Nutrient cycling in the major ecosystems of the cold desert of Himachal Pradesh, India

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Nutrient cycling study was carried out in three major ecosystems, viz. forest ecosystem, alpine pasture ecosystem and agroecosystem of Goshal village, Lahaul and Spiti district, Himachal Pradesh, India to assess the flow of nutrients from one ecosystem to another. Soil nutrients, plant biomass and nutrient content of grasses, herbs and woody species present in the study area were estimated. It was observed that in forest and alpine pasture ecosystems, nutrients from the woody species return to the system. In the alpine pasture ecosystem, of the total nutrients present in grasses and herbs, 30% returned to the system after decomposition and the remaining 70% was transferred to agricultural fields through grazing. In the agroecosystem, 90% of aboveground biomass of grasses and herbs was harvested as fodder for winter stall feeding, which returned to the agricultural fields as farmyard manure. Thus, 100% of belowground and 10% of aboveground nutrients in the agroecosystem remained in the field, got decomposed and returned to the system.

Keywords: Agroecosystem, alpine pasture ecosystem, forest ecosystem, nutrient flow, plant biomass.

NUTRIENT cycling is the movement of nutrients required by living organisms through different parts of the biosphere. In nature, the nutrient elements and their compounds continuously move from the non-living environment to living organisms and back to the non-living environment. This cyclic movement of minerals from their reservoirs (air, water and soil) to the living components and back to the reservoirs is called nutrient cycling or biogeochemical cycles[1]. Nutrient cycling occurs everywhere, being a necessary part of the ecosystem function, but at varying rates. The specific ecosystem service of fertility is unevenly distributed around the land and oceans of the world. For example, the most fertile soils, the deep, dark, loamy soils of the Eurasian steppes, the North American prairies and the South American pampas have been mostly converted from grasslands to intensive agroecosystems over the past two centuries[2].

Cold deserts are lands at the polar fringes of the continents in the Northern Hemisphere and the ice-covered waters of Greenland and Antarctica[3]. India's cold desert is located mainly in two states, viz. Himachal Pradesh (HP) and Jammu and Kashmir. The Himalayan region in HP is well known for its representative, natural, unique and socio-economically important plant diversity[4]. It is designated as one of the biodiversity hotspots and supports 18,440 species of plants with 25–30% of endemics[4,5]. Lahaul and Spiti, a tribal district of HP, falls under the cold desert region. The topography of the Lahaul and Spiti district is entirely hilly. The region is characterized by low precipitation, a short growing season, low primary productivity and high stocking density[6]. Temperatures generally do not exceed 30°C, with July and August as the hottest months. January and February are the coldest, with a mean temperature of –20°C (ref. 7). The growing season in cold deserts is restricted to less than six months a year. The key to settlement is through the intelligent use of glacial melts. Snow and glaciers are the only sources of water. At first glance, it may seem that human survival is impossible in this harsh climate. Yet, the local people have learned to make judicious and optimal use of their limited resources and have built a glorious civilization in the process. The increase in human population has also increased the demand for economically important biodiversity elements. This has caused the overexploitation and habitat degradation of many economically essential biodiversity elements and their rapid loss. With developmental activities such as education and communication facilities, the area experienced a drastic change in land-use patterns and nutrient balance of the ecosystem. Nutrients removed from the soil decide the nutritional security of a nation[8]. The soil nutrient status of an area is an important parameter in determining the nutrient status of plants. The present study was carried out to determine nutrient flow based on plant biomass, soil nutrient and plant nutrient estimates in major ecosystems of the cold desert.

The study was conducted in Goshal village, located in Lahaul and Spiti district, HP. It is one of the largest villages in this district, with maximum cropping diversity, abundant alpine pastures and adjoining forest area. HP forms part of the northwestern Himalayas. Lahaul valley comprises an area of 1761 miles (ref. 2). Goshal in the Lahaul valley is situated on the left bank of River Chandra just before it merges with River Bhaga. The village is located on fan-shaped alluvial deposits and occupies 28.90 ha of land. It is one of the largest villages in the main Lahaul valley. Above the agricultural fields, the village area supports grazing land; as the grazing land rises in elevation, we find an invasion of shrubs. At higher reaches, the area supports conifer forests, and above that level, glaciers exist from where the meltwater flows down through gorges and feeds the whole village. The entire village area according to the revenue records, and the adjoining alpine pastures and forest areas under the usage of village residents have been differentiated into (1) Forest ecosystem, (2) Alpine ecosystem and (3) Agroecosystem.

Each ecosystem was divided into nine grids for sampling. Sampling in each grid was carried out following the

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quadrat method. The size of the quadrat was estimated following species–area curve[9]. Based on the species–area curve, the size of the forest ecosystem was 50 m × 50 m for trees and shrubs. In the alpine pasture ecosystem, the quadrat size for shrubs was 25 m × 25 m, whereas for grasses and herbs it was 1 m × 1 m in the alpine ecosystem and agroecosystem. Three quadrats were laid in each grid in all three ecosystems for recording the phyto-sociological data. Tree species like *Betula utilis*, *Cedrus deodara* and *Juniperus macropoda* in the forest ecosystem and shrubs like *Berberis jaeschkeana*, *Ephedra gerardiana* and *Hippophae rhamnoides* were present in the study area. Four species of grasses, namely *Agropyron longearistatum*, *Festuca rubra*, *Brumus asper* and *Dactyluss glomerata* and 18 herbaceous species, were found in the alpine ecosystem and agroecosystem of the study area. They were sampled for plant biomass and nutrient estimation.

The performance of various vegetational units was studied for the total biomass production of grasses and herbaceous flora in the study area. The estimation was carried out using quadrats (1 m × 1 m) for aboveground biomass studies. Belowground estimations were done by digging of monoliths (25 cm × 25 cm × 25 cm). A minimum of three quadrats and three monoliths each were taken from each sampled field. The aboveground samples were cut, packed separately in paper bags, brought to the laboratory, dried in an oven at 80°C till constant weight, and weighed for biomass estimation. The belowground parts were first washed to remove all the adhering soil particles, packed collectively in paper bags, oven-dried at 80°C and weighed.

Soil and plant samples from each quadrat were collected from all three ecosystems. The nutrient status of soil was estimated to determine nutrient flow from the soil to grasses and herbs[10,11]. Soil samples were dug out from each quadrat at three different depths (0–10 cm, 10–20 cm and 20–30 cm) with three replications. To estimate aboveground and belowground plant nutrient content, oven-dried plant biomass samples were used. These samples were crushed and ground in Willy's mill to pass through a 2 mm sieve. The ground samples were packed separately and used for nutrient estimation. Nitrogen content (%) was estimated using the micro Kjeldahl method[10]. For estimation of P, K, Ca and Na, the ground plant material (1 g) was digested in a mixture of sulphuric acid + nitric acid + perchloric acid (5 : 3 : 1) on a hot plate till the solution became clear. The contents were cooled and the volume made up to 50 ml, which was treated as the stock solution. Phosphorus (%) was determined using chlorostannate molybdophosphoric acid[11] and the intensity of the blue colour developed was read using a spectrometer (Spectronic-20) at 660 nm against a blank. KH_2PO_4 was used to develop a standard curve for further calculations. Estimation of K, Ca, and Na percentages was carried out with a flame photometer using their respective filters. Standards for K, Ca and Na were prepared from KCl, $CaCO_3$, and NaCl respectively. Aboveground and belowground plant nutrient content of trees, shrubs, grasses and herbaceous species from each quadrat was estimated and was further converted into kilogram per hectare to study nutrient flow.

Figures 1 and 2 show the average nutrient content of the soil in alpine and forest ecosystems. In these ecosystems, nutrients in the twigs of trees and shrubs remain as such, while leaves after falling to the ground turn to litter; some part of it is lost some while it decomposes from which nutrients are returned to the soil. In a similar study on nutrient dynamics, it was found that environmental factors such as rainfall drives temporal variability in litter and nutrient inputs, whereas nutrient release from decomposing litter influences the magnitude[12]. Low temperature reduces microbial activity, litter decomposition rate and nutrient availability, and increases carbon accumulation in soil[13]. Another study was carried out on leaf decomposition, indicating that 77% of the original leaf biomass was lost within a year[14]. Concentration and monthly dynamics of

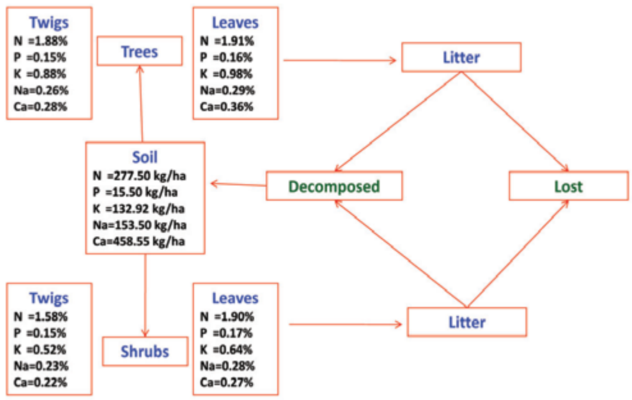

Figure 1. Nutrient cycling through trees and shrubs in forest ecosystem.

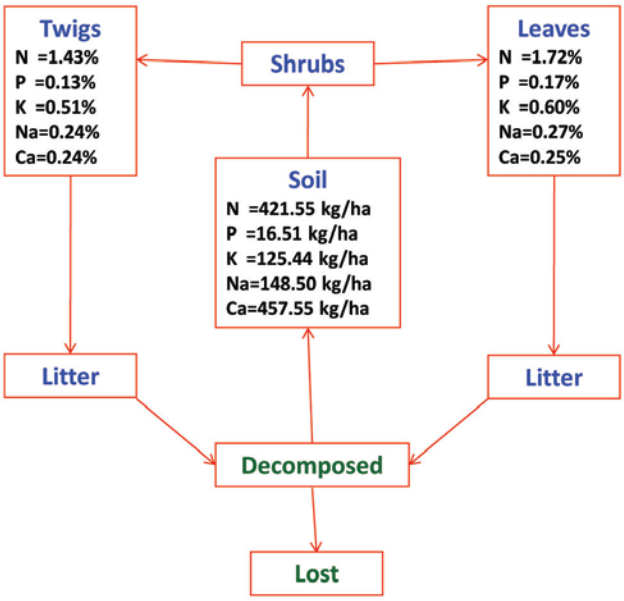

Figure 2. Nutrient cycling through shrubs in alpine pasture ecosystem.

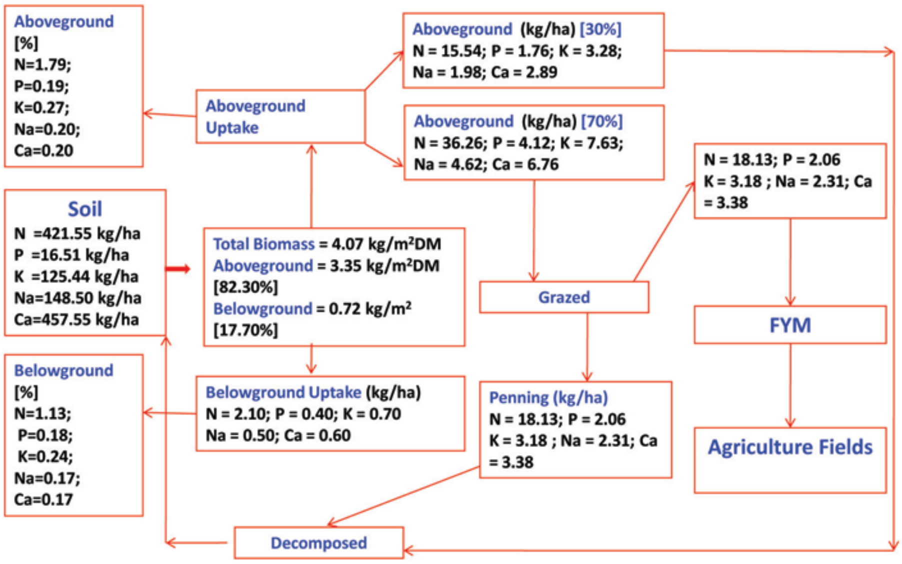

Figure 3. Biomass and nutrient cycling through grasses and herbs in alpine pasture ecosystem.

N, P and K also differed significantly among litter fractions[15]. The nutrient status of surface soil showed seasonal variability in a study on litterfall and nutrient dynamics in soil under a 20-yr-old *Eucalyptus* hybrid plantation[16]. Studies on nutrient cycling and nutrient use efficiency (NUE) for three 20-yr-old *Pinus taeda* plantations revealed that the requirement of N, P, K, Ca and Mg was 298, 15, 63, 70 and 15 kg/ha/yr respectively, and uptake was 161, 8, 36, 70 and 15 kg/ha/yr respectively[17]. The fractional annual turnover rate of plantations of six tree species varied between the elements (N, P, K, Ca and Mg), with N having the highest value (68–92%) and Mg the least (13–62%)[18].

The total aboveground and belowground nutrient uptake of grasses and herbs revealed that (i.e. N, 53.90 kg/ha; P, 6.29 kg/ha; K, 11.60 kg/ha; Na, 7.10 kg/ha and Ca, 10.26 kg/ha) of the total aboveground biomass 70% is grazed by animals and 30% (i.e. N, 15.54 kg/ha; P, 1.76 kg/ha; K, 3.28 kg/ha; Na, 1.98 kg/ha and Ca, 2.89 kg/ha) and 100% of belowground biomass (i.e. N, 2.10 kg/ha; P, 0.40 kg/ha; K, 0.70 kg/ha; Na, 0.50 kg/ha and Ca, 0.60 kg/ha) is left in the system; it is decomposed and returned to the system. Of the 70% aboveground biomass which is grazed by the animals, 50% (N, 18.13 kg/ha; P, 2.06 kg/ha; K, 3.18 kg/ha; Na, 2.31 kg/ha and Ca, 3.38 kg/ha) is decomposed after penning and returned back to the system, and rest 50% (N, 18.13 kg/ha; P, 2.06 kg/ha; K, 3.81 kg/ha; Na, 2.31 kg/ha and Ca, 3.38 kg/ha) goes to the agricultural fields as farmyard manure (FYM) and is thus removed from the system (Figure 3). Nutrients are accumulated in plant components in the order N > K > Ca > Mg > P. A large amount of nutrients is stored in the soil, and relatively less is distributed to various plant parts. The uptake of nutrients in the aboveground parts is higher than in the belowground parts[19]. A similar study on nutrient loss and redistribution in pasture ecosystems revealed that grass turnover had replaced litterfall return as the predominant mechanism of nutrient recycling[20]. A study[21] was carried out on the growing-season nutrient dynamics of four reindeer forage species (*Betula nana*, *Eriophorum angustifolium*, *Rumex acetosa* and *Vaccinium myrtillus*) in a mountainous subarctic landscape in northern Sweden. In the study, the N and P concentrations showed marked seasonal variations, with peaks occurring from the middle of June to the end of July depending on species and snowmelt progression[21]. A study on phosphorus cycling and losses in irrigated sheep-grazed pastures receiving superphosphate (SP) applications for 35 years suggested that P leaching losses from SP fertilizer, plant litter, root residue and sheep faeces were unlikely to occur beyond the major plant rooting zone[22].

Figure 4 depicts the average nutrient content of the soil in the agroecosystem. Soil fertility had direct implications on the agricultural production scenarios of a region[23]. Therefore, accurate estimates of the quantity and rate of soil nitrogen supply and other nutrients are essential to increase soil and farm N use efficiencies, particularly for soils with high organic matter[8,24]. The present study showed that soil and plant nutrient content in the agroecosystem was slightly higher than in forest and alpine ecosystems due to the continuous application of organic and inorganic fertilizers. Apart from biological N_2 fixation and atmospheric N deposition, the most important input sources are mineral fertilizer and animal manure[25]. From the total aboveground and belowground nutrient uptake of grasses and herbs in the agroecosystem, it was observed that the uptake of N was 81.30 kg/ha; P, 11.00 kg/ha; K, 21.10 kg/ha; Na, 11.10 kg/ha and Ca was 12.60 kg/ha. The aboveground uptake of N was 74.90 kg/ha; P, 10.10 kg/ha; K, 19.50 kg/ha; Na, 10.30 kg/ha and Ca was 11.60 kg/ha, whereas the belowground uptake of N was 6.40 kg/ha; P, 0.90 kg/ha; K, 1.60 kg/ha; Na, 0.80 kg/ha and Ca was 1.00 kg/ha. Ninety

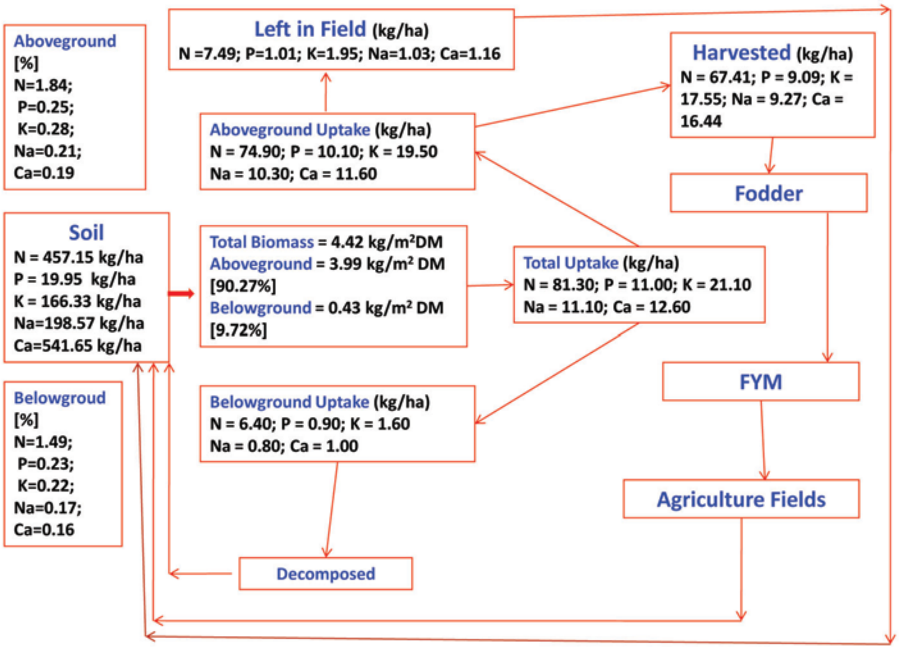

Figure 4. Biomass and nutrient cycling through grasses and herbs in agroecosystem.

per cent of the aboveground biomass is harvested for fodder and winter stall feeding and it is returned to the agricultural fields as FYM, whereas 100% of belowground and 10% of aboveground nutrients remain as such in the field, get decomposed and are returned to the system (Figure 4). We found a significant difference in nutrient content in the soil pool, supply, uptake and removal in all three ecosystems. Agroforestry and cover crops consistently reduced run-off and erosion, and improved carbon sequestration and nutrient balance compared to conventional systems[26]. Aboveground biomass increased by 78% when N alone was added.

In contrast to aboveground biomass, belowground biomass increased with P and K additions, but showed no significant increase with N. The aboveground biomass of all monocots increased with the addition of N, whereas dicots showed no response to the addition of nutrients[27]. Cultivation reduced the mean annual net nitrification and net nitrogen mineralization by 50.71% and 47.67% respectively[28]. In a similar study on nutrient content, no differences in N, K and Ca contents in the biomass were observed for various treatments; however, the highest P content was registered in coffee grown in the complete solar system, whereas the highest Mg content was found in coffee grown with *Gliricidia*[29]. The fraction of nutrients recycled on-farm before leaving the system. Improving nutrient cycling entailed the operational integration of livestock, utilizing ecological nutrient replenishment processes through legume intercropping, and optimizing nutrient transfer from extensive land-use systems. Nitrogen and phosphorus recycling grew steadily due to the increased application of mineral fertilizers[30].

We found a significant difference in the nutrient flow of forest ecosystems, alpine ecosystems and agroecosystems. In the forest and alpine pasture ecosystems, after the decomposition of leaves, the nutrient is returned to the soil. More biomass and nutrients return to the agroecosystem through decomposition of roots or FYM and human night soil. Thus, a major part of the energy, biomass and nutrients is recycled within the system in the case of agroecosystem, whereas a significant part of biomass, nutrients and energy is removed from the alpine ecosystem in the case of grasses and herbs. The present study concludes that farming communities should conserve the rich alpine biodiversity near their agricultural fields. It is also recognized that continuous grazing affects the nutrient status, biodiversity and rich, eco-friendly cultural heritage. Thus there is an urgent need to document the same to maintain the fragile, diverse and unique cold desert ecosystem, and harness its potential for the overall development of its inhabitants.

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Growth performance, biomass, carbon storage and carbon dioxide release abatement of bamboo plantation in Chhattisgarh plains of India

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This study was carried out in a bamboo (*Dendrocalamus strictus*) plantation (8 × 6 m spacing) at the forestry research farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India, during 2018–19. The average population of bamboo was 33.38 culms per clumps during July 2018 after 8 months bamboo population was 45.0 culms per clumps during March 2019. The girth of clump was measured 5.66 m during March 2019. The average bamboo height was 8.35 ± 0.54 m and diameter 3.56 ± 0.77 cm at the third internode. The emerging number of new culms per clump was recorded highest in August (5.25 ± 1.91) and lowest in October (0.25 ± 0.45) with no emerging new culms per clumps during November to March. The total biomass, carbon storage and carbon dioxide release abatement were estimated as 63.85 Mg ha^{-1}, 30.01 Mg ha^{-1} and 110.13 Mg CO_2 eq ha^{-1} respectively.

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