil-forming materials with organic wastes [2,4–6], these materials are not typically used during the creation of community woodland [7]. Little research currently exists which has specifically investigated CGW interactions with trees on reclaimed land. In one of the few relevant studies, Foot *et al*. [8] conducted a field experiment investigating the effect of CGW incorporation on soil development and establishment of sycamore (*Acer pseudoplatanus*) and Italian alder (*Alnus cordata*) on a capped landfill. Incorporation of CGW to 0.6 m depth and high rates of application (500 t ha^{-1}) of CGW were beneficial to the establishment of both tree species. Improved tree growth was attributed to provision of nitrogen to the N-limited sycamore and improving soil structure, enabling deeper root penetration and subsequently greater opportunity for nitrogen fixation by alder [8]. Reclaimed soils are widely heterogeneous [9], and tree survival and growth on reclaimed sites is based on individual species tolerance for soil conditions [10]. Further research is needed to build an evidence base for CGW effects on tree species and reclaimed soils, to inform and substantiate future land reclamation activities.

In recognition of their role in improving soil structure and fertility, earthworms have been the subject of research during land reclamation for over 50 years [11–13]. On reclaimed sites, the addition of OM to soil may benefit earthworm populations [14,15] and a range of organic waste types including CGW have been investigated for their suitability [15–17]. It has been shown that certain earthworm species (such as the deep-burrowing *Aporrectodea longa*) actively incorporate and mix organic waste materials into and within soils, improving mineralisation and benefiting soil fertility [14,18]. The supplementary addition of earthworms may therefore be an effective way of enhancing the benefits of organic waste utilisation during land regeneration. However, little research exists which investigates CGW interaction with earthworm populations in reclaimed soils [15,19,20]. The few available studies suggest that CGW can promote the development of earthworm populations on reclaimed sites, and may help promote soil development and tree growth; however uncertainties exist over species-specific earthworm interactions with CGW and tree species, particularly on reclaimed land.

An experiment was therefore set up on a reclaimed landfill site with the objectives to measure i) changes in soil physical and chemical quality over a two-year period following CGW addition, ii) the effects of CGW addition on the survival and growth of two tree species, and iii) the influence of earthworm addition on tree survival and growth, and on soil condition.

2. Material and methods

2.1. Study site

The experiment was conducted at Ingrebourne Hill Community Woodland, a 54 ha area of reclaimed land in Rainham, Essex, UK (51.527ºN, 0.198ºE). The area receives approx. 1,500 h sunshine and <600 mm rainfall per annum, and a mean daily maximum temperature of >14°C (Met Office, 2015). The site is a former gravel extraction and inert waste disposal landfill (1950s-1990s). It underwent clay capping, followed by placement of screened construction waste materials as soil substrate between 2000 and 2007. Soils at Ingrebourne Hill are comprised principally of sandy clay loam materials, with a high stone content [22]. Despite loose-tipping practices during site restoration, a survey 5 years after soil placement revealed heavy compaction (soil bulk density of >1.5 g cm^{-3}) and a shallow tree rooting depth (0.1 – 0.3 m). Soils were slightly alkaline with a pH of 7.9 and average soil organic matter (SOM) was 4%. Soil extractable total N was low at 0.19 mg l^{-1}, with a C:N ratio of 29. Metal contents were within the UK soil guideline values for non-residential uses, and not considered to be at levels harmful to fauna and trees [23].

2.2. Experimental design

Figure 1 shows the layout of the experiment, which consisted of five blocks, each containing a randomised arrangement of four 100 m^2 treatment plots: i) CGW addition only; ii) earthworm inoculation only; iii) both CGW addition and earthworm inoculation; and, iv) no treatment (control) (20 plots in total). Each 100 m^2 plot contained two monoculture planting stands (one per tree species, with 1 m planting distance between trees), separated by a 2 m intra-plot buffer zone to prevent mixed-species interaction effects. Prior to tree planting, each plot underwent complete cultivation of soil to 0.5 m depth by digging and mixing the soil with a 3 tonne 27 horse-power hydraulic excavator, to relieve soil compaction. For plots receiving CGW treatment, cultivation also included its incorporation into the soil, through surface application followed by thorough mixing during cultivation. A physical barrier to earthworm ingress/egress from experiment plots was installed during cultivation. This consisted of sheets of LDPE damp-proof membrane buried to 0.5 m depth, with 0.2 m above-ground along the perimeter of all experimental plots, considered suitable to prevent species movement between plots (after Bohlen *et al.* [24]). The whole experimental area was also surrounded by a conventional fence to prevent tree damage by the public and browsing animals (e.g. deer). The experiment was set up in April/May 2013 and ran for 24 months.

2.3. Experimental treatments

For CGW-treated plots, soil cultivation included incorporation of screened 0-25 mm PAS 100 "Soil Improver" grade CGW (courtesy of Viridor Waste Management Ltd, Croydon, UK) at a rate equivalent to 500 kg Total N ha^{-1} following legal limit set by Nitrates Directive (91/676/EEC) for the site which is in a Nitrate Vulnerable Zone (NVZ), and in keeping with guidance by Taylor [25] and Bending *et al*. [9]. Each CGW treatment plot received approximately 1 tonne CGW. Due to potential difficulty in mass determination of one tonne of CGW in the field, 2 m^3 of CGW (one digger bucket) was added to each plot, which equals approximately 1 tonne. At 10% N availability, this provided each 100 m^2 plot with 0.62 kg available N and 305 kg C. This application rate is equivalent to 30.5 kg C m^{-3}, resulting in an average initial total soil C concentration of 17.6% in CGW plots. A full summary of CGW nutrient content is provided in Table 1.

[INSERT TABLE 1]

Amended soils were allowed to settle for one week prior to tree planting. Tree species selected for this experiment were Italian alder (*Alnus cordata* (Loisel.) Duby) and Norway maple (*Acer platanoides* L.); two species recommended for planting on reclaimed or industrial land based on their tolerance for high soil pH and dry soil conditions [10]. One-year-old root-trainer seedlings (the standard age for trees planted for forestry purposes) were obtained from nursery stock. Seedlings of both tree species (n = 21 per species) were planted in each plot (20 plots X 21 trees = 420 per species) as shown in Figure 1.

[INSERT FIGURE 1]

This experiment also investigated the activity of the earthworm *Aporrectodea longa*, an anecic earthworm species previously identified as suited to land reclamation sites and involved in physical and chemical soil development [19]. Baseline survey post-cultivation revealed low numbers of *A. longa* (1 m^{-2}) across the experimental plots. In July 2013, the earthworm treatment plots were inoculated with additional *A. longa* to boost the population density. For inoculation, adult *A. longa* were collected using a mustard suspension vermifuge at a concentration of 50 g to 10 litres of water, applied liberally to the soil surface in areas of earthworm casting in surrounding, non-experimental parts of Ingrebourne Hill Community Woodland. Adult earthworms of this species were visually identified in the field during collection, washed to remove vermifuge and briefly stored in trays containing freshly dug soil. In total, 4,200 adult *A. longa* were collected and transported to the experiment. As appropriate, earthworms were randomly assigned to trees, at a rate of five earthworms per tree. The inoculation consisted of earthworms being added to 5 cm deep freshly dug holes at the base of each tree one week after planting, the soil replaced and soaked with fresh water. This inoculation rate tripled the baseline *A. longa* density in earthworm treatment plots to 3 m^{-2}.

2.4. Sampling and measurements

Tree survival and growth (height and ground-line diameter) were measured at six month intervals. Diameter was measured using callipers at the ground-line of trees, which is defined as the point on the main stem 2 cm above the soil surface [26]. To account for asymmetrical stem growth, diameter was measured twice, at right angles to each other, and the mean value recorded. The baseline diameter measurements were taken 2 weeks after tree planting, to allow soil at the base of the trees to settle. Tree height was measured using a tape measure, recording the vertical distance from the base of the tree to the uppermost point or tip.

At 0, 6, 12, 18 and 24 months, soil samples were taken from within each experimental plot for chemical analysis. This followed a 'W-shaped' sampling approach, whereby in each plot 21 samples were collected from 0 - 20 cm depth using a soil auger, and bulked into one sample per plot. This method ensures sufficient sampling cover per plot to account for the spatially heterogeneous nature of the soil [27]. Bulk soil samples had total C and N concentrations determined using a C:N Elemental Analyser (Carlo Erba (THERMO), FLASH EA 1112 Series), and total major elements (P, K, Ca and Mg) by inductively coupled plasma-optical emission spectrophotometry (ICP-OES) analysis after sulphuric acid digestion of the soil. Soil Moisture Content (SMC) was analysed by oven drying at 105^{o}C for 24 hours; OM content was determined by loss-on-ignition (550^{o}C for 2 hours), and soil pH was measured in water suspension. Extraction by 1M KCL-extraction was used on fresh soil for determining levels of available nitrate (NO_3^-) and ammonium (NH_4^+), by colorimeter analysis [28].

Earthworm community density and change were assessed to confirm earthworm inoculation outcome, and to identify any effects of tree species and soil treatment on earthworm populations. Earthworm surveying of experimental plots was carried out at the start of the experiment following soil cultivation and tree planting, and repeated at 30 months (in late October, as this provided more suitable seasonal conditions for earthworm sampling than at experiment termination in June after 24 months). Each experimental plot had 10 samples taken using a 0.1 m^2 quadrat dug to 15 cm depth, the soil removed and hand-sorted for earthworms and a mustard vermifuge solution applied to the pit to extract deep-burrowing earthworms [29]. Collected earthworms were placed directly into pre-labelled plastic bottles containing 4% formaldehyde solution, then transported to the laboratory and all adults identified to species level following the key of Sims and Gerard [30].

2.5. Statistical analysis

Statistical models were applied to data on tree survival, height and ground-line diameter, earthworm community density and species richness, and soil chemical parameters. Data were first tested for normality using the Shapiro-Wilk test, which is suited to small sample sizes (in this case n=5). Where data had a normal distribution, they were analysed using one and two-way analysis of variance (ANOVA) with the Tukey-Kramer post-hoc multiple comparison test applied to significant treatment interactions, and time-series data analysed using repeat-measures ANOVA. Where the assumptions of ANOVA were not met, non-parametric Kruskal-Wallis ANOVA or Mann-Whitney U tests were applied, as appropriate. Whilst the experimental design resembled a split plot design, the separation of trees into monoculture stands within plots enabled tree species to be analysed independently using the models described above. Statistical analysis was performed using the statistical software GenStat (Release 16.2).

3. Results

3.1. Effects of CGW addition on reclaimed soil quality

SOC (%) and SOM (%) content increased across all treatments as a consequence of the CGW addition and throughout the experiment (Figure 2). However, there was significantly greater SOC and OM (%) in soils that received the combined treatment (repeated measures ANOVA, treatment effect ($F (3, 12) = 3.82$, $p < 0.05$), and ($F (3, 12) = 3.82$, $p < 0.05$), respectively)). Total N (%) remained steady across all treatments until 18 months, after which it increased for all treatments. Final total N (%) was significantly greater in soils that received both the combination and CGW-only treatments (repeated measures ANOVA, treatment effect ($F (3, 12) = 5.07$, $p < 0.05$)). At the start of the experiment, soil total K (mg kg^{-1}) levels were higher in the CGW and combination treatments, however after 24 months there were similar K levels across all treatments (Figure 2), a statistically significant change (treatment effect, repeated measures ANOVA, ($F (3, 12) = 14.07$, $p < 0.001$)). Soil Na (mg kg^{-1}) levels were initially higher in the CGW and combination treatments, however after 24 months levels had reduced across all treatments to a similar amount (data not shown, treatment effect, repeated measures ANOVA, ($F (3, 12) = 9.42$, $p < 0.01$)). Soil pH rose slightly across all treatments, with highest initial pH of 8.3 under the combination treatment, and highest final pH of 8.4 under the control treatment (treatment effect, repeated measures ANOVA, ($F (3, 12) = 3.48$, $p < 0.05$)). There was a significant effect of time on SMC (repeated measures ANOVA, ($F_{(4, 12)} = 602.4$, $p < 0.001$)), but no treatment effect. Soil drought conditions were evident during early summer months with an average SMC of 15.3% and 8.1% at 12 and 24 months, respectively, compared with 33.0% and 28.8% in the late autumn at 6 and 18 months, respectively (data not shown).

[INSERT FIGURE 2]

3.2. Effects of CGW addition on tree survival and growth

A. cordata demonstrated high survival rates (>88%) across all treatments; no statistically significant treatment effect ($p > 0.05$) was found on *A. cordata* survival after 24 months (Table 2). Initially there was no difference in mean *A. cordata* tree height between treatments (Figure 3), but at termination of the experiment, a significant treatment effect was found under the combination and CGW-only treatments (ANOVA, ($F_{(3, 12)} = 13.71$, $p < 0.01$)). There was a significant effect of treatment (repeated measures ANOVA ($F_{(3, 12)} = 10.29$, $p < 0.001$)), and interaction effect of time and treatment (repeated measures ANOVA ($F_{(12, 64)} = 5.85$, $p < 0.001$)), under the combination and CGW-only treatments on *A. cordata* height. There was no difference in the mean basal diameter of *A. cordata* between treatments (Figure 3), however, at termination of the experiment a significant treatment effect was found (ANOVA, ($F_{(3, 12)} = 7.61$, $p < 0.01$)) under the combination and CGW-only treatments. There was a significant effect of treatment (repeated measures ANOVA ($F_{(3, 12)} = 5.81$, $p < 0.05$)), and interaction effect of time and treatment (repeated measures ANOVA ($F_{(12, 64)} = 3.27$, $p < 0.01$)), on *A. cordata* diameter under the combination and CGW-only treatments.

After 24 months, *A. platanoides* showed poor survival rates (51 to 64% survival) and no significant effects of treatment on survival, basal diameter or height (ANOVA and repeated measures ANOVA, $p > 0.05$) (Table 2).

[INSERT FIGURE 3]

[INSERT TABLE 2]

3.3. Effects of tree species and CGW addition on earthworm populations

Baseline survey of plots showed five earthworm species present, all at low mean densities, with no significant differences in abundance between plots: *Lumbricus festivus* (1 m^{-2}), *Lumbricus castaneus* (10 m^{-2}), *Lumbricus terrestris* (0.2 m^{-2}), *A. longa* (1 m^{-2}) and *Allolobophora chlorotica* (8 m^{-2}). Survey of control plots after 30 months revealed significantly higher final *A. longa* and *A. chlorotica* densities than the baseline (mean = 18.5 and 28.5 m^{-2}, respectively) (Mann-Whitney U test, df = 4, $p = 0.016$ and $p = 0.032$, respectively). However, at 30 months, there was no effect of CGW addition, earthworm inoculation treatment or tree species on *A. longa* density (Kruskall-Wallis non-parametric ANOVA, $p > 0.05$).

4. Discussion

4.1. Effects of CGW addition on soil quality

SOC and SOM (%) was significantly increased in soils that received the combination treatment, over and above that due only to the addition of CGW. Since there was slightly higher earthworm density under the combination treatment, this may be attributed in part to increased accumulation of leaf litter alongside the CGW in these plots through earthworm activity [31]. Whilst CGW application to soil-forming materials increased SOM content, SOM has been reported to rapidly decline after application due to utilisation by soil fauna [15,32]. However, in the case of the current study, SOM and SOC both remained relatively constant across all treatments, and then increased after 18 months. This may have been due to experimental trees reaching sufficient age to begin leaf litter contribution to the soil, and due to a low density of indigenous soil fauna to mineralise the added OM at the start of the experiment. This trend of increasing SOM, especially in the presence of earthworm activity, is likely to have beneficial outcomes on soil microbial diversity and associated nitrogen mineralisation [33].

Nitrogen is the major plant nutrient most often deficient in reclaimed soils [9]. Concentrations of total N followed a similar pattern to SOC in this experiment, remaining steady across all treatments until 18 months, after which it began to increase (and was significantly higher in CGW-receiving plots). The trend suggests that CGW was the primary source of the increase in soil total N until measureable input from leaf litter began after 18-months. Typically, levels of other essential plant nutrients in soil-forming materials and reclaimed soils vary widely depending on the nature of the source materials [9]. In this experiment, levels of soil K, P and Mg were higher irrespective of treatment than the minimum standard Agricultural Development and Advisory Service (ADAS) index values required for woodland establishment [34], so these should not have limited plant growth. CGW addition was shown to raise initial soil K levels in the current experiment, however after 24 months there were similar K levels across all treatments, likely due to leaching [6]. Foot *et al*. [8], investigating similar application rates to those used in this study, found that K was released in sufficient amounts to support tree growth for up to four years after application.

4.2. Effects of CGW addition on tree survival and growth

In the present experiment, *A. cordata* survival in the CGW-only treatment was 93%; which is much higher than the maximum of 74% (minimum of 11%) recorded by Foot *et al*. [8] for comparable *A. cordata* saplings, after three years in a higher quality reclaimed soil (sandy brown-earth) receiving CGW treatment. In our study, significantly greater *A. cordata* height was recorded under the treatments which included CGW. This is in keeping with the findings of Foot *et al*. [8], who found greatest *A. cordata* height under incorporation to 0.6 m depth of CGW at the same application rate used here; although this relationship was not statistically significant. The improvement in *A. cordata* growth through CGW addition was attributed to the encouragement of an open-structure in the soil, thus enabling deeper root penetration and subsequently greater opportunity for nitrogen fixation [8]. This was considered to be more likely than CGW conveying direct nutrient benefits to alder, which are not N-limited due to symbiosis with associated nitrogen-fixing bacteria.

Few studies were found which have investigated basal diameter as a measure of young tree growth in response to earthworm soil treatments [35,36]. Avendaño-Yáñez *et al*. [35] recorded significantly greater basal diameter of *Quercus insignis* seedlings with the addition of the exotic earthworm *Pontoscolex corethrurus*, legume compost and inorganic fertilizer, relative to a control. However, Rajapaksha *et al*. [36] found no influence on basal stem diameter of one year old saplings of the tree species *Betula pendula* and *Eucalyptus nitens* in the presence of the earthworms *Lumbricus terrestris* and *Allolobophora chlorotica*. In our experiment, basal diameter data mirrored the trends found in height data, with significantly greater basal diameter of *A. cordata* in treatments containing CGW. It is proposed therefore that basal diameter is a valuable metric for measuring the growth of very young trees, which cannot be recorded by traditional means of Diameter at Breast Height (DBH).

A. platanoides survival rates (42-55% overall) did not benefit from CGW addition or earthworm presence. However, this may reflect the effect of hostile climatic conditions within 6 months of planting, hindering establishment. The summer of 2013 was recorded drier and hotter than average, with a prolonged heatwave throughout July [37]. Visual assessment of trees and soil during that period indicated severe soil drought conditions and high levels of *A. platanoides* mortality. The hypothesis that drought caused this mortality is further supported by almost double mean survival rate (89.9% survival) of *A. platanoides* replacement trees planted after the summer drought conditions of the first 6 months. Comparatively, in a synchronous controlled nursey experiment, *A. platanoides* showed 100% survival in irrigated reclaimed soil from the Ingrebourne Hill site [38]. *A. cordata* demonstrated greater drought tolerance than *A. platanoides*, with >90% survival of the original tree stock after the first year. Initial site and climatic conditions have been shown previously to have a greater influence than CGW application on tree survival on reclaimed sites [8].

4.3. Effects of tree species and CGW addition on earthworm populations

Final earthworm density and species richness was similar across all treatments, although highest under the CGW only and combination treatments. It would appear that inoculation of *A. longa* did not affect the short-term population density of this species (an average and statistically non-significant density increase of 1.4% in inoculated plots), most likely due to a high mortality rate following inoculation. The methodology adopted for this experiment (a modified form of broadcasting), whilst suited to the timeframe available for experimental setup, was not as likely to ensure survival of the inoculated earthworms as methods such as the Earthworm Inoculation Unit [13]. Starvation is unlikely to be responsible for earthworm mortality, as a lower application rate of CGW (20 t ha^{-1} versus the 100 t ha^{-1} here) has been demonstrated to support earthworm populations for up to four years on reclaimed land [19]. CGW addition has thus been shown to sustain soil faunal populations on reclaimed sites in the initial period when trees are still becoming established, which is normally considered to be 3-5 years [39,40]; though such a conclusion is not supported by the results of this study.

As the earthworm density in the control plot after 30 months was similar to the other treatments, it is likely that the earthworm densities across all treatments are the result of natural population growth from the baseline population. The final earthworm populations may therefore reflect either the carrying capacity of the soil, or limited short-term population growth at the time of measurement. It is also possible that the observed increase in earthworm numbers in the plots which originally received no earthworm introduction is the result of earthworm migration between plots, by crossing the plot membrane barriers. Egress of experimental earthworms from the system, or the ingress of earthworms from the surrounding environment is a common issue with outdoor mesocosm/macrocosm earthworm experiments [41]. In our experiment, the barriers were observed to have lost above-ground rigidity within the first year, and therefore may not have been an effective barrier to earthworm movement.

5. Conclusions

This experiment demonstrated that CGW application was an effective method of improving soil quality and the growth of *A. cordata* on a reclaimed landfill site. Incorporation of CGW to soil materials during placement provided initial support to the young trees, and CGW addition therefore gives land reclamation professionals an opportunity to improve vegetation establishment. Tree species selection was also found to be important in their establishment on reclaimed land. Where soil quality is given due consideration and improved through the application of organic wastes then trees may show better performance than might be observed in un-amended soil. Further research could include an investigation of different application rates of CGW or other organic waste materials for additional information on its effects on woodland and earthworm establishment (although the CGW application rate used in this study was determined by legislative constraints). When considering tree growth, such studies should take place over longer timeframes (10+ years) to consider the longer term impacts of organic waste application and earthworm inoculation. Improved techniques for earthworm inoculation could be useful for earthworm establishment, and future research could explore the effects of alternative earthworm species in developing reclaimed soil.

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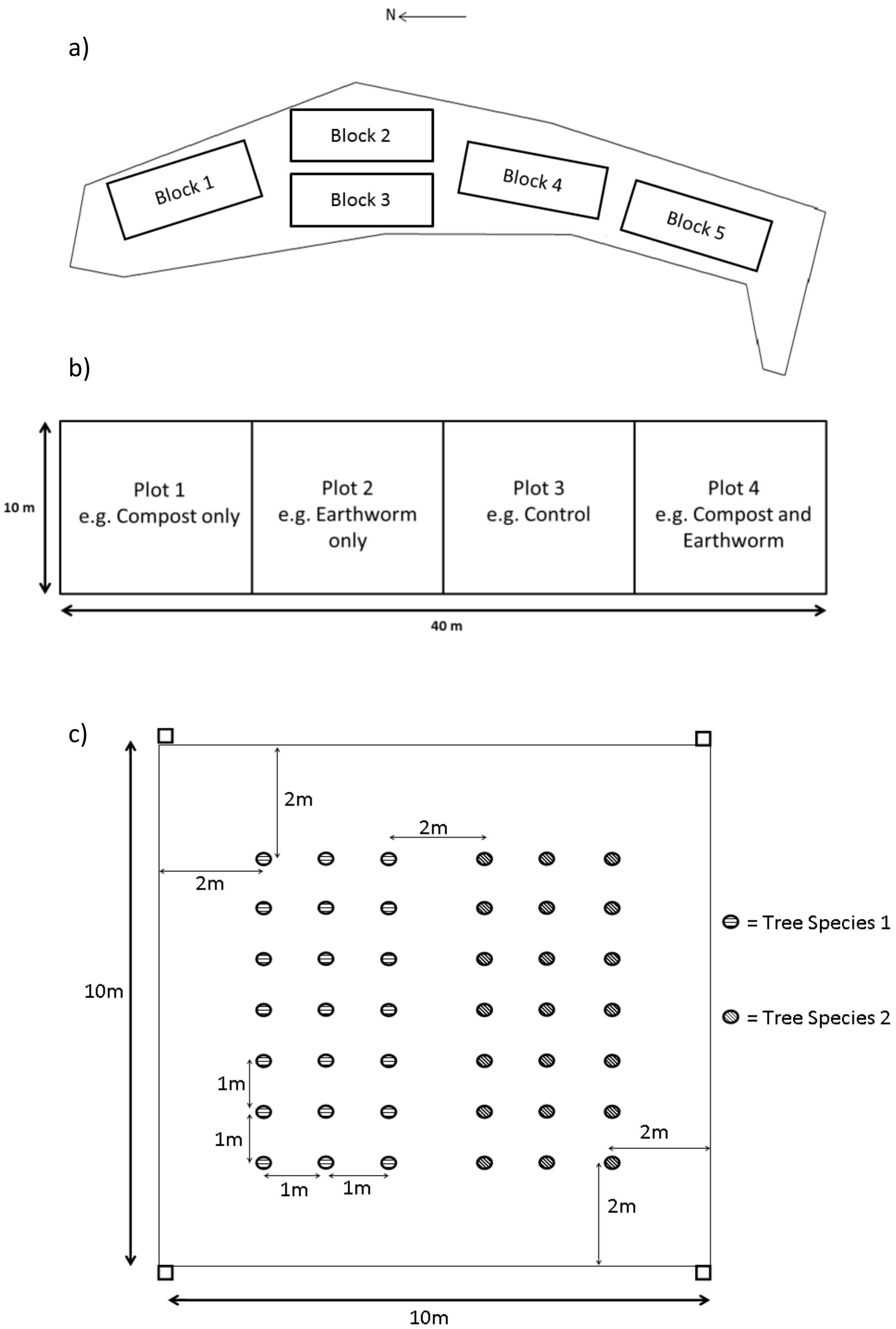
Table 1

Parameter	Oxide	Total nutrient Kg t^{-1} (Fresh Weight)	% nutrient availability (in first year)
Nitrogen	N	6.20	10
Phosphate	P_2O_5	2.12	75
Potash	K_2O	4.65	90
Magnesium	MgO	2.10	60
Sulphur	SO_3	3.05	30
Organic Matter	n/a	620	n/a

Table 2

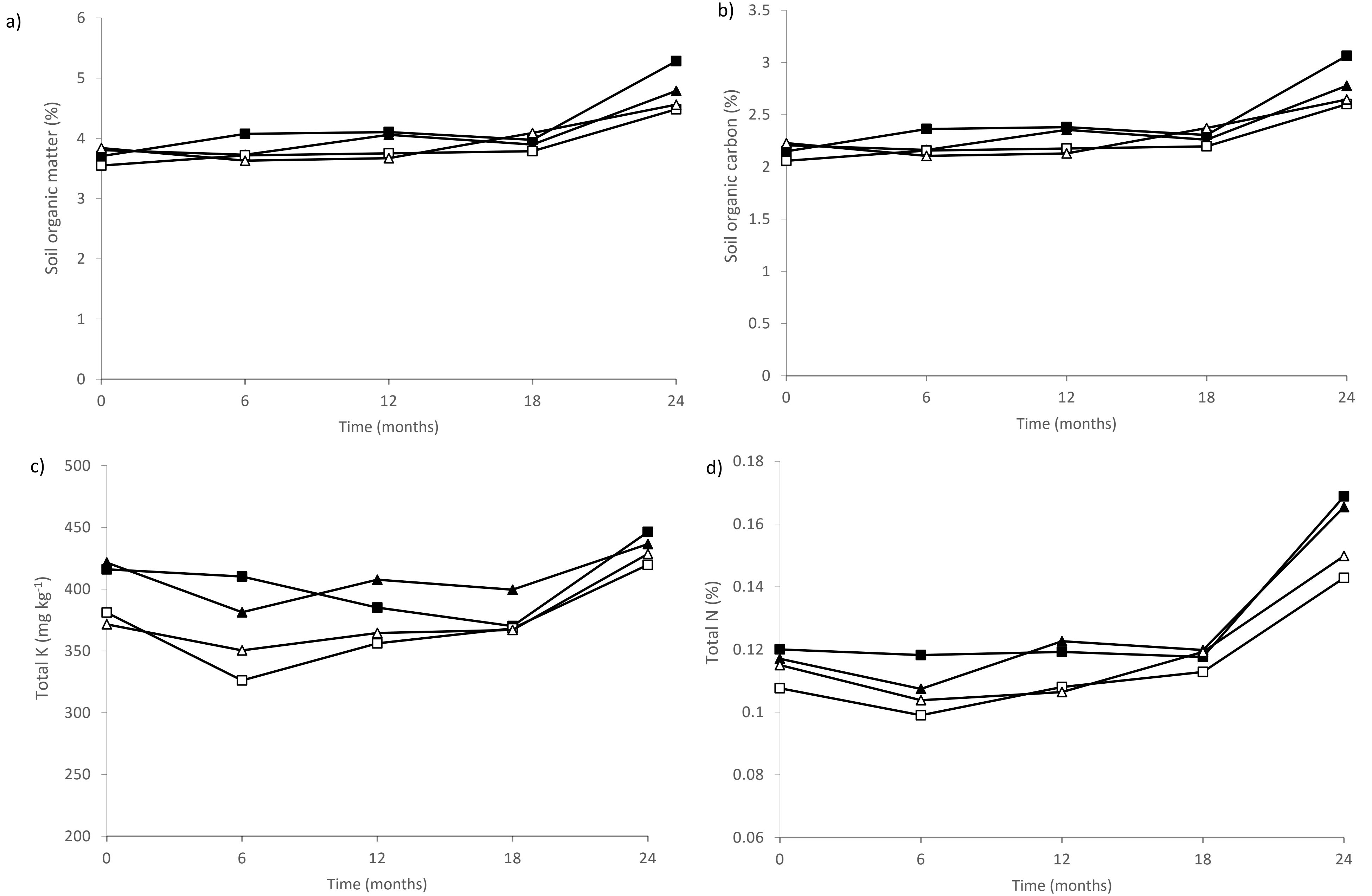
	A. cordata		*A. platanoides*	
Treatment	12 months	24 months	12 months	24 months
Control	93.3 ± 1.9	90.5 ± 2.1	63.8 ± 8.3	45.7 ± 11.3
Earthworm only	90.5 ± 1.5	88.6 ± 2.4	57.1 ± 8.1	54.3 ± 10.3
CGW only	98.1 ± 1.2	93.3 ± 1.2	51.4 ± 9.8	41.9 ± 10.4
Earthworm-CGW combination	99.1 ± 1.0	95.2 ± 2.6	59.1 ± 6.8	45.7 ± 6.5

Figure 1



N
a)
Block 1
Block 2
Block 3
Block 4
Block 5
b)
10 m
Plot 1
e.g. Compost only
Plot 2
e.g. Earthworm only
Plot 3
e.g. Control
Plot 4
e.g. Compost and Earthworm
40 m
c)
2m
2m
2m
10m
1m
1m
1m
1m
2m
2m
10m
= Tree Species 1
= Tree Species 2

Figure 2


a)
Soil organic matter (%)
0
1
2
3
4
5
6
0
6
12
18
24
Time (months)
b)
Soil organic carbon (%)
0
0.5
1
1.5
2
2.5
3
3.5
0
6
12
18
24
Time (months)
c)
Total K (mg kg-1)
200
250
300
350
400
450
500
0
6
12
18
24
Time (months)
d)
Total N (%)
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0
6
12
18
24
Time (months)

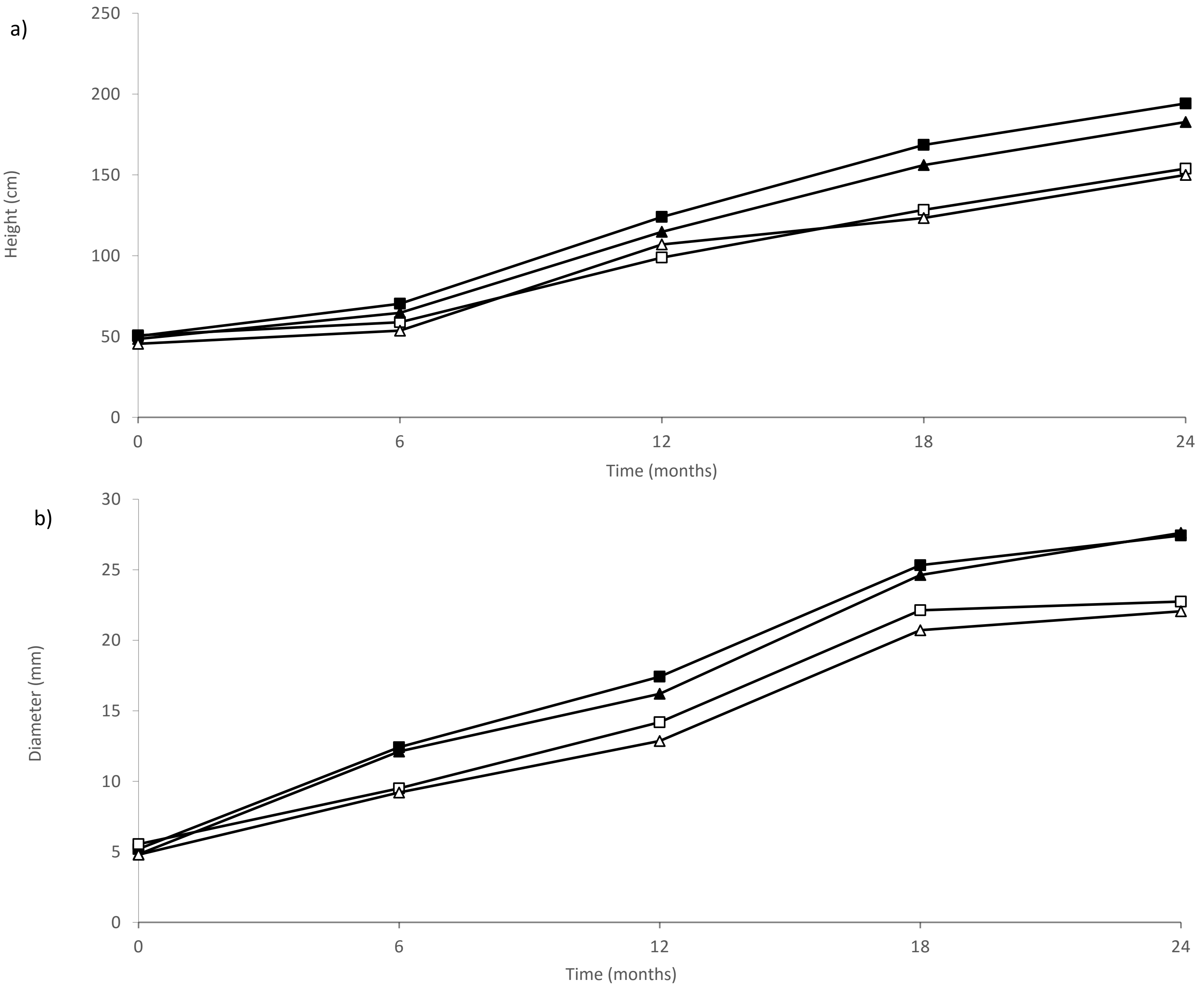

a)
Height (cm)
250
200
150
100
50
0
0
6
12
18
24
Time (months)
b)
Diameter (mm)
30
25
20
15
10
5
0
0
6
12
18
24
Time (months)

Table and figure captions

Table 1. Viridor 0-25 mm PAS 100 Composted Green Waste summary nutrient analysis (source: technical document supplied by Viridor Waste Management Ltd [42]) n/a: data not available.

Table 2. Mean tree survival (%) after 12 and 24 months under experimental treatments, $\pm$ SE (n =5). CGW = composted green waste, earthworm = *Aporrectodea longa*.

Figure 1. Diagram of the Ingrebourne Hill experiment design; a) arrangement of blocks within the fenced area, b) random layout of treatment plots within an individual block, and c) layout of tree species planting sub-plots within a treatment plot.

Figure 2. Selected mean soil chemical parameters throughout the experiment: (a) Soil organic matter (%), (b) Soil organic carbon (%), (c) Total K (mg kg^{-1}), (d) Total nitrogen (%) (n=5). CGW= composted green waste, earthworm = *Aporrectodea longa*. Treatments: ■= combination, ▲= CGW only, △= earthworm only, □= control. Error bars excluded for clarity, significance reported in text.

Figure 3. (a) Mean tree height (cm) and (b) mean basal diameter of *Alnus cordata* throughout the experiment (n =5). CGW= composted green waste, earthworm = *Aporrectodea longa*. Treatments: ■= combination, ▲= CGW only, △= earthworm only, □= control. Error bars excluded for clarity, significance reported in text.