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Effects of root pruning to growth and root growth potential of Benguet pine (*Pinus kesiya* Royle ex Gordon) seedlings

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Abstract

The country faces the dreaded consequences of its massive, deforested areas. To rehabilitate, restore, and preserve these areas, reforestation projects are needed and one of its essential activities is producing quality seedlings that could survive in harsh conditions. Thus, it is vital to consider a nursery management practice like root pruning that relatively assess nursery seedling quality and performance. The study was carried out to evaluate the effects of root pruning on the growth and root growth potential (RGP) of Benguet pine seedlings which is commonly used in the Cordillera Region, Philippines. The study was laid out following a completely randomized design with 4 treatments replicated 3 times: T_0 - Control (not root pruned), T_1 - root pruned (5cm from root collar), T_2 - root pruned (7cm from root collar), and T_3 - root pruned (10cm from root collar). The result showed that in terms of height growth, root pruned seedlings at 5cm from root collar (T_1) obtained the highest value with 16.70cm. While relative to root collar diameter, number of lateral roots, root length, root and shoot dry weights, root-shoot ratio, sturdiness quotient, and seedling quality index, not root pruned seedlings relatively showed higher and favorable results with 0.78mm, 44.47, 51.53cm, 11.10g, 32.83g, 0.34, 14.16, 13.33, respectively. With the proper management, care, and maintenance, 100% survival rate has been observed in the study. Statistically, the results showed significant difference on the number of roots, root dry weight, root-shoot ratio, and seedling quality index, while comparable results on the height, root collar diameter, root length, shoot dry weight, and sturdiness quotient. Thus, it is relevant to consider some factors like frequency of root pruning treatment, age of the seedlings, duration of conduct, number of nodules, and soil and water management for seedlings for more reliable assessment of plant quality and performance.

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Introduction

Reforestation is one of the frontier activities by the government and other private sectors to regenerate denuded forests. However, most of the reforestation activities are unproductive due limited resources, expertise, and lack of nursery grading practice to assess the quality of planting stocks (Gazal *et al.*, 2004; Khurram *et al.*, 2017). To produce quality planting materials for planting and/or reforestation activities, it is essential to observe appropriate care, maintenance, and proper nursery management practices in the production of planting stocks in the nursery until planting in the field.

Nursery practices such as root pruning can alleviate the presence of root deformities and alter seedling quality and field performance (Duryea, 1986; Khurram *et al.*, 2017). Basically, planted seedlings initially depend on the root system created by nursery culture. Several nursery procedures such as undercutting or root pruning have increased root-shoot ratio and root growth potential (RGP) that produces sturdier plants with well branched and fibrous root systems increasing field survival and overall growth performance of the seedlings (Comila, 2007; Onufre *et al.*, 2013). Likewise, root pruning is considered as the standard procedure for seedling preparation prior to transplanting in the field (Farmer & Pezeshki, 2004).

The proper conduct and timing of root pruning will produce a sturdier tree, force development of a more compact, fibrous root system, root branching, retard top growth and increase transplant survival and post-transplant growth (Du *et al.,* 2012; Zhang *et al.*, 2015). It is a horticultural tool or cultivation method to adjust the above and below ground plant sections and modifies or inhibits the vegetative growth processes by controlling the growth of root systems (Ritchie, 2003). Also, root pruning destroys the old growth balances of trees and changes their assimilation abilities, nutrient distributions, and hormone levels which entail high RGP and root fibrosity (Du *et al.*, 2012).

According to Grossnickle (2005), seedlings can undergo stress just after planting if root growth is not sufficient to couple the seedling to available soil and water. Root deformities results to restricted growth, seedling mortality, and poor resistance to stress, reduces water and nutrient uptake, vigor and mechanical stability after out planting (Khurram *et al.*, 2017). Thus, a newly planted seedling's ability to overcome planting stress is affected by its root system size and distribution, root soil contact, and root hydraulic conductivity. Root pruning increases the total length of the root system by stimulating lateral root development that promotes stronger RGP response by generating a larger basic framework for the new root network. Also, it has an impact to RGP by influencing the seedling's passage into physiological dormancy (Ritchie & Dunlap, 1980). RGP is the ability of a tree seedling to initiate and elongate roots when placed into an environment favorable for root growth (Duryea, 1986). Moreover, RGP was considered to represent the total quantity of new roots produced in a standard test (Ritchie & Dunlap, 1980).

It is a nursery manipulated activity through practices that induce dormancy, increase root fibrosity, and enhance carbohydrate reserves. It was further discussed that the standard method of measuring RGP is relatively straightforward. Seedlings are lifted and any new white tips are removed. The seedlings are then potted and held in a controlled environment under ideal conditions for root growth of the determined species and further observation. However, RGP can be reduced by improper handling between lifting and planting or nursery practices, different species respond differently according to time. Other factors may include soil temperature, soil moisture, soil characteristics and air temperature (Ritchie & Dunlap 1980).

Nowadays, Benguet pine (*Pinus kesiya*) is the main reforestation species planted as it is highly adaptable to the site, fire resistant and very common in the Benguet province, Philippines. Benguet pine is one of the native pines found in the Philippines and locally

known as "*saleng*" in Benguet and "*batang*" in Mountain Province. It is one of the most important and widely distributed species in the Cordillera Administrative Region (CAR), characterized as high elevation areas with cold climate (Lumbres *et al.,* 2013) suited for this kind of species. Also, Benguet pine is a large coniferous (Gymnosperm) and fast-growing tree species that thrives in high altitude and on comparatively poor soils with annual rainfall of 1,200-2,000mm and temperatures ranging from 15-30 ^{0}C (Racelis *et al.*, 2017). It is also considered as a native tree species in the area that reaches a maximum height of 60 feet and a maximum diameter of about one meter under Pinaceae family. Benguet pine is a large tree that grows about 140cm in diameter and 40 meters in height, has flaky bark and evergreen needle-like leaves, generally three needles per fascicle. Further, Napaldet *et al.* (2015) reported that Benguet pine dominates the montane rainforests or pine forests of the Cordillera Administrative Region in Northern Philippines. It also played a key role in continuous functioning of the ecosystem and offers opportunities for the development of human capacity to lessen the status of forest-dwellers and promote economic growth in the ecoregion. However, the resource base is being abused and misused. To meet the needs and aspirations of the people, strategic actions such as protecting and conserving the remaining forests and restoring the degraded forest should be done (Ganzon, 2003).

The main objective of the study is to assess the effects of root pruning to Benguet pine seedlings. Specifically, the study aims to determine 1) the effects of root pruning to the growth of Benguet pine seedlings in terms height, of root collar diameter, root length and shoot length and 2) the RGP (root length, root-shoot ratio, and total biomass) of the seedling as influenced by root pruning. The study would be helpful to nursery managers to know how effective root pruning is to the growth and RGP of Benguet pine seedlings, and what nursery practice is suited to produce quality seedlings. Hence, the data are essential in promoting the success of reforestation and afforestation activities.

Materials and methods

Experimental Area and Sample Preparation

The study was laid out following Completely Randomized Design (CRD) with three replications. Different length of root pruning were the treatments used in the study such as T_0 - Control (not root pruned), T_1 - root pruned (5cm from root collar), T_2 - root pruned (7cm from root collar), and T_3 - root pruned (10cm from root collar). There were 36 healthy Benguet pine seedlings used per treatment with a total of 144 seedlings for the whole study.

The Benguet pine seedlings of plantable sizes were raised at the College of Forestry - Benguet State University Nursery. The seedlings were transported to the Brgy. Bila, Bokod, Benguet that serves as the study area with an average relative humidity of 84% and average temperature of 24°C during the study period (Fig. 1.). The experimental area was prepared by cleaning and taking away the unnecessary debris or wastes, followed by the repotting of growing media. The growing media were sterilized by cooking at 100°C for 24 hours to kill harmful microorganisms and weeds. Further, the seedlings were repotted in a 5" x 8" polybag.

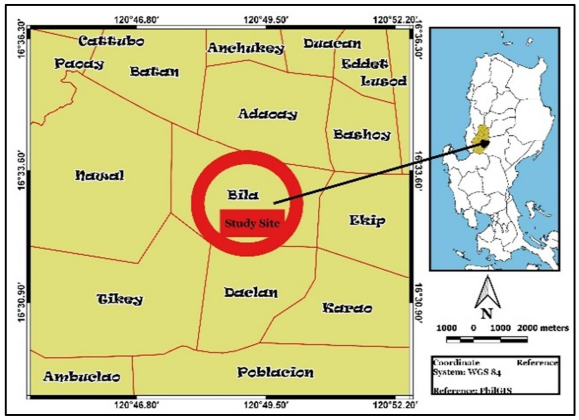

Fig. 1. The Area of the Study.

Prior to repotting, the seedlings were cleaned by drenching water from a faucet to remove soil particles in the roots, and then the roots were pruned at different lengths from the root collar as indicated in the treatments using pruning shear. Watering of seedlings was done twice a week without fertilizers/nutrients application.

Data Gathered

The root growth potential (RGP) and growth of Benguet pine seedlings were measured under different parameters like height, root collar diameter, root length, number of lateral roots, shoot and root dry weight, root-shoot ratio, sturdiness quotient, seedling quality index, and survival percentage.

Height (cm)

The height was measured by measuring the seedlings from the root collar (approximately 5mm above the ground) to the tip of the apical bud using a meter stick before and after the conduct of experiment.

Root Collar Diameter (mm)

The root collar diameter was measured at the root collar using a vernier caliper before and after the conduct of experiment.

Root Length (cm)

The root length was measured from the root collar diameter (5mm above the first lateral root) to the tip of the root.

Number of Lateral Roots

The number of roots was counted before and after the conduct of experiment.

Shoot & Root Dry Weight (g)

The root and shoot dry weights were measured by weighing the roots and shoots of Benguet pine seedlings after oven drying for 72 hours at 105°C.

Root-Shoot Ratio

The root-shoot ratio was determined by dividing the root dry weight and shoot dry weight of the Benguet pine seedlings.

Sturdiness Quotient

The sturdiness quotient was determined by dividing the height (cm) of the seedlings by the root collar diameter (mm) following the procedure used by Takoutsing *et al.* (2013).

Seedling Quality Index (SQI)

The seedling quality index was determined following the Dickson's Quality Index (DQI) developed by Dickson *et al.* (1960) which was calculated as:

$$\text{SQI:} = \frac{\text{Seedling Dry Weight (g)}}{\frac{\text{Height (cm)}}{\text{Root Collar Diameter (mm)}} + \frac{\text{Shoot Dry Weight (g)}}{\text{Root Dry Weight (g)}}}$$

Survival Percentage (%)

The survival percentage was determined by counting the total number of seedlings that survived up to the termination of the study divided by the total number of seedlings planted multiplied by 100.

Statistical Analysis

All the data gathered were tabulated, summarized, and analyzed using the Analysis of Variance (ANOVA) in Completely Randomized Design (CRD). Also, Tukey's Honestly Significant Difference test was used to determine the significant differences between and among treatment means/percentages.

All statistical analyses were generated using the Statistical Tool for Agriculture Research (STAR) v2.0.1 (IRRI, 2020).

Results and discussion

The root growth potential (RGP) and growth of Benguet pine seedlings such as height, root collar diameter, root length, number of lateral roots, shoot and root dry weight, root-shoot ratio, sturdiness quotient, seedling quality index, and survival percentage relative to root pruning treatments were shown in Table 1.

Height (cm)

The average height growth of Benguet pine seedlings was 13.10cm. The highest height growth was obtained by T_1 seedlings (pruned at 5cm from the root collar) with 16.70cm, followed by T_3 (pruned at 10cm from the root collar), T_0 (not root pruned), and T_2 (pruned at 7cm from the root collar) having 15.53, 11.69, & 8.47 (cm), respectively. It is observed that the root pruning may relatively increase the height growth considering the results of T_1 and T_3. However, no significant difference was observed among root

pruning treatments. This result corroborates the findings of Devine *et al.* (2014) about Oak species pruned 15cm. The study showed no effect on the height, diameter, shoot dry weight, seedling total dry weight, and root-shoot ratio after 1 year (Devine *et al.,* 2014). Likewise, Na *et al.* (2013) stated that regardless of root pruning intensity, height and diameter growth of the seedlings was not affected. However, in the findings of Yeboah *et al.* (2016), a reduction in shoot growth following root pruning was observed for many species, including peach and holly.

Table 1. The Root Growth Potential (RGP) and Growth of Benguet Pine Seedlings Affected by Root Pruning Treatments

Parameters	Root Pruning Treatments				*P*-value
	T_0 - not root pruned	T_1 – root pruned at 5cm from RC	T_2 – root pruned at 7cm from RC	T_3 – root pruned at 10cm from RC	
Height (cm)	11.69	16.70	8.47	15.53	0.5578^{ns}
Root Collar Diameter (mm)	0.78	0.50	0.59	0.42	0.0912^{ns}
Root Length (cm)	51.53	37.41	31.33	27.32	0.4658^{ns}
Number of Lateral Roots	44.47 ^{a}	4.47 ^{b}	12.44 ^{b}	15.19 ^{b}	0.0001*
Shoot Dry Weight (g)	32.83	25.57	25.13	27.67	0.1155^{ns}
Root Dry Weight (g)	11.10 ^{a}	2.97 ^{b}	2.83 ^{b}	5.37 ^{ab}	0.0071*
Root-Shoot Ratio	0.34 ^{a}	0.11 ^{b}	0.11^{b}	0.18 ^{ab}	0.0068*
Sturdiness Quotient	14.16	33.39	15.93	36.97	0.1434^{ns}
Seedling Quality Index	13.33 ^{a}	3.29 ^{b}	3.14 ^{b}	6.23a ^{b}	0.0065*

Notes: All means followed by different letters are significantly different at 0.05 level (HSD); * - significant; ns- not significant; RC- Root collar

Root Collar Diameter (mm)

The average diameter growth at root collar relative to root pruning treatments was 0.57mm, wherein the largest growth of diameter was obtained by the not root pruned seedlings with 0.78mm. While the root pruned seedlings obtained 0.59 (T_2), 0.50 (T_1), & 0.42 (T_3) (mm). However, the result showed no significant difference. Gilman (1992) discussed that root pruning as a nursery management practice entails redirection of assimilates to replace the pruned roots leading to retarded top growth of seedlings until the root stabilizes. Also, root pruning might relatively reduce absorption of water and nutrients while changing the hormone balance resulting to overall decrease of seedling growth.

This response of Benguet pine to root pruning is at least temporary and resume its growing after some days. As cited by Gazal *et al.* (2004), seedlings with large collar diameter would exhibit greater survival rate in the field as it also considered a good measure of outplanted seedling performance. Based on the result, the not root pruned seedlings were relatively favorable than the pruned seedlings, although no significant difference was observed.

Root Length (cm)

As shown in Table 1, the longest root was observed in the unpruned roots of Benguet pine seedlings with 51.53cm, it was relatively longer than the root pruned seedlings with 37.41, 31.33, and 27.32 (cm) (for T_1, T_2, and T_3, respectively) considering the long taproot present in the unpruned seedlings that continues to elongate. Moreover, PCAARRD (1984) reported that root pruning in Benguet pine seedlings retard rapid growth and consequently reduces transpiration, a condition that helps avoid water deficit. Comila (2007) cited that the physiological effect of root pruning could be anchored on the concept of root apical dominance which controlled by plant growth substances (auxins), that are primarily synthesized in the growing regions. Apical dominance suppresses the growth of lateral roots and prevents additional root tips. It could also the main reason that during the period of succulence, the roots are normally an unbranched taproot that drives into the soil and when broken, may branch very early in the seedling stage.

The auxin inhibition of lateral bud growth through experiment suggests that a balance between auxin and cytokinin was responsive for apical dominance. When auxin production is reduced, cytokinin increases which then promotes lateral roots development. This concept of apical dominance and hormone in shoot portion are also applicable to root system. Yabes (2018) also cited that reduced growth may be the cause of restriction in post-plant water transport as an effect of alarm to normal xylem embolism brought by root pruning.

On the other hand, the taproots of pruned seedlings temporarily stopped to elongate, instead stabilizing and producing new lateral roots and root hairs. Statistically, the result showed no significant difference. This comparable result was probably due to repotting of seedlings into wider and longer polybags that conveyed conducive root elongation. It also indicates that container dimensions might affect root characteristics of seedlings like Benguet pine that should be planted in larger or bigger containers (Landis *et al.*, 2014). Further, white color at end the roots were observed in all the treatments. This implies that root elongation is not only induced by root pruning but also the change of longer and wider polybags. Similar findings were reported by Devine *et al.* (2014) in the root pruning of 4-month-old Poplar clones showing an average of 2.8 taproot at a depth of 30cm, 1.1 taproot in the undisturbed treatment and 1.0 taproot in the repotted treatment. Thus, repotting has an effect to growth of roots.

Number of Lateral Roots

The result revealed that the not root pruned seedlings (T_0) showed the greatest number of lateral roots with 44.47, significantly higher than all root pruned seedlings with 4.47 (T_1), 12.44 (T_2), & 15.19 (T_3) roots. Although root pruning leads to the formation of new lateral roots and root hairs, it is observed in this study that the lesser the root pruning, the greater the number of lateral roots developed. However, more root nodules were also observed in the pruned seedlings than the unpruned. Thus, nitrogen fixation in the roots of pruned Benguet pine seedlings would be prevalent which relatively contribute to the growth of the seedlings. Statistically, significant difference was observed in the result. Furthermore, the root growth of plants might also be affected by the available soil moisture, wherein the lesser soil moisture content significantly stimulates the production of new roots to extend plant root system to supply the moisture needed for survival, establishment, and subsequent growth (Gazal *et al.,* 2004). Yabes (2018) cited that newly formed roots are capable of greater water and resource uptake than older roots.

In the present study, Benguet pine seedlings established new roots even in a short duration of time in response to root pruning. Moreover, the RGP of a plant is considered one most important measurable attributes of physiological quality because it quantifies the ability of seedlings to initiate and elongate new roots promptly and abundantly that is strongly correlated to seedling survival. Seedlings can undergo stress just after planting if root growth is insufficient to couple the seedling with available water in the soil (Grossnickle, 2005).

Root Dry Weight (g)

The average dry weight of Benguet pine roots was 5.57g. The heaviest dry weight was observed in the unpruned seedlings with 11.10g, followed by T_3 (5.37g), T_1 (2.97g), and T_2 (2.83g).

The result showed a significant difference on the root dry weight, wherein the unpruned seedlings exhibited heavier dry weight than the pruned seedlings, particularly under T_1 and T_2. Moreover, the higher root dry mass of unpruned root seedlings is probably due to the removal of about 69% of the root length on the pruned one (Darnell *et al.*, 2008).

On the other hand, Devine *et al.* (2014) observed that pruning the taproot of 4-month-old Oregon white oak (*Quercus garryana*) did not affect the dry weight of lateral roots above or below the 15cm depth.

This type of root pruning employed would not be practical on a large scale since end roots manifested morphological changes, but not the dry weight. Also, seedlings with higher root volume have a high RGP that is positively and significantly correlated with root dry mass.

Shoot Dry Weight (g)

With an average shoot dry weight of 27.80g, unpruned Benguet pine seedlings showed the heaviest weight with 32.83g, followed by T_3, T_1, and T_2 having 27.67, 25.57, and 25.13 (g), respectively. Although, analysis showed no significant difference indicating a comparable effect of treatments toward shoot dry weight of Benguet pine seedlings.

Root-Shoot Ratio

The average root-shoot ratio of Benguet pine seedlings was 0.19, wherein the unpruned seedlings showed the highest value with 0.34 followed by T_3 with 0.18. While both T_1 and T_2 got root-shoot ratio of 0.11 that were found to be significantly lower than the unpruned ones. This result relatively supported the report of Comila (2007) that root pruning or culturing reduces root-shoot ratios of plants. In short-term, root pruning decreases the root-shoot ratio and inhibits tree growth. In longer-term, the pruning stimulates regeneration of roots from each severed root while decreasing shoot growth, hence, increasing the root-shoot ratio. The time required for restoration of plant balance after root pruning also varies in terms of species (Yabes, 2018). This plants reaction would be to restore its inner balance by increasing root growth by directing more assimilates to the root system. This would promote a stronger RGP response by generating a larger basic framework for the new root network.

Further, seedlings should have balanced root-shoot ratios to match the efficiency of each other in the performance of their respective roles as interdependent systems forming a plant. The effects of root pruning to root-shoot would widely vary depending on the nature of pruning treatment applied and the prevailing environmental conditions. Basically, the root-shoot ratio is an important measure for seedling survival. Further, a seedling with balanced root and shoot biomass should have root-shoot ratio between one and two (Jaenicke, 1999), but none of the sample seedlings in the study attained the desired value.

Sturdiness Quotient

The average sturdiness quotient of Benguet pine seedlings was 25.11. The lowest value was obtained by unpruned seedlings, followed by T_2, T_1, and T_3 with a value of 15.93, 33.39, and 36.97, respectively. The result of the present study showed no significant difference signifying a comparable effect of root pruning treatments towards sturdiness quotient. Basically, sturdiness quotient expresses the vigor and robustness of the seedlings wherein seedlings with a value of 6.00 or lower are considered sturdy (Jaenicke, 1999).

Chauhan & Sharma (2017) specified that sturdiness quotient reflects the balanced growth of seedlings, comparatively taller seedlings may not withstand the wind pressure in the field, and additional balanced root collar diameter should support the seedling for quality. Based on the present result, unpruned and root pruned Benguet pine seedlings exceeded the standard value of sturdiness quotient that signifies a relatively less sturdy or less desirable quality seedlings to withstand adverse conditions in the field. Although, proper hardening or conditioning of seedlings before field planting could enhance its sturdiness status.

Seedling Quality Index (SQI)

The average seedling quality index of Benguet pine seedlings was 6.50, wherein not root pruned seedlings obtained 13.33, followed by T_3 (6.23), T_1 (3.29), and T_2 (3.14). Statistically, a significant difference was observed on the seedling quality index between treatments with unpruned roots and root pruned seedlings. Generally, all the results of the study surpassed the minimum seedling quality index that is 0.2 (Gregorio *et al.,* 2004). According to Gregorio *et al.* (2004), the lack of availability and low quality of planting stock appear to be the major impediments to both planting and selection of species by small-scale farmers in the Philippines. Thus, determining the health or quality of seedlings before planting will relatively increase the success rate of projects.

Survival Percentage (%)

With proper management, care and maintenance of the Benguet pine seedlings, 100% of survival rate was observed in the study. This signifies that, as long as proper management, care, and maintenance are practiced, a higher rate of survival for Benguet pine seedlings could be achieved regardless of root pruning treatments used.

Conclusions

The growth and root growth potential of the seedlings are extremely important when evaluating seedling quality and survival rates in the field. This study was primarily conducted to evaluate the effects of root pruning to growth and root growth potential of Benguet pine seedlings. The result showed that in terms of height growth, root pruned seedlings at 5cm from root collar (T_1) obtained the highest value. While relative to root collar diameter, number of lateral roots, root length, root and shoot dry weights, root-shoot ratio, sturdiness quotient, and seedling quality index, the not root pruned seedlings obtained higher and better results. Also, with the proper management, care, and maintenance, 100% survival rate has been observed in the study. Statistically, the results showed significant difference on the number of lateral roots, root dry weight, root-shoot ratio, and seedling quality index, while comparable results on the height, root collar diameter, root length, shoot dry weight, and sturdiness quotient.

In performing root pruning some factors must be considered like frequency of root pruning treatment, age of the seedlings, length of time involved in observing and other conditions. Slowing down of growth attributed to root pruning may have been effective only beyond three months after transplanting. The study showed that even though root pruning of Benguet pine seedlings temporarily retard growth; it still produces new lateral roots. This entails that root pruning of Benguet pine helps in establishing new roots to become a quality planting stock. Involving longer time duration (like until 4 months), season of root pruning application, proportion, or length of root to be pruned, and additional pruning techniques such as box pruning may also be considered. Follow-up studies on the field performance of seedlings with unpruned and pruned roots, application of root pruning treatments at different seedling growth stages, and root pruning economics are recommended.

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