

N-pool in volcanic ash-derived soils in Chile and its changes in deforested sites

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Abstract

Changes in N-distribution patterns in volcanic-ash of Chile after deforestation of a primary forest were measured. There is a clear tendency towards the depletion of N linked to high molecular weight fractions (humins, humic acid fractions) after the disturbance. These changes are illustrated schematically in relation to N input and output and to rhizosphere behavior after deforestation.

N-pool and its pattern distribution within soil organic macromolecules is postulated to be a good indicator of N-dynamics in soils, which could be applied to detect soil deterioration processes. As an experimental model, it is proposed to characterize organic-N as N-fulvic, N-humic, N-humin and light organic-N.

Keywords: Nitrogen cycle; Volcanic soils; Rhizosphere changes

Information on the size and the cycling of nitrogen pools in soil is important to develop good soil fertilization management to improve N-uptake by plants. This includes the assessment of chemical forms of N and its dynamic changes related to organic matter and type of microbial population, clay mineralogy, cultivation practices, etc.

Chilean volcanic soils represent a good model to obtain an insight on N cycle in natural ecosystems and its changes after the intervention of man and application of large amounts of fertilizer, mainly P and N. The formation processes of volcanic soils in Chile have been mainly influenced both by the chemical composition of the parent volcanic ashes and the climate of southern hemisphere beyond a latitude of 35°S (Chillán), characterized by high annual rainfall (1500–3000 mm) and low temperature regimes (12–15 °C) (Besoain, 1985). Soil formation resulted in acidic volcanic-derived soils, whose clay fractions are composed of allophane or allophane-like minerals. In these acid soils, the microflora is clearly dominated by fungi and *Actinomyces* spp. which show a very high capacity of humus biosynthesis (Zunino et al., 1982a). The physico-chemical properties of allophane, interacting with the unusually high microbial activity, has been the motor force to stimulate in non-disturbed soil an accumulation of organic macromolecules with high levels of C, N, P and S

(Borie and Zunino, 1983; Zunino and Borie, 1985; Aguilera et al., 2000). Biological activities such as enzymatic and respiratory ones are also noteworthy in these soil systems (Peirano et al., 1992).

Reported total N in soils range in general from 0.02 to 0.4% with a mean value of 0.14 (Lindsay, 1979). Nitrogen is found mainly in organic forms, while a tendency to accumulate as amino acids has been observed in extremely humid and organic soils (Savant and De Datta, 1982; Stevenson, 1982). The inorganic N (NO_2^- , NO_3^- and NH_4^+) accounts for 5% of total N and is easily lost by leaching as nitrate and/or volatilization as ammonia. Dynamic changes from organic to inorganic forms regulates the N-availability to plants of indigenous N. The fate of N added as fertilizer depends on biological soil properties and cultivation practices which over the long-term will impose N-losses by leaching and volatilization or its incorporation into the soil organic matter complex (Stevenson, 1982).

In Chilean volcanic soils it has been postulated that microbiological N-mineralization processes are limited by low C-availability, in spite of their high total-C content (Urbina et al., 1969, 1972). These studies also showed that the N-mineralization rate is inversely correlated to the degree of polymerization of soil organic matter (SOM).

Agricultural use of these soils has led to a drastic decrease in total C content, but knowledge is scarce on how and when indigenous or added-N is associated with the different chemical forms of SOM (Aguilera et al., 1998, 1999).

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Table 1

Selected properties of Chilean volcanic ash-derived soils (F: wild forest; P: natural prairie; O: untreated deforested soil; Pf: cultivated and fertilized prairie; C: soil under agronomic rotation)

Soils	pH	% C	% N	C/N
Andisols (trumaos)				
Osorno O	5.6	8.02	0.57	14.0
Osorno Pf	4.9	7.92	0.68	11.6
Temuco O	5.6	6.49	0.54	12.0
Temuco Pf	5.6	7.08	0.58	12.2
Puerto Octay O	6.0	12.57	0.87	14.5
Puerto Octay Pf	5.7	9.18	0.70	13.1
Puerto Octay C	5.8	8.82	0.70	12.6
Placandepts (Ñadis)				
Frutillar F	4.8	20.06	1.50	13.4
Frutillar P	5.6	13.60	1.10	12.4
Frutillar Pf	5.6	12.74	1.00	12.7
Piedras Negras O	5.2	17.46	1.50	11.6
Piedras Negras Pf	5.3	14.68	1.16	12.7
Ultisols (rojo-arcillosos)				
Cudico F	5.6	8.61	0.57	15.1
Cudico P	5.6	4.79	0.39	12.3
Cudico C	4.9	4.68	0.37	12.6
Collipulli O	5.6	3.23	0.23	13.9

Undoubtedly a better knowledge on this subject will help to develop more rational fertilization practices consistent with a proper conservation policy of volcanic soils. To increase the knowledge on N-fertilizer utilization, it seems important to study how N-availability correlates to soil layers and to soil organic and inorganic main constituents. Paramasivam and Breitenbeck (1994) found that in the first 0–15 cm soil layer 78–87% of total N is recovered as organic-N, and was closely correlated to organic-C and to 2:1 type layered clay minerals. Exchangeable NH_4^+ and NO_3^- were very low, accounting in total for about 0.7% of total N. Wander and Traina (1996) studied C and N distribution in non-volcanic soils, under different agricultural forms of management, by isolating humin, humic acid, and light fractions. They found the highest percentages of N in the more highly humified organic forms.

Here we report the distribution and cycling of N within the organic matter matrix in volcanic ash-derived soil in Chile, being under different levels of intervention and agronomic management. Our approach is based on the characterization of organic-N as N-fulvic, N-humic, N-humin and light organic-N, whereas inorganic-N is measured as NH_4^+ and NO_3^- .

The following Chilean volcanic ash-derived soils were selected for this study:

- (I) Andisols (trumaos): Osorno, Temuco and Puerto Octay.
- (II) Placandepts (ñadis): Frutillar and Piedras Negras.
- (III) Ultisols (rojo-arcillosos): Cudico and Collipulli.

Soil samples were selected in duplicate from sites

adjacent to each other and under the following management regime:

- undisturbed wild forest (F)
- natural prairie (P)
- cultivated and fertilized prairie (Pf)
- soil under agronomic rotation (C)
- untreated deforested soil (old road-cuts) (O).

Soil samples correspond to a composite sample prepared by mixing five representative samples of each plot, taken at 0–30 cm depth. All samples were sieved (2 mm) and kept refrigerated until laboratory processing.

Actual conditions, resulting from ancient soil utilization practices, do not allow for all the soil series sampled with all the management regimes included. For this reason, not all of the tables present all the corresponding mark-letter samples indicated earlier.

Organic matter was extracted using a modified alkaline extraction method (Aguilera et al., 1997), and fractionated into humic acid (HA), fulvic acid (FA) and humin (Hum).

In each soil sample and isolated organic fraction, total C and N were determined by dry combustion using a Vario-El Analyzer. Inorganic N was analyzed as NO_3^- and NH_4^+ according to Keeney and Nelson (1982). NO_2^- was not detected. Low molecular weight extractable organic N is calculated by difference between total soil-N and the sum of inorganic-N plus organic-N of molecular weight over 12,000 Da.

All analyses were made in duplicate, and the analytical error was <5%. Data were expressed on a dry weight basis (105 °C). To calculate the N distribution within different fractions of soil samples—to be called hereinafter N balance—it was necessary to measure separately the gross weights of the following fractions:

- (a) Soil residue, after extraction with 0.1N NaOH.
- (b) Humic acid, after acidification of alkaline soil extracts and purification with HCl–HF and finally by dialysis (Aguilera et al., 1997).
- (c) Fulvic acid, after purification first by ion-exchange and then through dialysis tubing (cut-off 12,000 Da) of acidic solution from (b).
- (d) Soluble soil fraction, composed of low molecular weight chemical species removed from the dialysis tubing after successive washings, contain soil soluble-salts, amino acids, monosaccharides and polysaccharides. Fraction (d) was estimated by weight difference between the original dry weighed sample and the sum of the (a), (b) and (c) fractions.

Table 1 shows the main properties of the soil samples studied. The pH values ranged from 4.8 to 6.0 showing a tendency of acidification of trumao soils (Puerto Octay and Osorno) after fertilization and cultivation. As expected for volcanic ash-derived soils the organic matter concentration is

Table 2

Nitrogen concentrations in different chemical soil fractions (g kg^{-1}) in Chile (F: wild forest; Pf: cultivated and fertilized prairie; O: untreated deforested soil; N-HA: N-humic acid; P: natural prairie; C: soil under agronomic rotation; N-Hum: N-humin; N-FA: N-fulvic acid)

Soils	N-total	N-Hum	N-HA	N-FA	N sol	N-NO ₃ ⁻	N-NH ₄ ⁺
Andisols (trumaos)							
Osorno O	5.7	2.9	1.3	0.09	0.86	0.48	0.070
Osorno Pf	6.8	2.5	1.9	0.33	1.33	0.71	0.030
Temuco O	5.4	2.7	1.1	0.52	0.82	0.24	0.020
Temuco Pf	5.8	3.1	1.5	0.57	0.32	0.29	0.020
Puerto Octay O	8.7	5.5	1.7	0.87	0.23	0.28	0.120
Puerto Octay Pf	7.0	3.4	1.7	0.99	0.55	0.36	0.004
Puerto Octay C	7.0	4.0	1.6	0.64	0.36	0.40	0.003
Placandeps (Ñadis)							
Frutillar F	15.0	7.7	4.8	0.71	0.54	0.75	0.500
Frutillar P	11.0	5.9	2.6	0.85	0.91	0.70	0.040
Frutillar Pf	10.0	4.0	2.5	0.79	2.57	0.13	0.010
Piedras Negras O	15.0	10.5	2.9	0.56	0.07	0.96	0.008
Piedras Negras Pf	11.6	4.9	3.0	0.92	2.03	0.74	0.007
Ultisols (rojo-arcillosos)							
Cudico F	5.7	2.6	1.0	0.35	1.11	0.64	0.002
Cudico P	3.9	1.7	0.7	0.44	0.83	0.23	0.002
Cudico C	3.7	1.2	1.0	0.35	0.77	0.33	0.050
Collipulli O	2.3	1.2	0.7	0.28	0.06	0.01	0.050

high. Organic C varied from 65 to 126 g kg^{-1} for andisols soils, from 127 to 200 for placandeps and from 32 to 86 for ultisols.

Total N-contents in the whole soil, organic-N in (a)–(d) fractions, N-NO₃, N-NH₄ (inorganic N) are shown in Table 2.

Fig. 1 globally shows the main known mechanisms

contributing to the formation of indigenous N pool in volcanic ash-derived soils under native forest (Stevenson, 1982). Fig. 2 shows the subsequent changes of these soil series after human intervention. Fig. 3 shows the distribution of total N among different soil fractions.

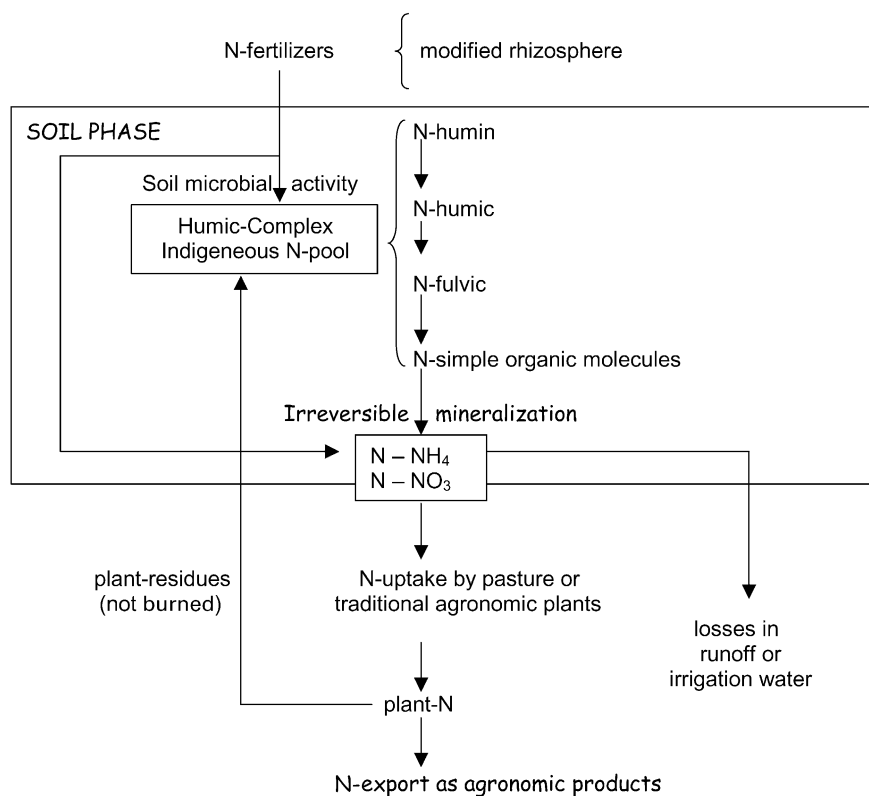


Fig. 1. Schematic representation of soil nitrogen equilibria and preservation in wild forest.

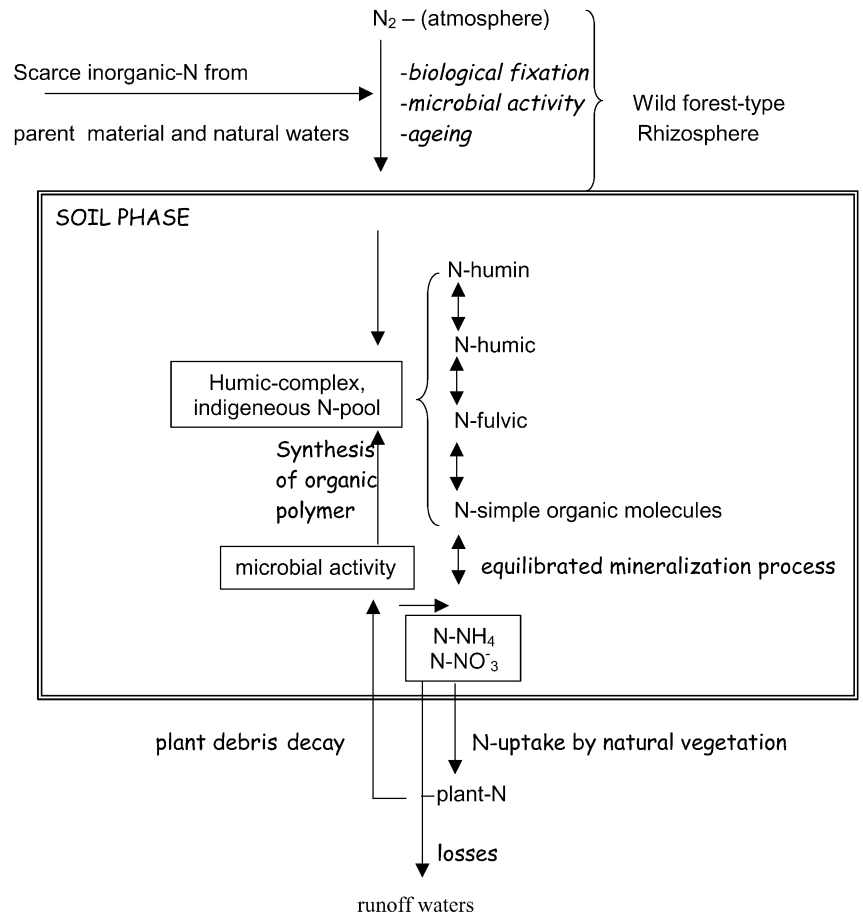
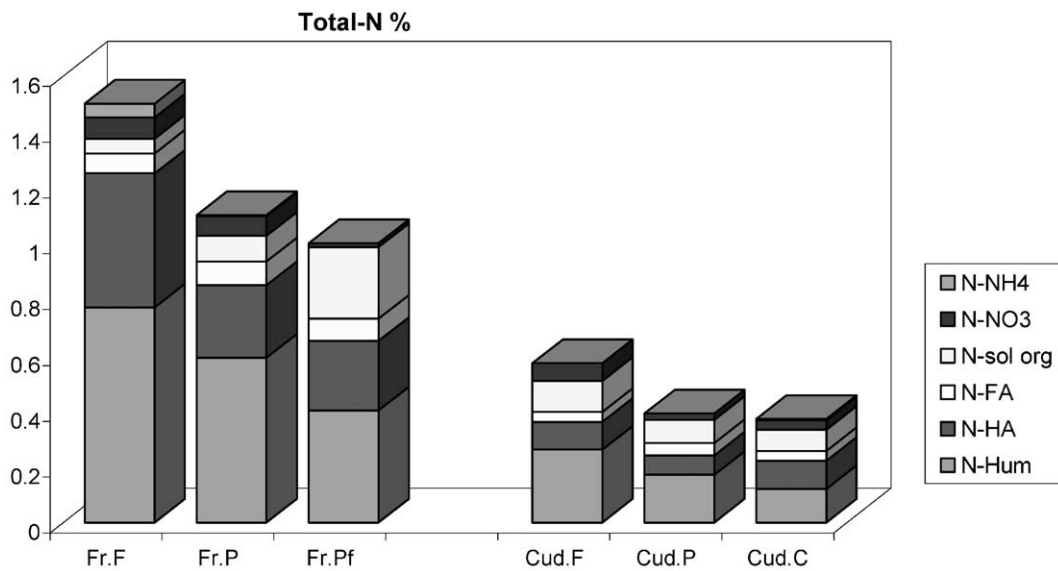


Fig. 2. Schematic representation of changes of indigenous N-pool in deforested soils subjected to agronomic utilization.



Fr.=Frutillar; Cud.=Cudico; F=wild forest; P=natural prairie
 Pf=cultivated and fertilized prairie; C=agronomic rotation

Fig. 3. Changes in total-N and its distribution pattern associated with forest removal in placandeps and ultisol soils.

There was a clear reduction of organic-C when soils were converted to agricultural uses (Table 1). Total-N values ranged from 0.2 to 0.6% for ultisols, from 1.0 to 1.5% for placandeps and stayed relatively constant for andisols soils at a level of 0.6–0.8%. Total N soil levels are high when compared to mean values reported elsewhere (Lindsay, 1979) and were well correlated to total-C ($r = 0.988951$). C/N ratios ranged between 11 and 15 and remained relatively constant despite the kind of soil management.

The effect of different soil management upon the modification of the N-distribution between different chemical soil fractions is noted in Table 2. Total N clearly decreased in placandep and ultisol series when they were deforested; the reduction in total N was of the order of 30% after approximately 50–60 years of the deforestation processes, generally as a consequence of forest fires (Besoain, 1985). These changes are directly related to the corresponding reductions on total-C (Table 1) which are of the order of 50%. Simultaneously, N linked to fulvic-type molecules and to small organic molecules (less than 12,000 Da) showed a considerable increase. This suggests that in Chilean volcanic ecosystems subjected to anthropogenic disturbance, the pool of indigenous N accumulated over thousands of years is moving rapidly toward loss of N.

The natural N input processes active in these soil systems proceeds by microbiological processes mainly through N_2 fixation processes (*Rhizobium*, *Azotobacter* spp.) associated with endomycorrhizal activity (Zunino and Borie, 1985). Also microbial synthesis of humic polymers (Zunino et al., 1982b) is another important group of mechanisms which is heavily involved in the natural ecosystem, resulting in the preservation of N and C cycles in these soil systems. The drastic changes from wild forest to agronomic regimes implies a corresponding change in the rhizosphere system, because root systems of natural plants should be quite different to those of introduced plant species. The latter do not necessarily have genetic abilities to serve as hosts to endomycorrhizae infected specimens and free-living N-fixing microbes, which finally result in an inability to fix atmospheric N and to incorporate it into organic structures. In other words, the fast N mineralization processes described earlier was pushing towards an irreversible soil deterioration process, with a clear loss of fertility and severe risks of erosion and desertification. Nitrogen loss and changes in its organic structures occur along with the severe depletion in the total C content, in spite of the fact that C/N ratios are kept relatively constant at values between 11 and 15 (Table 1).

Under natural conditions N-forms are permanently subjected to continuous changes, but equilibrated through biological and physico-chemical processes, all of them working interactively at the rhizosphere level (Fig. 1).

In deforested volcanic soil under present agronomic land use, the indigeneous rhizosphere has been dramatically superceded by a different one, composed of root systems from different plant species (Fig. 2). This produces a loss,

or at least a heavy disturbance, of the natural equilibria shown in Fig. 1, affecting the rotation and preservation of N pool, as well as N and C cycles. Of course, N incorporated as fertilizer under good fertilization practices does have the chance to be incorporated in organic macromolecules. This requires further research focused on the understanding of the natural mechanisms involved in the N-cycle. Hence, it is essential to accelerate studies on the scarce undisturbed soil systems, still available in some remote areas of the world. As long as we insist on the application of huge amount of fertilizer to counter the high P-fixation capacity of these soils and their increased needs of N, we will push these extremely complex and delicate soil systems to their complete destruction.

The net values of each N-fraction clearly diminishes after human intervention, but the internal balance of the N associated with each fraction (humins, humic, fulvic, low molecular weight organic molecules and inorganic constituents) kept relatively the same (Fig. 3). This is an interesting point which deserves closer examination since it suggests that these soils have a good capacity to restore internal equilibria for the N pool, perhaps founded on their high microbial and biochemical activities.

There is a real need to accelerate research in N pool characterization, especially at sites where good historical information exists on the management and cultivation practices of deforested volcanic soils. More studies on N and C cycles, using N-balance as a good indicator of soil deterioration, appear to be one of the best strategies to achieve rational agricultural and sustainable uses of volcanic soils.

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