

Soil nutrient status, nutrient return and retranslocation in poplar species and clones in northern Iran

Ali Salehi⁽¹⁾, Neda Ghorbanzadeh⁽¹⁾, Maryam Salehi⁽²⁾

In this study several same-aged poplar species and clones were selected including *Populus deltoides* Marsh. CV. "Lux" (*P.d* "Lux"), *Populus deltoides* Marsh. CV. "Harvard" (*P.d* "Harvard"), *Populus x canadensis* Moench "Triplo" (*P.xc* "Triplo"), *Populus x canadensis* Moench "I-45/51" (*P.xc* "I-45/51"), planted in poplar research station about 20 years ago in the north of Iran, and *Populus caspica* Bornm. (*P. caspica*) as endemic and endangered poplar species. Some quantitative characteristics of the trees and soil samples were taken based on completely randomized block design. Samplings of live and senescent leaves were carried out in two-stages, mid-summer during the peak nutritional activities of trees and mid-autumn for senescent leaves. Soil samples were analyzed to determine organic carbon (OC), total nitrogen (N), available phosphorus (P) and exchangeable potassium (K). OC, total of N, P and K were also determined in live and senescent leaves. The results showed that *P.d* "Harvard" had the highest total height, DBH and diameter of crown compared to the other species and clones. The amount of OC, N and P in soil and live leaves of *P.d* "Harvard" clone are more than those of the other species and clones. OC, N, P, and K returned by senescent leaves were higher and lower for *P.d* "Harvard" and *P. caspica* respectively. P retranslocation for all of the clones and species was higher compared to N and K. The highest retranslocation percentage was observed in *P. caspica* (N=18.93, P=39.63, K=24.02) and the lowest (N=12.09, P=32.46, K=21.14) in *P.d* "Harvard" clone. It could be concluded that poplar species and clones have different nutritional requirements and retranslocation capabilities. It appears that *P.d* "Harvard" clone showed higher quantitative growth it could be beneficial for maintaining the soil nutrient status for successive plantings.

Keywords: Poplar, Retranslocation, Nutrient Return, Soil Properties, Plantation

Introduction

In natural forests and man-made plantations, cycling of nutrient is an important aspect, as significant amounts of nutrients are returned to soil through litter fall and become available for nutrient cycling. Among nutrients, some are used in physiological responses and other stored in different plant organs, or returned to the soil through the litter and then partially absorbed by the root of trees (Breeman 1995). Uptake and release of nutrients are important factors at the stand level, because they represent the major

fluxes through the system (Miller & Alpert 1984). Nutrient concentration in plant biomass is the result of the balance between nutrient uptake, plant growth and nutrient retranslocation, and the loss of these processes are likely to be influenced both by plant genetic make-up and soil fertility, as well as other environmental conditions (Hagen-Thorn et al. 2004).

Forest litter fall is the major flux responsible for nutrient transfer to soil (Parzych et al. 2008) and the growth and productivity of forest ecosystems depends mainly on the

amount, the nature and the rate of decomposition of litter fall (Victor et al. 2001). Tree species can play an important role in nutrient cycling through different properties, such as the amount of litter produced, nutrients release and chemical composition of the litter (Rahajoe 2003). Different tree species involve different nutrient release patterns, which are related to litter quality and seasonal environmental factors (Khiewtam & Ramakrishnan 1993). Tracking nutrient returns through litter fall under different tree species is important to understand the dynamics of soil fertility.

Soil and old leaf nutrient retranslocation, are the primary sources of nutrients in the leaves (Binkley & Sollins 1995, Piatek & Lee Allen 2000) and litter fall nutrient abundance is related to intensity of retranslocation processes in autumn (Parzych et al. 2008). The nutrient retranslocation, movement and transfer nutrients from the old leaves to the every year store, is an important process in nutrient dynamics in most ecosystems, especially broadleaf ecosystems (Killingbeck 1996, Duchesne et al. 2001). Retranslocation has been characterized as one of the most important strategies used by trees to conserve nutrients, which consequently influences competition, nutrient uptake, and productivity (Killingbeck 1996). Within the same community, foliar nutrient concentrations vary largely amongst different species and different individuals of the same species despite similar soil conditions (Niinemets & Kull 2003). The relative importance of site and species, as the factors determining nutrient concentrations in plant biomass, may differ depending on nutrient element and biomass fraction. Comparative studies of several species growing on the same soils allow a better understanding of species nutrient function (Hagen-Thorn et al. 2004).

Different species and clones of poplar are commonly planted as fast-growing species in the world and some parts of plain areas in the north of Iran. Poplar has been planted by the villagers and big companies at different levels in the north of Iran, particularly in Guilan province. Some important species of poplar, such as *Populus x canadensis* and *Populus deltoides* (different clones) were commonly used for plantations. On the other hand, *Populus caspica* (Persian poplar), an endemic and endangered poplar species, existed naturally in plain areas of the Guilan province beside the planted species (Asadi & Mirzaie-Nodoushan 2011).

As these fast-growing tree species provide social, economic and environmental benefits over short rotations, a better understanding of their impacts on nutrient cycling processes and various aspects of soil fertility is essential. The objectives of this study were: (i) to examine the nutrient status in soil and

□ (1) Department of Forestry, Natural Resources Faculty, University of Guilan, Guilan (Iran); (2) Department of Forestry, Natural Resources Faculty, University of Tehran, Tehran (Iran)

@ Ali Salehi (asalehi@guilan.ac.ir)

Received: Feb 18, 2013 - Accepted: May 11, 2013

Citation: Salehi A, Ghorbanzadeh N, Salehi M, 2013. Soil nutrient status, nutrient return and retranslocation in poplar species and clones in northern Iran. iForest 6: 336-341 [online 2013-08-29] URL: <http://www.sisef.it/forest/contents/?id=ifor0976-006>

Communicated by: Roberto Tognetti

its patterns; (ii) to quantify nutrient return through senescent leaves; and (iii) to evaluate and compare the nutrient retranslocation, in different poplar species and clones.

Materials and Methods

Study area

The study area is located at Safrabasteh poplar research station in Guilan province, Iran (37° 19' N, 49° 57' E). The area is on flat and uniform terrain in a plain region with the altitude of -10 m above sea level. Annual mean rainfalls and temperature are 1186 mm and 17.5 °C respectively. The soil of the study area is formed on the alluvial fine textured sediment with silt loam texture, and with neutral to low acidic reaction. The area is dominated by natural forests of native species such as *Alnus glutinosa*, *Pterocarya fraxinifolia*, *Populus caspica*, *Gleditschia caspica*. Extensive plantations have been established by different poplar species and clones 20 years ago.

Experimental design, tree measurement, soil sampling and analysis

The experimental plantations considered in this study were established in 1993 using a completely randomized block design, including three replications with the following five species/clones (treatments): (i) *P.d* (*Populus deltoides*) "Harvard"; (ii) *P.d* "Lux"; (iii) *P.xc* (*Populus × canadensis*) "Triplo"; (iv): *P.xc* "I-45/51"; and (v) *P. caspica*. The area of poplar research station was approximately 4 ha and about 3000 m² were allocated as experimental plantation in this study. After the removal of tree buffer rows, the number of poplar trees was 120 and 24 for all the treatments and per treatment, respectively. In each treatment, there were 3 replications with 8 poplar trees, planted at 4×4 m spacing, assigned to each replication.

Total height, diameter at breast height (DBH) and diameter of crown (by measuring two perpendicular diameters and calculating their mean) were measured for each tree. Three soil samples were randomly taken from 0-20 cm depth of soils under the crown of the tree in each treatment using a core sampler. All of soil samples were air-dried and passed through a 2 mm mesh. Soil organic carbon (OC) was determined by Walkley and Black method and total nitrogen (N) using Kjeldhal method. The available phosphorus (P) was determined according to Olsen methods and exchangeable potassium (K) extracted by using 1 M ammonium acetate at pH 7.0 and analyzed with flame-photometer (Jackson 1967).

Leaf collection, leaf nutrients analysis and calculation of retranslocation rate

Live and senescent leaves were collected from six trees in each treatment (two trees

Tab. 1 - Mean with standard error of height and diameter at breast height (DBH) among the treatments. Different letters indicate significant differences between individual mean values for a particular parameter.

| Treatment | Total height (m) | DBH (cm) | Diameter of crown (m) |
|-----------------------|---------------------------|----------------------------|--------------------------|
| <i>P. caspica</i> | 10.58 ± 0.34 ^c | 13.84 ± 1.43 ^b | 3.21 ± 0.39 ^c |
| <i>P.d</i> "Lux" | 20.58 ± 0.57 ^a | 20.40 ± 1.54 ^a | 6.69 ± 0.11 ^a |
| <i>P.d</i> "Harvard" | 22.59 ± 0.62 ^a | 25.70 ± 2.78 ^a | 6.71 ± 0.16 ^a |
| <i>P.xc</i> "Triplo" | 16.18 ± 0.41 ^b | 22.40 ± 1.38 ^a | 4.12 ± 0.14 ^b |
| <i>P.xc</i> "I-45/51" | 16.16 ± 0.38 ^b | 20.98 ± 1.80 ^{ab} | 4.80 ± 0.17 ^b |

per replication). Live leaves were collected in middle of July 2011. The leaves of each tree were collected from the bottom one-third twigs located on the opposite sides of the crown (Rouhi-Moghaddam et al. 2008). The senescent leaves were collected in litter traps (1×1 m with 30 cm height, wooden sides with a nylon net in bottom, located beneath the crown of the same trees previously sampled for live leaves) in November 2011, with the beginning time of leaf fall season (Rostamabadi et al. 2010). In order to obtain minimum 3 g of powdered leaf materials, at least 10 leaves were collected for each sample category. All of the collected live and senescent leaves were dried at 70 °C for at least 48 h. The powdered leaf materials were analyzed for some important macro elements.

Carbon was determined by loss ignition after heating at 375 °C for 24 h. The total nitrogen was determined with Kjeldahl method, the total phosphorus and potassium was determined after dry ashing and extraction with HCl by colorimetric procedure and flame-photometer, respectively (Jackson 1967). Percentage retranslocation was calculated by the following equation (Huang et al. 2007, Hashemi et al. 2012 - eqn. 1):

$$NRE = \frac{(Nu_{live} - Nu_{dead})}{Nu_{live}} \cdot 100$$

where *NRE* is the nutrient resorption efficiency, *Nu_{live}* is the nutrient concentration of live leaves (mature leaves) and *Nu_{dead}* is the nutrient concentration of senescent leaves (leaf litter).

Statistical analyses

Normality of variables was checked by

Kolmogorov-Smirnov test, and Levene's test was used to examine the quality of the variances. One-way analysis of variance (ANOVA) was used to compare tree quantitative characteristics, soil properties and leaf nutrients data among the experimental treatments. Tukey-HSD test was used to separate the means of dependent variables that were significantly affected by the treatments. For all statistical analyses, SPSS® software (version 17.0) was used.

Results

Quantitative characteristics of trees and soil nutrient status

The results of ANOVA indicated that *P.d* "Harvard" had the highest total height, DBH and diameter of crown compared to the other species and clones. In contrast, *P. caspica* showed the lowest performances amongst the treatments, as indicated by average total height, DBH and crown diameter (10.58 m, 13.84 cm and 3.21 m, respectively - Tab. 1).

OC, N and P in the 0-20 cm soil layer differed significantly among poplar clones. The amounts of N and P as the most important nutrient elements and also OC are higher in soil under *P.d* "Harvard" clone. Soil nutrient status of *P. caspica* showed the lowest amounts of OC, N and P compared to the other species and clones. Exchangeable potassium did not show any significant differences amongst clones and species (Tab. 2).

Nutrient concentration in live and senescent leaves

ANOVA results did not show any significant differences between blocks in live and senescent leaves. However, significant differences amongst treatments have been ob-

Tab. 2 - Mean with standard error of soil nutrient elements among the treatments. Different letters indicate significant differences between individual mean values for a particular parameter.

| Treatment | OC (%) | N (%) | P (%) | K (%) |
|-----------------------|---------------------------|--------------------------|---------------------------|--------------------------|
| <i>P. caspica</i> | 1.61 ± 0.14 ^b | 0.13 ± 0.01 ^b | 0.01 ± 0.04 ^b | 0.01 ± 0.13 ^a |
| <i>P.d</i> "Lux" | 2.41 ± 0.21 ^{ab} | 0.21 ± 0.01 ^b | 0.02 ± 0.08 ^{ab} | 0.02 ± 0.13 ^a |
| <i>P.d</i> "Harvard" | 2.85 ± 0.31 ^a | 0.24 ± 0.02 ^a | 0.04 ± 1.01 ^a | 0.02 ± 0.21 ^a |
| <i>P.xc</i> "Triplo" | 1.78 ± 0.13 ^b | 0.15 ± 0.01 ^b | 0.01 ± 0.08 ^b | 0.01 ± 0.13 ^a |
| <i>P.xc</i> "I-45/51" | 1.70 ± 0.27 ^b | 0.14 ± 0.02 ^b | 0.01 ± 0.04 ^b | 0.01 ± 0.21 ^a |

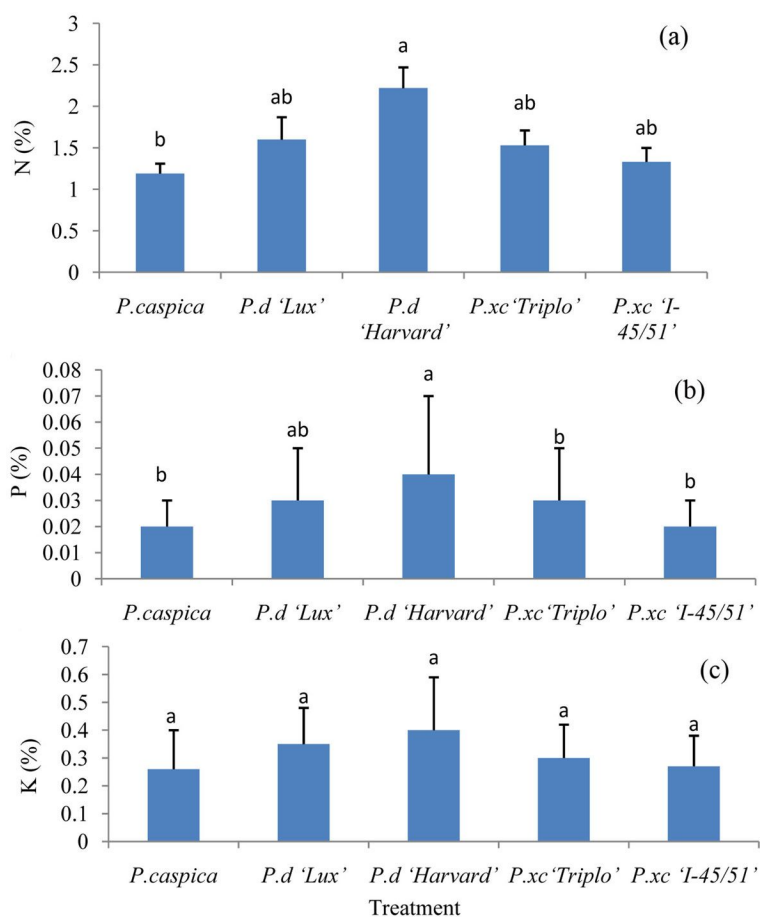


Fig. 1 - Concentration of N (a), P (b) and K (c) in live leaves among different treatments (Mean \pm SE, n= 6 for each treatment). Different letters above bars indicate significant differences among treatments (P<0.05).

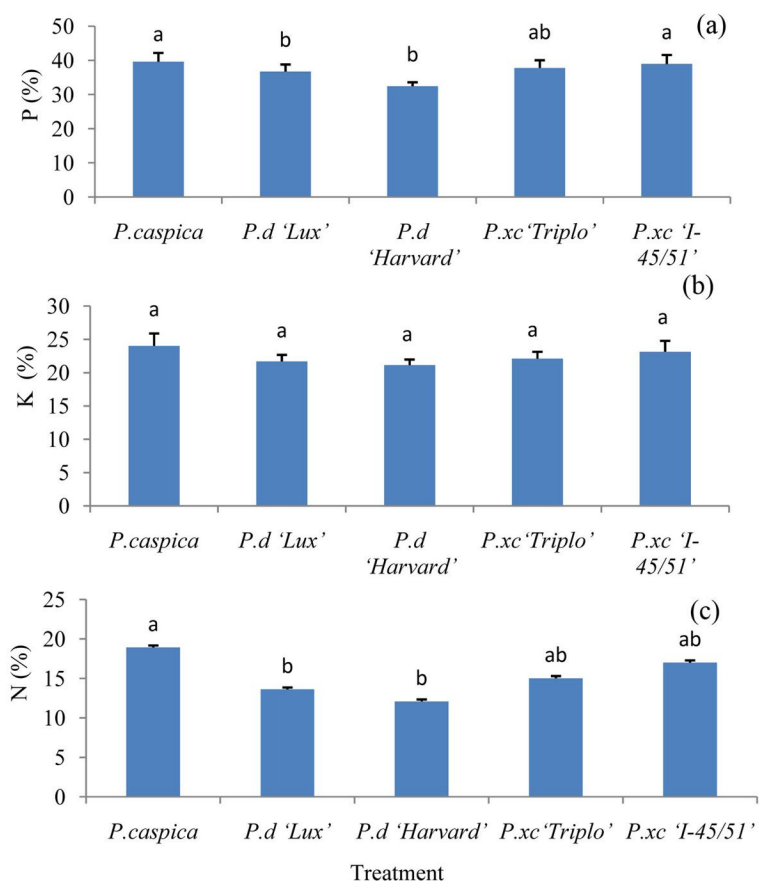


Fig. 2 - Retranslocation of P (a), K (b) and N (c) among different treatments (Mean \pm SE, n= 6 for each treatment). Different letters above bars indicate significant differences among treatments (P<0.05).

Tab. 3 - Mean of nutrient concentration in senescent leaves with their standard error among the treatments. Different letters indicate significant differences between individual mean values for a particular parameter.

| Treatment | OC (%) | N (%) | C/N | P (%) | C/P | K (%) |
|-----------------------|----------------------------|---------------------------|----------------------------|---------------------------|---------------------------|---------------------------|
| <i>P. caspica</i> | 16.23 ± 0.89 ^b | 1.11 ± 0.12 ^b | 15.24 ± 0.12 ^a | 0.01 ± 0.11 ^b | 72.01 ± 1.27 ^a | 0.12 ± 0.19 ^b |
| <i>P.d</i> "Lux" | 20.07 ± 1.04 ^{ab} | 1.50 ± 0.17 ^{ab} | 13.47 ± 0.67 ^{ab} | 0.02 ± 0.05 ^{ab} | 45.32 ± 1.63 ^b | 0.22 ± 0.35 ^{ab} |
| <i>P.d</i> "Harvard" | 22.34 ± 1.15 ^a | 2.17 ± 0.28 ^a | 11.31 ± 0.34 ^b | 0.03 ± 0.13 ^a | 31.22 ± 1.21 ^b | 0.35 ± 0.73 ^a |
| <i>P.xc</i> "Triplo" | 19.18 ± 0.86 ^b | 1.23 ± 0.08 ^b | 14.06 ± 0.51 ^{ab} | 0.01 ± 0.02 ^{ab} | 33.00 ± 1.23 ^b | 0.21 ± 0.24 ^{ab} |
| <i>P.xc</i> "I-45/51" | 29.16 ± 1.72 ^b | 1.18 ± 0.17 ^b | 14.21 ± 0.48 ^{ab} | 0.02 ± 0.13 ^{ab} | 42.31 ± 1.08 ^b | 0.13 ± 0.14 ^b |

served. N and P were higher in live leaves of *P.d* "Harvard" compared to the other clones and species, although N showed significant differences only between *P.d* "Harvard" and *P. caspica* (Fig. 1a, b). The amount of K did not show any significant differences for live leaves among the clones and species (Fig. 1c).

All of the nutrient elements showed significant differences for senescent leaves among the clones and species. OC, N, P, and K return by senescent leaves were higher and lower for *P.d* "Harvard" and *P. caspica*, respectively. C/N and C/P ratio for senescent leaves of *P. caspica* had higher value compared to the other treatments (Tab. 3).

Total nutrient content was higher in live leaves than senescent leaves. In addition, nutrient concentration in leaves was higher than that in soil.

Nutrient retranslocation

Significant differences in nutrient retranslocation for N and P were observed among the treatments. Among the clones and species, *P. caspica* had higher retranslocation for all of the nutrient elements. In contrast, nutrient retranslocation in *P.d* "Harvard" follows opposite trend and the lowest P and N retranslocation were observed for this clone. P retranslocation for all of the clones and species was higher compared to N and K. Retranslocation percentage of the nutrient was in order: P (32.46-39.63%), K (21.14-24.02%) and N (12.09-18.93% - Fig. 2a, b, c).

Discussion

After about 20 years, different poplar species and clones have had different effects on soil nutrient status. N, P, K and organic carbon exhibited significant differences among the soil under the treatments and their higher and lower amounts were observed in *P.d* "Harvard" and *P. caspica*, respectively. As the same aged and adjacent clones and species of poplar were planted and developed under the same site conditions, it seems that the surface soil nutrient differences are due to the nutrient function of each poplar species and clones. Nutrient returns through litter fall under different tree species are important to understand the dynamics of soil fertility, and the rates of forest litter falls and

their decomposition contribute to the regulation of nutrient cycling and the maintenance of soil fertility in forest ecosystems (Onyekwelu et al. 2006). N, P, K and organic carbon returns by senescent leaves showed significant differences amongst the clones and species. The concentration of all of the nutrient elements in senescent leaves was higher and lower in *P.d* "Harvard" and *P. caspica*, respectively. The nutrient returned to the soil through senescent leaves was in the order of N>K>P. Pattern of nutrient concentration in senescent leaves varied according to the species. Similar to our results, Singh et al. (1989) and Lodhiyal & Lodhiyal (1997) reported the returned nutrient content by leaf litter in the order of N>K>P in *Populus deltoides* plantations in moist plain area in the north of India. However, Mahmood et al. (2009, 2011) reported nutrient release from leaf litter of three tree species in Bangladesh follows the order of K>N>P.

The amount of nutrient added to the soil through decomposition of leaf litter depends on climatic conditions, litter quality, and other site conditions such as topographic factors (Morrison 2003). In this study, as the climatic and other site conditions for all of the poplar clones and species are the same, the variations in decomposition rate of different tree litters can be resulted from differences among the substrate quality of different tree species. Generally, litter with high lignin and low N concentration has a slower decomposition rate and immobilizes more N than litter with low lignin and high N content. Cornwell et al. (2008) and Berg et al. (2010) observed that decomposition depends on the type of humus and on the N and P content of the leaves. In our study, the senescent leaves had higher N, P and K contents in *P.d* "Harvard" than the other poplar clones and species, and the pattern of C/N was in the order of *P. caspica* > *P.xc* "I-45/51" > *P.xc* "Triplo" > *P.d* "Lux" > *P.d* "Harvard". C/P ratio is also higher in *P. caspica* compared to the other species and clones. There is a highly significant and negative correlation between C/N and C/P of senescent leaves with N concentration and extractable P in the soil (Augusto et al. 2002). Rostamabadi et al. (2010) reported lower decomposition and release of nutrient from the litter with high C/N and C/P ratio

in the plantations in the north of Iran.

Retranslocation percentage of nutrients (NPK) were in the order of *P. caspica* > *P.xc* "I-45/51" > *P.xc* "Triplo" > *P.d* "Lux" > *P.d* "Harvard". Several researches have clearly shown that tree species differ in their retranslocation (Hagen-Thorn et al. 2006, Rouhi-Moghaddam et al. 2008, Hashemi et al. 2012). Sharma & Sharma (2004) suggested that different retranslocation of nutrients depends upon many factors such as, plant growth, species, and stature associated with age and site characteristics. Cuevas & Lugo (1998) showed that tree species differ in N and P retranslocation and these differences are in response to eco-physiological reactions of each tree to site conditions. In this study, it seems that different response of nutrient retranslocation of poplar species and clones are according to their nutritional requirements and site characteristics. Wright & Westoby (2003) stated that retranslocation proficiency is a much more accurate indicator of site fertility. According to our results, *P. caspica* showed the lowest total height, DBH and crown diameter amongst the different species and clones analyzed. The soil under *P. caspica* also contained poor nutrient supply compared to the other clones and species. Consistent with our results, Liu et al. (2004) reported that high element retranslocation and low growth rate are the characteristics of plants under element-poor conditions. On the other hand, since the soil under *P.d* "Harvard" is relatively nutrient-rich, the nutrients were not retranslocated as efficiently as to the other clones and species. Low rate of retranslocation for *P.d* "Harvard" suggests these trees are less nutrient conservative and the nutrients are being recycled into the soil (Townsend et al. 2007).

In our study, the percentage of retranslocation of nutrients (NPK) was in the order P>K>N. Similar to our results, Hashemi et al. (2012) and Rostamabadi et al. (2010) reported high P retranslocation in different tree species in northern Iran. In contrast to our results, Lodhiyal & Lodhiyal (1997, 2003) and Rouhi-Moghaddam et al. (2008) found low P retranslocation in tree layers. The extent to which an element can be retranslocated depends on its physical properties, as well as its importance to the plant's nutrient requirements (Fife et al. 2008). The agree-

ment between the high P retranslocation and potentially low P content in the soil for *P. caspica* plantation indicates that P retranslocation can be a strong approach of this species to soil phosphorous availability. So, lower N retranslocation can result in proper balance of nitrogen in the soil.

Conclusion

Understanding the mass and nutrient content of leaves, litter and soil will help to evolve appropriate strategies of nutrient management in plantations. In this study, total height, DBH and diameter of crown, as important tree growth indicators, and OC, N, P, K content of senescent leaves and soil somewhat differed among poplar clones and species in the order: *P. caspica* < *P.xc* "Triplo" < *P.xc* "I-45/51" < *P.d* "Lux" < *P.d* "Harvard". Retranslocation percentage of N and P were in the order of *P. caspica* > *P.xc* "I-45/51" > *P.xc* "Triplo" > *P.d* "Lux" > *P.d* "Harvard", and P retranslocation for all of the clones and species was higher compared to N and K. It could be concluded that the studied poplar species and clones have different nutritional requirements and retranslocation capabilities. It appears that *P.d* "Harvard" clone showed higher quantitative growth and it could be beneficial for maintaining the soil nutrient status for successive plantings in the north of Iran and other sites similar to the study area.

Acknowledgments

We specially thank to University of Guilan and Poplar Research Station of Safrabasteh. They have guided us through various steps of the preparation of our research.

References

- Asadi F, Mirzaie-Nodoushan H (2011). Evaluation of different treatments in sexual reproduction of *Populus caspica* for broadening its genetic basis in the nature. Iranian Journal of Forest and Poplar Research 19: 441-452.
- Augusto L, Ranger J, Binkley D, Rothe A (2002). Impact of several common tree species of temperate forest on soil fertility. Annals of Forest Science 59: 233-254. - doi: [10.1051/forest:2002020](https://doi.org/10.1051/forest:2002020)
- Berg B, Davey M, De Marco A, Emmett B, Fauri M, Hobbie S, Johansson MB, Liu C, Mc Clagherty C, Norell L, Rutigliano F, Vesterdal L, De Virzo Santo A (2010). Factors influencing limit values for pine needle litter decomposition: a synthesis for boreal and temperate pine forest systems. Biogeochemistry 100: 57-73. - doi: [10.1007/s10533-009-9404-y](https://doi.org/10.1007/s10533-009-9404-y)
- Binkley D, Sollins P (1995). Factors determining in soil pH in adjacent conifer and alder-conifer stands. Soil Science Society of America Journal 54: 1427-1433. - doi: [10.2136/sssaj1990.03615995005400050036x](https://doi.org/10.2136/sssaj1990.03615995005400050036x)
- Breeman NV (1995). Nutrient cycling strategies. Plant and soil Journal 1: 321-326. - doi: [10.1007/BF00029344](https://doi.org/10.1007/BF00029344)
- Cornwell WK, Cornelissen JHC, Amatangelo K, Dorrepaal E, Eviner VT, Godoy O, Hobbie SE, Hoorens B, Kurokawa H, Pérez-Harguindeguy N, Quested HM, Santiago LS, Wardle DA, Wright IJ, Aerts R, Allison SD, Bodegom P, Brovkin V, Chatain A, Callaghan TV, Diaz S, Garnier E, Gurvich DE, Kazakou E, Klein JA, Read J, Reich PB, Soudzilovskaia NA, Vaieretti MV, Westoby M (2008). Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. Ecology Letters 11: 1065-71. - doi: [10.1111/j.1461-0248.2008.01219.x](https://doi.org/10.1111/j.1461-0248.2008.01219.x)
- Cuevas E, Lugo AE (1998). Dynamics of organic matter and nutrient return from litterfall in stands of tropical tree plantation species. Forest Ecology and Management 112: 263-279. - doi: [10.1016/S0378-1127\(98\)00410-1](https://doi.org/10.1016/S0378-1127(98)00410-1)
- Duchesne L, Ouimet R, Camire Houle D (2001). Seasonal nutrient transfers by foliar resorption, leaching and litter fall in a northern hardwood forest at Lake Clair Watershed, Quebec, Canada. Canadian Journal of Forest Research 31: 333-344. - doi: [10.1139/x00-183](https://doi.org/10.1139/x00-183)
- Fife D, Nambiar E, Saur E (2008). Retranslocation of foliar nutrients in evergreen tree species planted in a Mediterranean environment. Tree Physiology 28:187-196. - doi: [10.1093/treephys/28.2.187](https://doi.org/10.1093/treephys/28.2.187)
- Hagen-Thorn A, Armolaitis KS, Callesen I, Stjernquist (2004). Macronutrients in tree stems and foliage: a comparative study of six temperate forest species planted at the same sites. Annals of Forest Science 61: 489-498. - doi: [10.1051/forest:2004043](https://doi.org/10.1051/forest:2004043)
- Hagen-Thorn A, Varnagiryte I, Nihlgard B, Armolaitis K (2006). Autumn nutrient resorption and losses in four deciduous forest tree species. Forest Ecology and Management 228: 33-39. - doi: [10.1016/j.foreco.2006.02.021](https://doi.org/10.1016/j.foreco.2006.02.021)
- Hashemi SF, Hojati SM, Hosseini-Nasr SM, Jalilvand H (2012). Comparison of nutrient elements and elements retranslocation of *Acer velutinum*, *Zelkova carpinifolia* and *Pinus brutia* in Darabkola-Mazandaran. Iranian Journal of Forest 4: 175-185.
- Huang J, Wang X, Yan, E (2007). Leaf nutrient concentration, nutrient resorption and litter decomposition in green broad-leaved forest in eastern China. Forest Ecology and Management 239: 150-158. - doi: [10.1016/j.foreco.2006.11.019](https://doi.org/10.1016/j.foreco.2006.11.019)
- Jackson ML (1967). Soil chemical analysis. Prentice Hall Inc, Englewood Cliffs, NJ, USA.
- Khiewtam RS, Ramakrishnan PS (1993). Litter and fine root dynamics of relic sacred grove forest of Cherrapunjee in northeastern India. Forest Ecology and Management 60: 327-344. - doi: [10.1016/0378-1127\(93\)90087-4](https://doi.org/10.1016/0378-1127(93)90087-4)
- Killingbeck K (1996). Nutrients in senesced leaves: keys to the search for potential resorption and resorption proficiency. Journal of Ecology 77: 1716-1727. - doi: [10.2307/2265777](https://doi.org/10.2307/2265777)
- Lodhiyal LS, Lodhiyal N (1997). Nutrient cycling and nutrient use efficiency in short rotation, high density Central Himalayan Tarai poplar plantations. Annals of Botany 79: 517-527. - doi: [10.1006/anbo/79.5.517](https://doi.org/10.1006/anbo/79.5.517)
- Lodhiyal N, Lodhiyal LS (2003). Aspects of nutrient cycling and nutrient use pattern of Bhabar Shisham forests in Central Himalaya, India. Forest Ecology and Management 176: 237-252. - doi: [10.1016/S0378-1127\(02\)00268-2](https://doi.org/10.1016/S0378-1127(02)00268-2)
- Liu XXU, Berninger H, Li O (2004). Nutrient distribution in *Picea likiangensis* trees growing in a plantation in West Sichuan, Southwest China. Silva Fennica 38: 235-242.
- Mahmood H, Limon SH, Rahman MS, Azad AK, Islam MS, Khairuzzaman M (2009). Nutrients (N, P and K) dynamics associated with the leaf litter of two agroforestry tree species of Bangladesh. iForest 2: 183-186. - doi: [10.3832/ifer0510-002](https://doi.org/10.3832/ifer0510-002)
- Mahmood H, Mohammad R, Hasan S, Saidur R, Zaber HM (2011). Nutrient dynamics associated with leaf litter decomposition of three agroforestry tree species (*Azadirachta indica*, *Dalbergia sissoo*, and *Melia azedarach*) of Bangladesh. Journal of Forestry Research 22: 577-582. - doi: [10.1007/s11676-011-0175-7](https://doi.org/10.1007/s11676-011-0175-7)
- Miller NG, Alpert P (1984). Plant association and edaphic features of a high arctic mesotopographic setting. Arctic and Alpin Reserch. 16: 11-24.
- Morrison IK (2003). Decomposition and element release from confined jack pine needle litter on and in the feather moss layer. Journal of Forest Research 33: 16-22. - doi: [10.1139/x02-149](https://doi.org/10.1139/x02-149)
- Niinemetts U, Kull K (2003). Leaf structure vs. nutrient relationships vary with soil conditions in temperate shrubs and trees. Journal of Ecology 24: 209-219. - doi: [10.1016/S1146-609X\(03\)00094-8](https://doi.org/10.1016/S1146-609X(03)00094-8)
- Onyekwelu JC, Mosandl R, Stimm B (2006). Productivity, site evaluation and state of nutrition of Gmelina arborea plantations in Oluwa and Omo forest reserves, Nigeria. Forest Ecology and Management 229: 214-227. - doi: [10.1016/j.foreco.2006.04.002](https://doi.org/10.1016/j.foreco.2006.04.002)
- Parzych A, Astel A, Trojanowski J (2008). Fluxes of biogenic substances in precipitation and throughfall in woodland ecosystems of the Slowinski National Park. Archives of Environmental Protection 34: 13-24.
- Piatek KB, Lee Allen H (2000). Site preparation effects on foliar N and P use, retranslocation, and transfer to litter in 15-years old *Pinus taeda*. Forest Ecology and Management 129: 143-152. - doi: [10.1016/S0378-1127\(99\)00150-4](https://doi.org/10.1016/S0378-1127(99)00150-4)
- Rahajoe JS (2003). The role of litter production and decomposition of dominant tree species on the nutrient cycle in natural forest with various substrate conditions, Doctoral dissertation, Hokkaido University, Sapporo, Japan, pp. 250.
- Rostamabadi A, Tabari M, Salehi A, Sayad E, Salehi A (2010). Comparison of nutrition, nutrient return and nutrient retranslocation between stands of *Alnus subcordata* and *Taxodium distichum* in Tashbandan, Amol (Mazandaran). Journal of Wood & Forest Science and Technology 17: 65-78.
- Rouhi-Moghaddam E, Hosseini SM, Ebrahimi E,

- Tabari M, Rahmani A (2008). Comparison of growth, nutrition and soil properties of pure stands of *Quercus castanifolia* and mixed with *Zelkova carpinifolia* in the Hyrcanian forests of Iran. *Forest Ecology and Management* 255: 1149-1160. - doi: [10.1016/j.foreco.2007.10.048](https://doi.org/10.1016/j.foreco.2007.10.048)
- Sharma JC, Sharma Y (2004). Nutrient cycling in forest ecosystems - a review. *Agriculture Review* 25: 157-172. [online] URL: <http://www.arccjournals.com/pdf/Reviews/ar-25-3/ar-25-3-001.pdf>
- Singh K, Chauhan HS, Rajput DK, Singh DV (1989). Report of a 60 month study on litter production, changes in soil chemical properties and productivity under poplar (*P. deltoides*) and Eucalyptus (*E. hybrid*) interplanted with aromatic grasses. *Agroforestry Systems* 9: 37-45. - doi: [10.1007/BF00120154](https://doi.org/10.1007/BF00120154)
- Townsend AC, Cleveland G, Bustamante M (2007). Controls over foliar N/P ratios in tropical rain forests. *Ecology* 88: 107-118. - doi: [10.1890/0012-9658\(2007\)88\[107:COFNRI\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2007)88[107:COFNRI]2.0.CO;2)
- Victor A, Dimitrios A, Alexandros T, Georgios B, Georgios S (2001). Litterfall, litter accumulation and litter decomposition rates in four forest ecosystems in northern Greece. *Forest Ecology and Management* 144: 113-127. - doi: [10.1016/S0378-1127\(00\)00365-0](https://doi.org/10.1016/S0378-1127(00)00365-0)
- Wright I, Westoby M (2003). Nutrient concentration, resorption and lifespan: leaf traits of Australian sclerophyll species. *Functional Ecology* 17:10-19. - doi: [10.1046/j.1365-2435.2003.00694.x](https://doi.org/10.1046/j.1365-2435.2003.00694.x)