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Contributions of Jellyfish Fertilizer to Survival and Growth of Seedlings Planted in a Recently Burned Forest, Republic of Korea

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In April 2012, a forest fire burned a large proportion of the understory and overstory vegetation on Mount Jubong, which is located in Hoengseonggun, Gangwondo in the Republic of Korea. In this forest, we examined the contributions of jellyfish fertilizer on survival and growth of *Pinus thunbergii* and *Quercus palustris* seedlings. The results showed that jellyfish fertilizer contributed high concentrations of the available moisture and nutrients to soil conditions. Jellyfish fertilizer contains high concentration of organic matter, which plays an important role for improving the physical structure of the soil. This is likely to increase the soil moisture and supply nutrients, which could promote survival and growth of seedlings. However, the effect of jellyfish fertilizer on survival of *Q. palustris* seedlings varied with its application rate whereas it of *P. thunbergii* seedlings increased with application rate of jellyfish fertilizer. This should be because that excessive salt concentration, which can be caused by high application of jellyfish fertilizer, affect adversely the growing plants and/or root distribution. Under the considering survival rates of both seedlings, the results showed that the optimum application rates of jellyfish fertilizer for enhancement of seedling growths were 50 g/tree for *P. thunbergii* seedlings and 30 g/tree for *Q. palustris* seedlings, respectively. This reflects that the jellyfish fertilizer promotes soil amendment, and has a positive contributor to the growths of both shoot and root parts, which is obviously required to secure competitiveness in an early growth stage. Although this study was spatially and temporarily limited, the findings are likely to provide important information regarding the establishment of forest restoration strategies in the burned and degraded areas where the possibilities of human and property damages are high.

Key words: jellyfish fertilizer, post–fire, rehabilitation treatment, seedling growth, seedling quality index

INTRODUCTION

Fire is a natural and significant part of the disturbance regime affecting hydrology and geomorphology in forested landscapes (Hamilton and Rowe, 1949; Swanson, 1981). Although forest fires are highly variable depending on location, climate, topography, soil type and fire severity and extent, they produce a reduction in the coverage of the litter layer on the forest floor and of the understory and/or overstory vegetation, causing quantitative and qualitative changes in the hydrological response and subsequent surface soil erosion of burned areas (DeBano, 1981; McNabb and Swanson, 1990; Meyer and Wells, 1997; Shakesby and Doerr, 2006). These changes in the post–fire hydrologic regime and surface soil erosion are further affected by other environmental factors, such as rainfall amount and intensity, slope, aspect, and vegetation type and recovery rate (Marques and Mora 1992; Gimeno–García *et al.*, 2007; Lanini *et al.*, 2009) and ultimately influence the delivery of sediment to stream channels (Cannon *et al.*, 2001; Benda *et al.*, 2003). Therefore, increasing overland flow and surface soil erosion in burned areas can lead to the risk of flooding and sedimentation, which impairs aquatic habitats of stream–dwelling organisms and threatens human life, property, and natural resources both within and outside of the burned area (Robichaud *et al.*, 2000; Graham, 2003).

Numerous studies (e.g., Meyer and Wells, 1997; Cannon *et al.*, 2001; Martin and Moody, 2001; Lee *et al.*, 2004) reported that the majority of surface soil erosion in burned areas occured in the first two years following the forest fire. However, in recent years, several studies (e.g., Kim *et al.*, 2008; Seo *et al.*, 2010) found that severely burned areas with steep slopes required at least three years to achieve surface soil stability by the natural recovery of the native vegetation. Therefore, in the burned and degraded areas where the possibilities of human and property damages are high, prompt field rehabilitations are strongly required to stabilize the surface soil within a short time.

As one of the emergent rehabilitation treatments, tree planting is commonly applied for early vegetation

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recovery and subsequent surface stability in the Republic of Korea (Chun *et al.*, 2003; Seo, 2004). Under the ground, trees reinforce soil layers and form buttresses against soil movement (Abe and Ziemer, 1991), and influence soil moisture level and thus reduce landslide risks (Watson *et al.*, 1999). Above the ground, trees lead to rainfall interception and reduced overland flow, thereby reducing surface soil erosion (Swanson, 1981; Gimeno–Garcia *et al.*, 2007). At the time of tree planting, fertilizer is often applied to facilitate optimal growth of seedlings and to maximize subsequent reforestation success (Austin and Strand, 1960; Carlson and Preisig, 1981; Rose and Ketchum, 2003).

Recently, with a high consideration on envirommental protection, organic fertilizers gain increasing global attention. Jellyfish, which has increased dramatically worldwide and thereby has caused various damages in coastal areas (Ishii and Tanaka, 2001; Kang and Park, 2003; Uye and Shimauchi, 2005), can be used as a source of organic fertilizer for enhancing tree growth and improving soil properties in terms of physical and chemical properties. Fukushi *et al.* (2004) conducted the experiments for the potential use of jellyfish as a fertilizer for the vegetable field. They reported that jellyfish had high concentrations of five principle components of fertilizer (i.e., nitrogen, phosphorus, potassium, magnesium, and calcium) and thus had a positive effect on the growth rates of vegetables. Similarly, Ezaki *et al.* (2011) examined the possibility of jellyfish fertilizer application to tree survival and growth for erosion control works on the degraded mountain hillslopes. Despite these studies suggested that jellyfish have a high possibility as an organic fertilizer, no study documented the usefulness of jellyfish fertilizer for early and successful restoration in burned forest areas.

As a case study to examine the contributions of jellyfish fertilizer on survival and growth of seedlings planted in a recently burned forest, we first planted seedlings of *Pinus thunbergii* and *Quercus palustris* on a recently burned hillslope. At this time, we applied jellyfish fertilizer of 0, 10, 30 and 50 g/tree at 10 cm in depth around the roots of seedlings. Then, we investigated changes in soil property and subsequent survival and growth rates of seedlings, which were regulated by different application rates of jellyfish fertilizer. Based on the results, we finally suggested the best application rate of jellyfish fertilizer for early restoration in burned forest areas.

STUDY SITE

Fieldwork was conducted on a hillslope on Mount Jubong (713.3 m), which is located in Hoengseonggun, Gangwondo in the Republic of Korea (Fig. 1). The study hillslope is primarily underlain by igneous rock which was formed through the cooling and solidification of magma or lava. In addition, the surface of the study hillslope is mainly covered by poorly graded sands, based on the Unified Soil Classification System, which is widely used in Southeast Asia.

Initially, the study hillslope was primarily covered with evergreen conifers (e.g., *P. densiflora*) with 10–26 cm in diameter at breast height and 5–10 m in height and broad–leaved tree (e.g., *Q. variabilis, Q. mongolica*) with 8–16 cm in diameter at breast height and 5–10 m in height. However, in April 2012, a large proportion of the understory and overstory vegetation of the hillslope were consumed by a fire. Upon considering the fire severity classification proposed by Agee (1993), this fire can be classified into mixed–severity fire regime.

The study area has a temperate climate with four seasons. According to meteorological data for the past ten years (2003–2012), which were monitored at the Hoengseong dam reservoir management office closest to the study site, the mean annual temperature is approximately 11.9°C and the mean annual precipitation ranges from 1,142 mm to 2,026 mm. Most precipitation occurs as localized torrential downpours caused by typhoons between July and September and as frontal rainstorms in the summer.

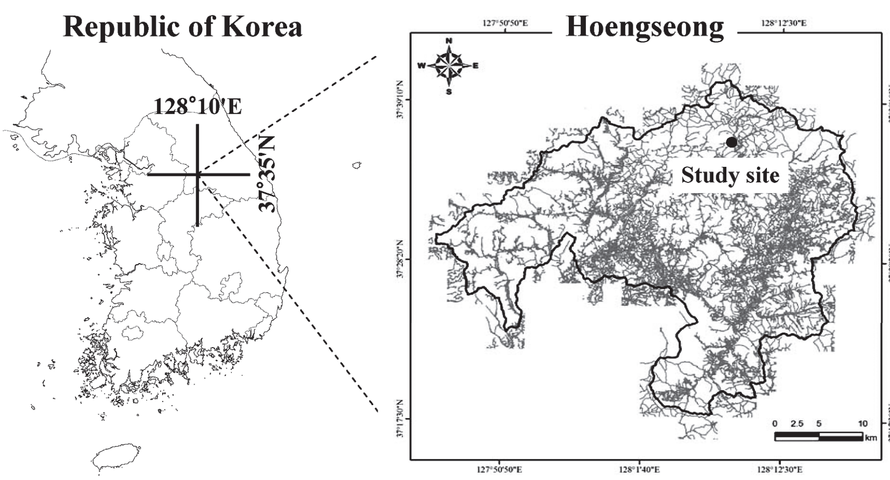

Fig. 1. Location of the study site.

Table 1. Experimental design of the field experiment

Planted seedling Species	0 g/tree (Untreated control)	10 g/tree	30 g/tree	50 g/tree	Total
Pinus thunbergii	12	12	12	12	48
Quercus palustris	12	12	12	12	48

METHODS

Hillslope treatments

At the beginning of June in 2012, the burned trees on the study hillslope were manually cut and skidded, and then two plots with 4 m wide and 12 m long were established. To normalize the potential effects of rainfall events across the plots, the plots were established at the distance of approximately 20 m on the slope with steep gradient of approximately 35°. We planted two–year–old seedlings of *P. thunbergii* in one plot and *Q. palustris* in the other plot. Here, we planted the seedlings of approximately 1.0 m apart in vertical and horizontal rows at the density of 48 trees per plot. Each plot was vertically subdivided into four subplots based on the jellyfish fertilizer treatments: 0 (untreated control), 10, 30 and 50 g/tree (Table 1). The methods of jellyfish fertilizer application and seedling planting are as described in the following: 1) excavated the planting holes with 30 cm in diameter and 30 cm in depth; 2) put the excavated sediment in the holes up to 10 cm in depth after provisional standing of seedlings; 3) dredged evenly jellyfish fertilizer around the roots of the seedlings but without any touch the roots; 4) finally covered the dredged jellyfish fertilizer and filled the holes with the excavated sediment.

Evaluation of seedling survival and growth

To examine the effect of jellyfish fertilizer on the survival and growth of seedlings, we counted the number of the survived seedlings, and measured the height from the soil surface to the top and the root–collar diameter at 5.0 cm above the soil surface at the beginning (June) and the end (September) of field experiment.

At the end of field experiment, we gently removed three seedlings from each plot and dried them for approximately 48 hours in the oven with 70°C after thorough cleaning. Then, the oven–dried seedlings were separated into shoot and root parts, and their dry–weights were recorded. Using these data, we calculated seedling quality index (SQI) which is commonly used to evaluate the healthiness of seedling (Deans *et al*., 1989; Bayala *et al*., 2009). The SQI was defined as:

$$\mathrm{SQI} = \mathrm{SD}/(S \cdot R + H \cdot D)$$

where SD is total dry–weight of each seedling (g), and S and R are the dry–weights (g) of seedling shoot and root, respectively. H and D are the height (cm) and root–collar diameter (mm) of seedling, which were measured previously.

Evaluation of on–site soil conditions

During August–September in 2012, soil moisture was measured three times at three different places within each subplot. We used soil moisture meter (Model PMS–714): the soil moisture probe was placed into 10 cm in depth of the soil and then the moisture data were recorded automatically.

At the removal stage, soil samples were collected at a depth of 10–30 cm in the center of each subplot to examine the effects of soil chemical property on the seedling survival and growth. The soil samples were air–dried and then sieved with a 2 mm sieve (US Standard No. 10). Using the sieved sample, hydrogen ion concentration (pH), electrical conductivity (EC), organic matter content (OM), and NO_3^-, P_2O_5, K_2O, Cl^- and Na^+ contents were analyzed.

Statistical analysis

One–way analysis of variance (ANOVA) was used to evaluate significant differences as a function of application rates of jellyfish fertilizer in the heights, root–collar diameters and SQI. Nested ANOVA was also used to evaluate significant differences as a function of application rates of jellyfish fertilizer in the soil moisture. When the effects of application rates of jellyfish fertilizer were significantly different on one–way and nested ANOVA, Tukey–HSD multiple comparisons were performed. The normality of distributions was tested using the Kolmogorov–Smirnov test. $P < 0.05$ was considered to indicate statistical significance for all tests. The statistical analysis was carried out with the statistical software package SPSS (20).

RESULTS

Soil moisture

The results showed that mean soil moisture contents of both plots increased significantly with increasing application rate of jellyfish fertilizer (Fig. 2). Specially, the mean soil moistures in the subplot treated with jellyfish fertilizer of 50 g/tree were approximately two to three times greater than those in the untreated control subplot, respectively.

Soil chemical property

All soil chemical properties analyzed in this study were clearly regulated by the application rate of jellyfish fertilizer (Table 2). With increasing application rate of jellyfish fertilizer, the pH decreased from 5.9 (0 g/tree) to 5.4 (50 g/tree) but the EC increased from 0.05 dS/m (0 g/tree) to 0.30 dS/m (50 g/tree). In addition, the appli-

Table 2. Change in soil chemical properties in relation to the application rates of jellyfish fertilizer

Application rate of jellyfish fertilizer (g/tree)	pH	EC	OM (%)	NO_3^- (mg/100 g)	P_2O_5 (mg/100 g)	K_2O (mg/100 g)	Cl^- (mg/100 g)	Na^+ (mg/100 g)
0 (Untreated control)	5.9	0.05	4.9	3.0	0.3	6.2	0.05	0.5
10	5.8	0.1	5.6	4.2	0.4	6.6	0.1	0.6
30	5.6	0.2	5.7	5.4	0.5	7.0	0.2	0.7
50	5.4	0.3	6.6	6.1	0.6	9.1	0.3	1.1

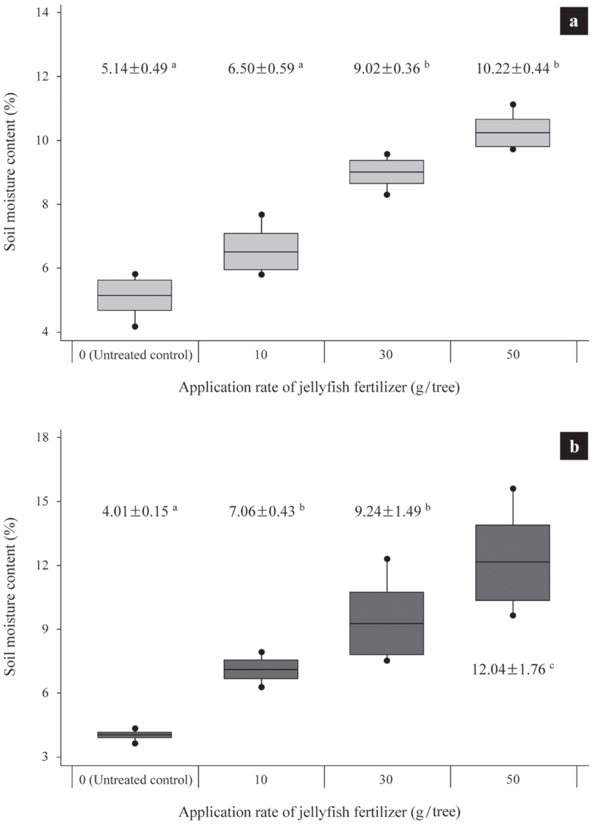

Fig. 2. Changes in soil moisture contents of subplots planted with (a) *Pinus thunbergii* and (b) *Quercus palustris* seedlings in relation to the application rates of jellyfish fertilizer. The line within box is the mean value, box ends are the mean±standard errors, and whisker dots are the maximum and minimum values. Different letter above the box indicates significant (P<0.05) differences based on Tukey–HSD multiple comparisons. Values above the box–and–whisker plots represent the mean ± standard errors.

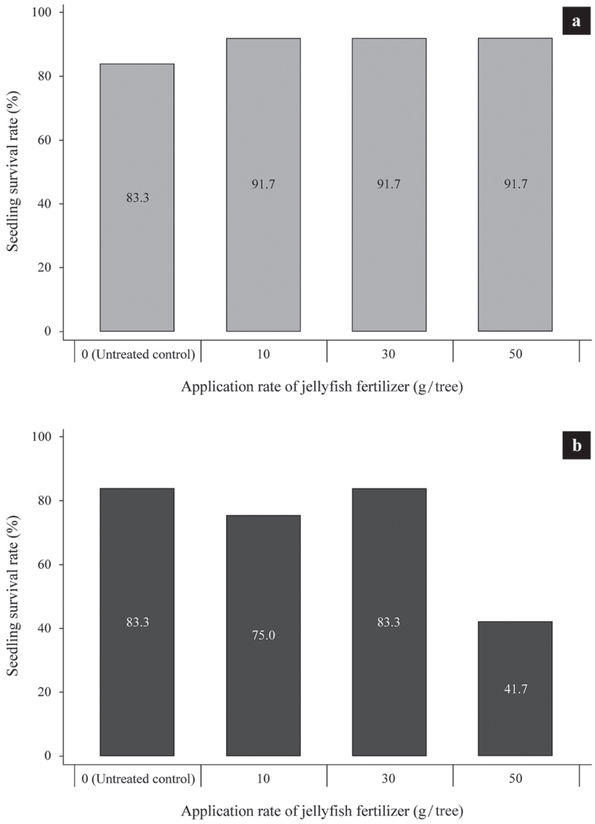

Fig. 3. Changes in survival rates of (a) *Pinus thunbergii* and (b) *Quercus palustris* seedlings in relation to the application rates of jellyfish fertilizer.

cation of jellyfish fertilizer resulted in the highest available soil nutrients, which may be able to promote the growth of seedlings. The OM, NO_3^-, P_2O_5 and K_2O contents in the subplot treated with the jellyfish fertilizer of 50 g/tree increased up to 1.3, 2.0, 2.0, and 1.5 times, respectively, compared to those in the untreated control subplot. Similarly, in this subplot, Cl^- and Na^+ contents increased up to 6.0 and 2.2 times, compared to those in the untreated control subplot.

Seedling survival rate

The results showed that the survival rates of *P. thunbergii* and *Q. palustris* seedlings were differently influenced by the application rates of jellyfish fertilizer (Fig. 3). The survival rate of *P. thunbergii* seedling was weakly influenced by the application rate of jellyfish fertilizer. Compared to *P. thunbergii* seedling, *Q. palustris* seedling showed a less tolerance to the high application rate of jellyfish fertilizer. Specially, the seedling survival rate in the subplot treated with jellyfish fertilizer of 50 g/tree was only 41.7%.

Seedling growth

Application of jellyfish enhanced the height growths of *P. thunbergii* and *Q. palustris* seedlings (Fig. 4). The mean height growth of both seedlings increased

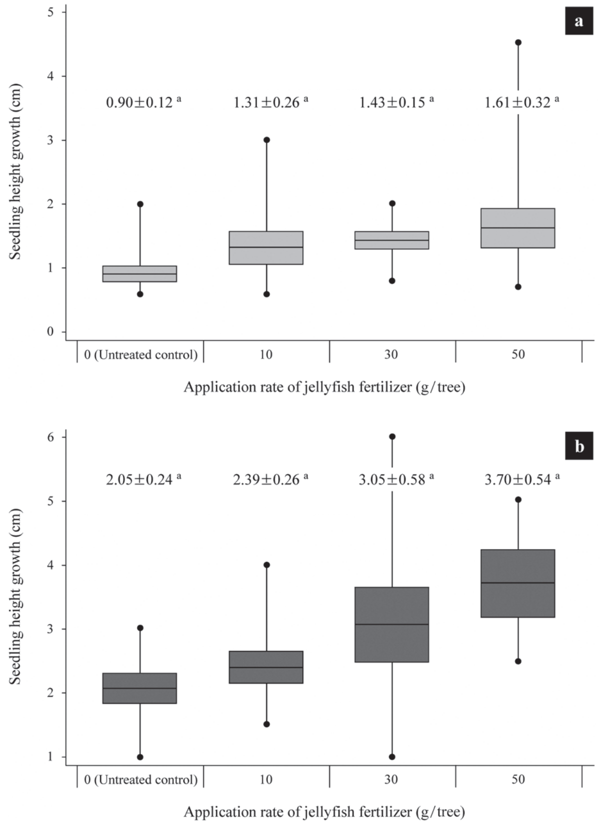

Fig. 4. Changes in height growths of (a) *Pinus thunbergii* and (b) *Quercus palustris* seedlings in relation to the application rates of jellyfish fertilizer. The line within box is the mean value, box ends are the mean±standard errors, and whisker dots are the maximum and minimum values. Different letter above the box indicates significant (P<0.05) differences based on Tukey–HSD multiple comparisons. Values above the box–and–whisker plots represent the mean ± standard errors.

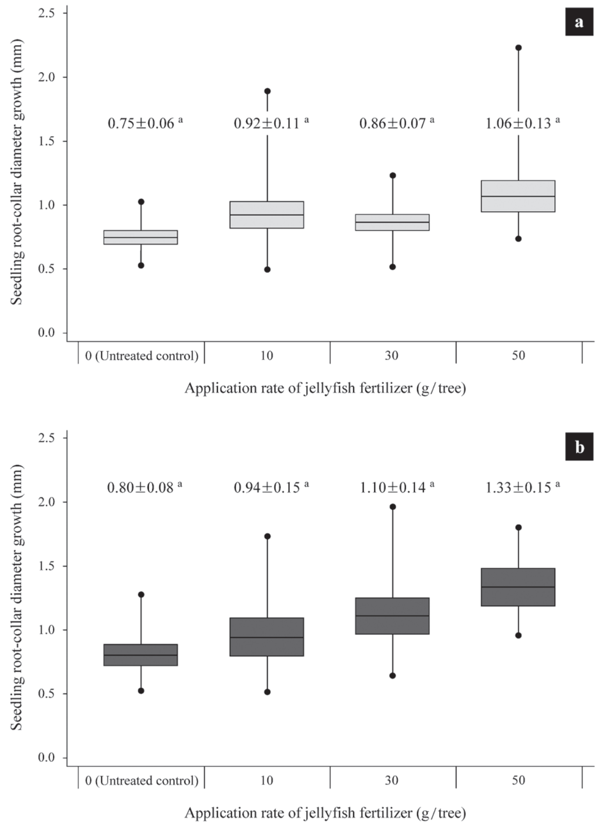

Fig. 5. Changes in root–collar diameter growths of (a) *Pinus thunbergii* and (b) *Quercus palustris* seedlings in relation to the application rates of jellyfish fertilizer. The line within box is the mean value, box ends are the mean ± standard errors, and whisker dots are the maximum and minimum values. Different letter above the box indicates significant (P<0.05) differences based on Tukey–HSD multiple comparisons. Values above the box–and–whisker plots represent the mean ± standard errors.

slightly with increasing the application rate of jellyfish fertilizer. Although the mean height growth of *Q. palustris* showed relatively clearer increase compared to *P. thunbergii* seedling, there were no significant differences in both seedlings.

Whereas the root–collar diameter growth of *P. thunbergii* seedling was slightly variable along the spectrum of applied jellyfish fertilizer amount, the root–collar diameter growth of *Q. palustris* seedling increased with its application rate (Fig. 5). For the *P. thunbergii* seedling, the mean root–collar diameter growths were approximately 0.75 and 0.92 mm in the subplot untreated (0 g/tree) and treated with jellyfish fertilizer of 10 g/tree, respectively. However, the mean value (0.86 mm) in the subplot treated with jellyfish fertilizer of 30 g/tree was relatively lower than it in the subplot treated with jellyfish fertilizer of 10 g/tree. Unlike the *P. thunbergii* seedling, the root–collar diameter growth of *Q. palustris* seedling was positively related with the application rate of jellyfish fertilizer.

Seedling quality index (SQI)

The SQIs of both seedlings were positively influenced by the application rates of jellyfish fertilizer (Fig. 6). However, the SQI of *P. thunbergii* seedling showed considerably small values (approximately 0.30–0.65) compared to *Q. palustris* seedling (approximately 3.9–6.2), regardless of the application rate of jellyfish fertilizer. Specially, the SQI of *P. thunbergii* seedling in the untreated control subplot showed a larger range compared to other subplots, as well as non–significant differences among the treatments. Conversely, the SQI of *Q. palustris* seedling showed a clear increasing trend with the application rates of jellyfish fertilizer and partially significant differences among the untreated and treated subplots.

DISCUSSION

Improvements of on–site soil conditions

In this study, jellyfish fertilizer seemed to contribute high concentrations of the available moisture to soil conditions (Fig. 2). Similar to the present study, previous studies showed that the jellyfish fertilizer absorbed water seven to eight times greater than its own weight (Ezaki *et al.*, 2008). Jellyfish fertilizer consists of high

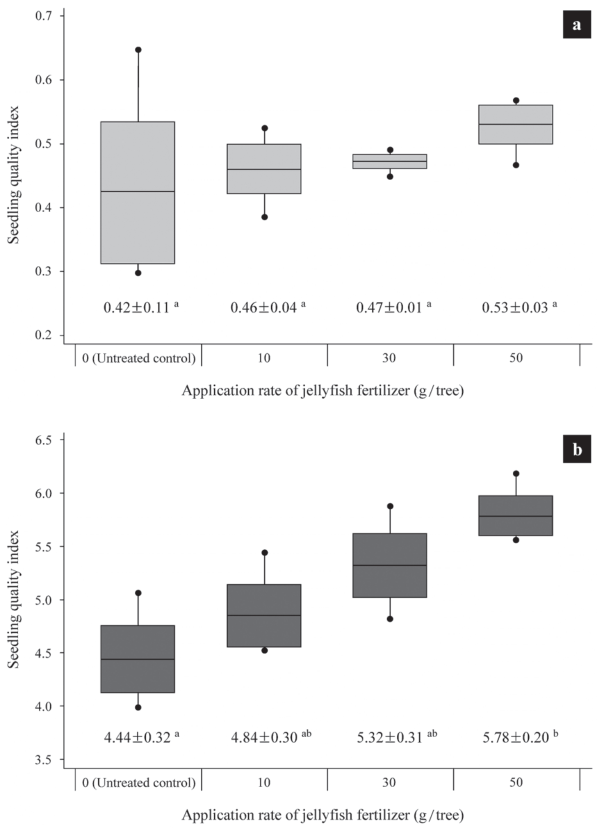

Fig. 6. Changes in seedling quality indexes of (a) *Pinus thunbergii* and (b) *Quercus palustris* in relation to the application rates of jellyfish fertilizer. The line within box is the mean value, box ends are the mean ± standard errors, and whisker dots are the maximum and minimum values. Different letter above the box indicates significant ($P<0.05$) differences based on Tukey-HSD multiple comparisons. Values below the box-and-whisker plots represent the mean ± standard errors.

organic matter (approximately 81%), which plays an important role for improving the physical structure of the soil; and consequently, increases the soil moisture. When jellyfish is distributed over the soil surface, it creates a vapor barrier between the soil and the atmosphere, resulting in decreases in soil temperature and evaporative water loss (Power, 2002).

The results in this study showed that the application of jellyfish fertilizer resulted in elevated concentration of the available nutrients (Table 2). Organic matter supplied by jellyfish fertilizer is also a suitable source for nutrient supply (Ezaki *et al.*, 2008). In general, vegetation residues, manures, turfs and leaf falls on forest floor, and compost from organic wastes have been used to increase soil organic matter content and accordingly improve soil physical properties in croplands (Stratton *et al.*, 1995). Improvement in soil aggregation by addition of organic matter positively affects the germination of seeds, and the growth and development of shoots and roots (Noordwijk *et al.*, 1993). The reduction of soil pH could be caused by the presence of organic matter; that is, its decomposition and the release of organic acids into the soil played an important role for soil pH reduction. Therefore, it is worthy to mention that jellyfish fertilizer has an acidic physiological effect. Application of organic fertilizers significantly increased levels of organic C and N and the formation of water stable aggregates, as compared with application of chemical fertilizers (Taiz and Zeiger, 2002; Chen *et al.*, 2008). Therefore, it is recommended to apply liming materials in combination with jellyfish fertilizer to overcome the acid physiological effect of jellyfish fertilizer.

Seedling survival and growths

The overall survival rate of *P. thunbergii* seedlings was higher than the one of *Q. palustris* seedlings (Fig. 3). Particularly, in the subplot treated with jellyfish fertilizer of 50 g/tree, the survival rate of *Q. palustris* seedlings was less than 50 % whereas the one of *P. thunbergii* seedlings was greater than 90 %. This should be because that the influence of jellyfish fertilizer on survival of the planted seedlings depends on salt resistance. Logan (1975) considered that thickness of *P. thunbergii* needles was responsible for its greater tolerance to salt. Therefore, thickness of *P. thunbergii* needles should help exclude salt ion and lead to higher survival rate than *Q. palustris* seedlings. However, salt toxicity is one of the major edaphic factors limiting vegetation production and eco–environmental quality in salinized and sodic soils (Barrick *et al.*, 1987), especially for *Q. palustris* seedlings. Several studies (e.g., Ayers and Hayward, 1948; Garg and Gupta, 1997) reported the retardation of seedling settlement at high salinity. As a consequence, excessive salt concentrations, which can be caused by high application of jellyfish fertilizer, affect adversely the growing plants and/or root distribution (Miller and Donahue, 1990; Ramoliya and Pandey, 2006), although natural conditions and buffering capacity of the natural soil may slightly recovered the negative impacts of the elevated applications of jellyfish fertilizer (Hund, 2010).

Under the considering survival rates of both seedlings, the results showed that the optimum application rates of jellyfish fertilizer, which were sufficient to enhance the seedling growths, were 50 g/tree in the plot planted with *P. thunbergii* seedlings and 30 g/tree in the plot planted with *Q. palustris* seedlings, respectively (Figs. 4 and 5). As described previously, contents of soil moisture and chemical properties were remarkably increased in the soil treated highly with jellyfish fertilizer, compared with those in the untreated control subplot (Fig. 2 and Table 2). Specially, increment in available nutrients, including nitrogen, phosphorus and potassium which are key components to support growth of seedlings, enhanced the nutrient uptake (Lim and Cousens, 1986; Marschner, 1995). The increments in soil moisture and chemical properties caused by application of jellyfish fertilizer are likely to play an important role not only for enhancing the seedling growth but also for wide distribution of root system. In general, the root system, that is largely influenced by soil physical features (Gebauer *et al.*, 2011), show large variability, especially under natural environmental conditions. However, Fares *et al*. (2008) and Ferreras *et al*. (2006) documented that organic amendment may facilitate root penetration by improving porosity and stabilizing soil structure. Although we did not deal with net growth of root system in this study, the SQI, which is considering the balance of above– and underground biomasses, was highest in the subplot treated with high application rate of jellyfish fertilizer (Fig. 6). This result reflects that the jellyfish fertilizer promotes soil amendment, and has a positive contributor to the growths of both shoot and root parts, which is obviously required to secure competitiveness in an early growth stage.

CONCLUSIONS

We focused on determining the optimum application rates of jellyfish fertilizer as soil amendment for enhancing the survival and growth of *P. thunbergii* and *Q. palustris* seedlings. Although the treatment plots in this study were not replicated due to spatial, temporal, and economical restrictions, the results showed that, in recently burned forest areas, the application of jellyfish fertilizer improved the chemical soil characteristics and enhanced the subsequent survival and growth of *P. thunbergii* and *Q. palustris* seedlings. At the same time, the results showed that the effect of jellyfish fertilizer on survival of *Q. palustris* seedlings varied with its application rate whereas the one of *P. thunbergii* seedlings increased with application rate of jellyfish fertilizer. The study suggests that (i) the application of liming materials in combination with jellyfish fertilizer is recommended to overcome the acid physiological effect and (ii) the washing stage to make jellyfish fertilizer prior to its application to the burned areas is required to decrease the Cl^- and Na^+ accumulation. These findings are likely to provide important information regarding the establishment of forest restoration strategies in recently burned areas where natural regeneration is very slow.

Nevertheless, several knowledge gaps remain in our understanding of the effectiveness of rehabilitation treatments using jellyfish fertilizer. For example, the short term experiment might be not sufficient for observing the complete role of jellyfish fertilizer on soil fertility improvement and seedling growth enhancement. Ezaki *et al*. (2008) suggested that the effect of rehabilitation treatment using jellyfish fertilizer is expected to continue for a long duration. Also, this study does not cover a range of various forest types (e.g., species, seral stage, growth rate, artificial versus natural and harvested versus non–harvested) and/or geological conditions in the source watersheds; that is, this study is based on the results monitored using *P. thunbergii* and *Q. palustris* seedlings within plots measuring 4 m in width and 12 m in length. The results obtained from the limited seedling species and plot size should greatly regulate absolute magnitude of vegetation cover increment and subsequent sediment yield reduction after burning. Hence, the effectiveness of post–fire rehabilitation treatment using jellyfish fertilizer examined in this study may not be applicable to watersheds with different natural conditions.

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