Throughfall and stemflow nutrient flux in deodar and oak forests, Garhwal Himalaya, India
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ABSTRACT

A study to understand the throughfall and stemflow chemistry under deodar and oak forests of Garhwal Himalaya was conducted during 2014–2015. Total rainfall during experimental period was 1473.8 mm and estimated interception loss was 34.018% for deodar forest, 24.85% for oak forest. Stemflow represented the minimum proportion of gross rainfall, i.e. 0.321% in deodar forest and 0.463% in oak forest. pH of throughfall and stemflow in both deodar (6.087 and 6.47 respectively) and oak forests (6.75 and 7.03 respectively) was significantly more acidic than the gross rainfall (7.15). Electrical conductivity was recorded higher in deodar stemflow (231.89 μS/cm) and throughfall (102.75 μS/cm) compared to oak forest (172.92 μS/cm and 83.83 μS/cm respectively). Net nutrient leaching and stemflow were considerably higher from oak forest than deodar forest. Oak forest has better water yield capacity than deodar forest as the interception loss was higher in deodar forest. The idea of sustainable agriculture may be possible surrounding such forests as the need for chemical fertilizer and water can be met by the nutrient-rich soil, available soil moisture and surface water.

Key words | deodar, ecosystem service, hydrological flux, nutrient deposition, oak

HIGHLIGHTS

- Oak forest has better water yielding and nutrient deposition capacity than deodar forest.
- Climate and its changing condition have influence on rainfall partitioning.
- Precipitation input plays significant role in nutrient cycling.
- Sustainable agriculture may be possible around such forests as the need for chemical fertilizer and water can be met by nutrient-rich soil, available soil moisture and surface water.
**INTRODUCTION**

The nutrient cycle, similar to the hydrological cycle and energy flow involves the cycling of elements via biotic and geochemical components of ecosystems. The nutrient turnover rate is considered as one of the most important factors in the functioning and stability of ecosystem (Brasell et al. 1980). Precipitation is a significant nutrient source for forested ecosystems (Parker 1983). Quality of rainfall after passing through surface of trees is dramatically altered (Eaton et al. 1973; Parker 1983; Lovett & Lindberg 1984; Liu et al. 2003) due to additional deposition of mineral matter by throughfall and stemflow. Via stemflow and throughfall tree stands return nutrient elements to the soil (Chuyong et al. 2004). There is very close link between nutrient cycle in forests and the hydrological cycle because, being the main solvent, water transports nutrient elements from aboveground tree stands to the soil underneath (Bruijnzeel 2001). An attempt was made to measure rainfall partitioning as throughfall, stemflow and interception loss under oak and deodar forests in the Garhwal Himalayan region. A specific objective was to determine nutrient concentration of rainfall components including gross incident rainfall, throughfall and stemflow as well as pathway characteristics of nutrient elements (addition by absorption/deduction by leaching) to soil under oak and deodar forests, two most important tree species of the region.

**MATERIALS AND METHODS**

The study was conducted on deodar (Cedrus deodara) and oak (Quercus leucotrichophora) trees in Garhwal Himalaya, India. As the study area, the Tarakeshwar sacred grove [Worshipped deity is Lord Shiva and area coverage is 20 hectare (ha) (Bisht 2007)], i.e. dominated by deodar (29°50’ 30” N–78° 47’ 31.6” E, elevation 1,779 m–1,834 m above M.S.L, located in Pauri district of Uttarakhand and its adjacent area, i.e. dominated by oak (30°33’22.3”–30°33’ 13.9” N latitude and 79°02’47.3”–79°03’4.3” E longitude, elevation 1,4341,727 m) which is approximately 5 km away from deodar dominated forest, were selected. The
vegetation of the study area is composed of deodar spp. mixed with oak and pine. The area shows a typical monsoon climate, with recorded annual rainfall of 1,500–1,700 mm (Bisht 2007). The study areas (Tarkeshwar and its adjacent area) were divided into three plots each. Plots were selected in different locations within the study area so that they represented the whole study area. Each plot consisted of a 10 × 10 m area. In each plot three trees, making it nine trees from each forest types, were sampled.

ANALYSIS

Gross rainfall, throughfall and stemflow were studied on a rain event basis. For chemical analysis of samples, 16 rainfall events between June 2014 and May 2015 were considered. Gross rainfall was measured after each rainfall event in four collection flasks and two rain gauges, placed in adjoining large forest openings in the representative forest plots of deodar and oak. Rainfall events with a time gap between previous and following rain of at least 10 h to give time for the canopy to be dried out completely, were defined as individual rain events (Ahmadi et al. 2009). For throughfall measurement, a PVC pipes with an internal diameter of 120 mm were taken and divided lengthwise and then were connected with plastic tubing to 20 L containers (Cantu Silva & Gonzalez Rodriguez 2001). Three such collectors were installed under three individual trees of each plot. For stemflow sample collection, a stemflow collector was made (a tube-like structure made from aluminium sheet, which was then spiralled around the trunk of each tree) and fixed firmly with silicon sealant after smoothing the bark surface. The collection collar was installed at 1.37 m above ground level (Ahmadi et al. 2009) and stemflow was delivered to a 20 L container. In each forest type, the stemflow sample was collected from trees that had been selected for collection of throughfall samples. To estimate both throughfall and stemflow quantity, the crown projection area was calculated for individual selected trees (Delphis & Levia 2004; Ahmadi et al. 2009). To calculate stemflow depth for individual chosen trees, collected stemflow volume was divided by the crown projection area (Ahmadi et al. 2009). Dividing stemflow volume of a tree by its crown projection area, we calculated the fraction of incident rainfall that the tree received as stemflow and by subtracting the net precipitation (Stemflow + Throughfall) from gross precipitation we resulted in the amount of canopy retention. Samples of rainfall, throughfall and stemflow were measured just after each rain event. Net rainfall was computed as quantity of rainfall that reaches ultimately the forest floor and that was actually the sum total of stemflow and throughfall. Mass deposition per unit area of a particular element through rainfall, throughfall and stemflow was calculated by: (i) multiplying each element concentration with sample volume during that particular rain event; (ii) resultant product was divided by the collector area (Cantu Silva & Gonzalez Rodriguez 2001). Net deposition of elements by throughfall and stemflow was calculated by subtracting deposition of the element via throughfall and stemflow individually from element deposition via gross rainfall. Positive net deposition value for a particular element represents leaching by rain water and wash-off of dry deposition and negative value stands for absorption by canopy (Cantu Silva & Gonzalez Rodriguez 2001). Nutrient deposition via stemflow was quantified on area basis from the concentration of individual elements, the collected volume per tree and by number of trees per ha. Nutrient deposition in each fraction of rainfall (gross rainfall, canopy throughfall and stemflow) was estimated on a rain-event basis. In all collected samples, pH and electrical conductivity were measured in the field (Hannah combined pH and ORP meter) and then samples were filtered and stored at 4°C and brought back to the laboratory for further analysis. Base cations (Na⁺, Ca²⁺, K⁺) were determined by flame photometer, whereas anion concentrations (NO₃⁻, PO₄³⁻, Cl⁻) were measured by phenol di-sulfonic acid (for NO₃⁻), stannous chloride spectrophotometric method (for PO₄³⁻) and by argentometric titration method (for Cl⁻). To find out the existing trends in pH, electrical conductivity and the net and cumulative deposition of nutrient through gross rainfall, throughfall and stemflow for each forest type, a completely randomized design was used that included treatments for gross rainfall and two forest types (deodar and oak). One-way analysis of variance was attempted on all rain events for area weighted gross rainfall, throughfall, stemflow, net deposition, pH, Electrical conductivity was used with nutrient elements (Na⁺, Ca²⁺, K⁺, NO₃⁻, PO₄³⁻, Cl⁻) for testing the
mean differences among forest plots. Differences among means were determined by Tukey’s significant difference procedure at $p = 0.05$ confidence level (Mehra et al. 1985). All analyses were done using the SPSS statistical software package (16.0 version).

RESULTS

Hydrological flux (volume of precipitation)

Gross incident rainfall during study period was averaged as 1,473.8 mm. Throughfall, stemflow and interception loss as percent of gross incident rainfall is listed in Table 1.

Concentration of nutrients (mg L$^{-1}$) in different rainfall components

Under deodar forest in different rainfall components quantities of phosphate (PO$_4^{3-}$), calcium (Ca$^{2+}$), chloride (Cl$^{-}$) and electrical conductivity were higher compared with oak forest and for nitrate (NO$_3^{-}$), potassium (K$^+$), sodium (Na$^+$) and pH the scenario was opposite (Table 2). Nutrient components, pH and electrical conductivity were statistically different in each rainfall component. There was no difference in the nutrient concentration of rainfall under the two forest types. The stemflow under both forest types was more nutrient rich compared with throughfall, except for phosphate, chloride and calcium under deodar forest stands (Table 3).

Oak throughfall and stemflow were more nutrient rich than deodar, except phosphate, calcium, chloride and sodium in deodar throughfall. The average pH of rainwater was higher than pH for both throughfall and stemflow under both forests (Table 3).

Nutrient deposition (kg ha$^{-1}$ year$^{-1}$) by rainfall components

Relative contribution of stemflow of each forest to the gross nutrient deposition is presented in Table 4. Mean total nutrient deposition by throughfall and stemflow were higher in oak than deodar forests. Net gain of nutrients (nitrate, calcium, potassium, sodium) from the canopy was higher in oak compared to deodar forests. PO$_4^{3-}$ and Cl$^{-}$ were absorbed by both forests (Table 4).

DISCUSSION

In oak-dominated forests, stemflow value has been recorded as $<1\%$ of the gross rainfall and was similar to other reported studies of similar sites (Table 5). This may be due to the thick epiphyte growth on the bark that may impede stemflow. Throughfall in oak-dominated forests was estimated as about 75% and was similar to recorded values for similar sites. Even throughfall in similar ranges has been recorded by several researchers for broad leaf forests (Table 5). Our estimated canopy interception was 24.85%, which was similar to the recorded value (17.7–32.4%) of some researchers at similar sites (Table 5). As found in a separate study, our results also revealed that canopy interception was higher in the coniferous canopy than in

| Table 1 | Percent (%) of precipitation components in Tarkeshwar sacred grove and adjacent area, Pauri Garhwal, Uttarakhand, India |
|---------|---------------------------------------------------------------|
| Stand characteristics | Deodar | Oak |
| Mean crown area (sq. m) of selected trees | 45.69 ± 32.56 | 44.34 ± 63.77 |
| Throughfall | 65.66% | 74.69% |
| Stemflow | 0.321% | 0.463% |
| Interception loss | 34.018% | 24.85% |

| Table 2 | Mean comparison of nutrients, pH and electrical conductivity under deodar and oak forests |
|---------|---------------------------------------------------------------|
| Forest type | NO$_3^{-}$ (mg/l) | PO$_4^{3-}$ (μg/l) | Ca$^{2+}$ (mg/l) | K$^+$ (mg/l) | Na$^+$ (mg/l) | Cl$^{-}$ (mg/l) | pH | EC (μS/cm) |
|-----------|-----------------|-----------------|--------------|----------|-----------|--------------|----|----------|
| Deodar    | 0.566           | 0.0208          | 4.779        | 6.877    | 2.678     | 2.087        | 6.575 | 128.830   |
| Oak       | 0.681           | 0.0206          | 4.588        | 10.679   | 2.918     | 1.909        | 6.977 | 107.809   |
the broadleaf forest canopy (Neary & Gizyn 1994). Rainfall partition of tropical forests, in Manipur at different times of year, i.e. drier and wetter months were found to be quite different than that in temperate forests found by several different workers at different times over different years (Table 5). If rainfall partitioning is considered year-wise then a continuous deterioration of rainfall partitioning (throughfall and stemflow) is observed clearly (Table 5). From the study, an influence of changing climate is observed on rainfall partitioning of similar sites. The variation of interception loss between two forests, i.e. between deodar and oak forests, indicates a difference in potentiality of water yield capacity among the two types of forest stands. Less interception loss in oak forests indicates a higher water yield of oak forest and greater water ecosystem service from such forests. But, due to climatic change and subsequent invasion of oak forests by aggressive pine, large tracks of oak are vanishing. With the passage of time this will increase, resulting into water scarcity not only in hills but also in low flow in Himalayan rivers especially during the lean season. On both the rain event basis (data not presented) and on a mean annual basis, nutrient concentration, pH and electrical conductivity of throughfall and stemflow varied significantly with forest type. Highest net nutrient deposition was observed for potassium, followed by calcium, in oak forest. Earlier studies have also found highest amounts of potassium in net deposition under oak forests, followed by calcium (Pathak & Singh 1984). Conversely in deodar forests, the scenario was just the opposite. These results depict the fact that leaching of nutrient occurs from both or either the bark or leaf tissues. It also indicates that nutrients were transported to the soil much

Table 3 | Mean comparison of nutrients, pH and electrical conductivity between incident rainfall (IR), throughfall (TF) and stemflow (SF) under deodar and oak forests

| Component a | Deodar | Oak | Mean b | Component | Deodar | Oak | Mean b |
|-------------|--------|-----|--------|-----------|--------|-----|--------|
| NO₃⁻ (ppm)  |        |     |        | IR        |        |     |        |
| IR          | 0.246  | 0.246 | 0.246  p | IR        | 1.376  | 1.376 | 1.376  p |
| SF          | 0.856  | 1.089 | 0.973  q | SF        | 4.613  | 6.14  | 5.376  q |
| TF          | 0.595  | 0.706 | 0.651  q | TF        | 2.045  | 1.239 | 1.642  p |
| Mean        | 0.566  | 0.681 | Mean   |           | 2.678  | 2.918 |        |
| PO₄³⁻ (ppm) |        |     |        | Cl⁻ (mg/L)|        |     |        |
| IR          | 0.029  | 0.03  | 0.030  q | IR        | 2.085  | 2.085 | 2.085  p |
| SF          | 0.015  | 0.019 | 0.017  p | SF        | 1.417  | 2.692 | 2.055  p |
| TF          | 0.018  | 0.012 | 0.015  p | TF        | 2.757  | 0.951 | 1.854  p |
| Mean        | 0.021  | 0.021 | Mean   |           | 2.087  | 1.909 |        |
| Ca²⁺ (mg/L) |        |     |        | pH        |        |     |        |
| IR          | 2.538  | 2.538 | 2.538  p | IR        | 7.169  | 7.171 | 7.17   q |
| SF          | 5.361  | 7.223 | 6.292  r | SF        | 6.472  | 7.01  | 6.741  p |
| TF          | 6.437  | 4.002 | 5.220  r | TF        | 6.084  | 6.751 | 6.418  p |
| Mean        | 4.779  | 4.588 | Mean   |           | 6.575  | 6.977 |        |
| K⁺ (mg/L)   |        |     |        | EC (μs/cm)|        |     |        |
| IR          | 1.733  | 1.733 | 1.733  p | IR        | 62.913 | 62.913 | 62.913  p |
| SF          | 14.171 | 22.317 | 18.244  r | SF        | 215.309 | 175.33 | 195.319  p |
| TF          | 4.726  | 7.987 | 6.357  q | TF        | 102.267 | 85.184 | 93.726  q |
| Mean        | 6.877  | 10.679 | Mean   |           | 126.803 | 107.809 |        |

NS, not significant; CD, critical difference; IR, incident rainfall; TF, throughfall; SF, stemflow.

aCD (0.05) P-value = 0.05; Component (NO₃⁻) 1 = 0.091, PO₄³⁻ = 0.0052, Ca²⁺ = 0.37, K⁺ = 1.035, Na⁺ = 0.74, Cl⁻ = 0.049, EC = 13.93; Forest Type (NO₃⁻) 1 = 0.074, PO₄³⁻ = NS, Ca²⁺ = NS, K⁺ = 0.85, Na⁺ = NS, Cl⁻ = 0.33, pH = 0.04, EC = 11.38; Component × Forest Type (NO₃⁻) 1 = NS, PO₄³⁻ = NS, Ca²⁺ = NS, K⁺ = 1.46, Na⁺ = 1.04, Cl⁻ = 0.57, pH = 0.07, EC = 19.70.

bSame letter represents statistically homogeneous group. This will remain same until not specified.
more via throughfall and stemflow than through rainfall. Potassium, calcium, sodium and nitrate were added to precipitation by foliage while phosphate and chloride were absorbed by canopy in both forests. Highest throughfall deposition (gain from canopy) is recorded in case of potassium followed by calcium in oak forest stands. Similar results were reported by some workers (Pathak & Singh 1987). As the ambient atmospheric dry deposition of the elements was low in the study area its mobility and concentration in foliage must be extremely high in the forest and the high level of potassium and calcium may be derived almost entirely by means of foliar leaching (Ling-hao & Peng 1992). Thus, nutrient deposition by means of throughfall on an area basis is more for oak forests than deodar forests. This result corroborates the observation that oak forest has higher foliar biomass than deodar forest. The elements in cell sap, preliminary in ionic form (for example potassium) are generally cycled rapidly as well as moved

### Table 4 | Mean annual nutrient input and net gain (kg ha\(^{-1}\) year\(^{-1}\)) from precipitation components

| Precipitation components | NO\(_3\) \(^{-}\) | PO\(_4\) \(^{3-}\) | Ca \(^{2+}\) | K \(^{+}\) | Na \(^{+}\) | Cl \(^{-}\) |
|--------------------------|----------------|----------------|----------|--------|--------|--------|
| Deodar-dominated forest   |                |                |          |        |        |        |
| Rainfall                 | 0.525765       | 0.058242       | 5.228858 | 2.76736| 0.913902| 5.695984|
| Throughfall              |                |                |          |        |        |        |
| Total                    | 1.342812       | 0.041965       | 15.76416 | 5.07364| 3.188445| 4.704433|
| Stemflow                 |                |                |          |        |        |        |
| Rainfall                 | 0.027375       | 0.001519       | 0.407904 | 0.256237| 0.070601| 0.8938 |
| Total                    | 0.390473       | 0.006083       | 2.357819 | 2.752349| 1.326211| 1.199741|
| Throughfall + stemflow   |                |                |          |        |        |        |
| Total                    | 1.733286       | 0.048048       | 18.12198 | 7.82599 | 4.514656| 5.904173|
| Net gain from/ by canopy | 1.180146       | –0.0117\(^{b}\) | 12.48522 | 4.802393| 3.530152| –0.68561|
| Oak-dominated forest      |                |                |          |        |        |        |
| Rainfall                 | 1.27499        | 0.13966        | 12.92145 | 6.936709| 2.324259| 14.43556|
| Throughfall              |                |                |          |        |        |        |
| Total                    | 4.260936       | 0.049269       | 24.11032 | 22.88165| 6.33347 | 6.103699|
| Stemflow                 |                |                |          |        |        |        |
| Rainfall                 | 0.09789        | 0.005423       | 1.459493 | 0.917033| 0.2527  | 3.199403|
| Total                    | 2.148733       | 0.011002       | 10.23857 | 10.40999| 4.4687  | 1.580533|
| Throughfall + stemflow   |                |                |          |        |        |        |
| Total                    | 6.409668       | 0.060271       | 34.34888 | 33.29164| 10.80205| 7.684232|
| Net gain from/ by canopy | 5.036789       | –0.08481       | 19.96793 | 25.4379  | 6.226909 | –9.96873|

\(^{a}\)Gain of nutrient from forest has been calculated as: (i) the difference between the amount of nutrient in rainfall and throughfall for a given volume of throughfall; and (ii) the difference between the amount of nutrient in rainfall and stemflow for a given volume of stemflow.

\(^{b}\)The negative sign stands for absorption of nutrient by forest stand.

### Table 5 | Comparison of rainfall partitioning in the oak dominated forest influenced by different climatic conditions

| Type of forest based on climate | Year     | Months | TF (as % of rainfall) | SF (as % of rainfall) | In (as % of rainfall) |
|--------------------------------|----------|--------|-----------------------|-----------------------|-----------------------|
| Temperate forest, Uttarakhand\(^{a}\) | 1981–1983 | W       | 84.7                  | 0.4                   | 14.9                  |
|                                  |          | W       | 80.8                  | 0.9                   | 18.3                  |
| Temperate forest, Uttarakhand\(^{b}\) | 1981     | W       | 78.92                 | 0.46                  | 20.6                  |
|                                  | 1982     | W       | 77.75                 | 0.92                  | 22.5                  |
| Tropical forest, Manipur\(^{c}\) (1) | 2009     | D       | 39.3                  | 1.8                   | 58.69                 |
|                                  |          | W       | 53.3                  | 3.1                   | 43.50                 |
| Tropical forest, Manipur\(^{c}\) (2) | 2009     | D       | 24.8                 | 2.7                   | 72.67                 |
|                                  |          | W       | 61.3                 | 4.7                   | 33.42                 |
| Temperate forest, Uttarakhand (Current study) | 2014–2015 | D & W   | 74.69                | 0.463                 | 24.85                 |

\(^{a}\)Pathak et al. (1985).

\(^{b}\)Pathak & Singh (1984).

\(^{c}\)Gupta & Usharani (2009).
predominantly in throughfall. By contrast, elements which are predominantly non-ionic in form (N, P), associated with plant tissue are usually cycled slowly (Pathak & Singh 1984). Due to this reason perhaps, throughfall shows higher concentrations of elements such as potassium and lowest concentrations of elements like nitrate and phosphate (Pathak & Singh 1984). Several workers have reported a relationship between throughfall chemistry and frequency, intensity, quantity, as well as duration of precipitation (Pathak & Singh 1984), the chemical characteristics as well as tree crown capture ability of dry deposition (Pathak & Singh 1984), species (Edmons et al. 1991), growing season (Neary & Gizyn 1994), forest type (Forti & Neal 1992), site fertility (Shepard & Mitchell 1991), temporal and spatial variability (Robson et al. 1994) and leaf anatomy, physiology and morphology (Cantu Silva & Gonzalez Rodriguez 2001).

Due to the non-uniformity of canopy density and efficiency difference in canopy structure in filtering dry deposition, temporal and spatial variability in throughfall chemistry has been observed (Robson et al. 1994). Greater nutrient concentration in stemflow is possible, as percolating water comes after washing down the decomposition product of bark. The identified pattern of nutrient concentration in incident rainfall was in the order: Ca$^{2+} >$ Cl$^-$ > K$^+$ > Na$^+$ > NO$_3^-$ > PO$_4^{3-}$. Similar results were reported earlier regarding calcium, potassium, nitrate and phosphate concentration (Neary & Gizyn 1994). The observed pattern of stemflow nutrient flux was different than that of the throughfall pattern under both forest types. Highest stemflow deposition was recorded in case of potassium followed by calcium in both oak and deodar forests. For the oak forest the result is supported by an earlier study (Pathak & Singh 1984). In stemflow the concentration of nutrient elements was considerably higher in both forests compared to incident rainfall. Calculated proportional stemflow nutrient flux reveals the relative significance of stemflow as an input to soil in nutrient cycle of forest where stemflow nutrient flux has been calculated as stemflow/(stemflow + throughfall) (Ling-hao & Peng 1998). Under both forests important contribution was via nitrate (22.53% and 33.52% by deodar and oak forests respectively), phosphate (12.66% and 18.25% by deodar and oak forests respectively), calcium (13.01% and 29.81% by deodar and oak forests respectively), potassium (35.17% and 31.27% by deodar and oak forests respectively), sodium (29.38% and 41.37 by deodar and oak forests respectively) and chloride (20.32% and 20.57% by deodar and oak forests respectively).

Nutrient concentration in stemflow is considerably higher than that of throughfall established by earlier studies (Parker 1985; Ling-hao & Peng 1998). From an ecosystem service point of view, stemflow can be a very important source and route of nutrient transfer to soil. Stemflow, though, is more infrequent than throughfall, but almost always contributes to the stemflow zone of the forest floor the largest input of water and nutrient content (Ling-hao & Peng 1998). Under both forests both throughfall and stemflow have lower pH than incident rainfall. Again, deodar throughfall has lower pH than oak throughfall and confirms previously endorsed facts that coniferous canopies tend to have lower throughfall pH relative to both incident rainfall and hardwood canopy pH (Edmons et al. 1991; Levia & Herwitz 2000; Cantu Silva & Gonzalez Rodriguez 2001). Our results indicate the throughfall pathway is the major contributor to the annual nutrient return to forest floor in both deodar and oak forests compared to the stemflow pathway. As a whole, both throughfall and stemflow play important roles in nutrient cycles of the study area.

**CONCLUSION**

Oak forest has better water yield capacity than deodar forest, as the interception loss was higher in deodar forest than oak forest. Climate and its changing conditions also have an influence on rainfall partitioning. In oak forest, nutrient deposition by means of throughfall on an area basis was more than for deodar forest. Perhaps these are the reasons that, in this part of Himalaya, people consider oak as a water conserving tree and there is no scarcity of water where oak forests are present. These are the ecosystem services provided by oak forest. Precipitation input plays a significant role in nutrient cycling as nutrients are found readily available in precipitation in both forests. Based on the result it may be proposed that if local people start agricultural practices surrounding the area it may be beneficial from the view point of human health, as well as appropriate use of land. The idea may be successful as the practice will need less or no chemical fertilizer input for
crop production. The idea of sustainable agriculture may be possible surrounding such forests, as the need for chemical fertilizer and water can be met by the nutrient-rich soil, available soil moisture and surface water.

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**DATA AVAILABILITY STATEMENT**

All relevant data are included in the paper or its Supplementary Information.

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