Soil solution chemistry and elemental balance of Fushan natural hardwood forest ecosystem in Taiwan

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Abstract
Studies of soil solution composition have been used as the means of improving knowledge of basic ecological characteristics of a study area. The objectives of this study were to determine the cations and anions in throughfall, surface runoff and soil solution and to estimate the elemental inputs and outputs in the Fushan subtropical Forest Dynamics Plot (Fushan FDP). Throughfall, surface runoff, and soil solution of A and B horizons were collected monthly for two years (January 1, 2007 to February 28, 2009) both in Inceptisols and Ultisols with 3 replicated soil profiles in each soil. During the study period, the mean pH of throughfall is 4.7, and is changed to 6.4 after it percolated into the soil pedon. The mean Ca concentration which is the dominant cation in the soil solution (341 μeq/L), was higher than in throughfall (20.9 μeq/L) and surface runoff (42.4 μeq/L). The higher Ca concentration in the soil solution could be one of the buffering mechanisms in Fushan FDP. The results also indicate that the ions of Si, Ca, Fe, and nitrate have larger output than those of input in the forest ecosystem, the loss of Al and Mn for the study site is limited, and the ions of K, Na, Mg, Cl, and sulphate are retained in the study site.

Key Words
Fushan forest dynamic plot, Soil solution, Throughfall, Soil elements, Nutrient budget.

Introduction
The chemical composition of the soil solution changes with time and space reflecting biological and chemical processes during transport and storage of the soil water (Tokuchi *et al*. 1993; Hseu and Chen 1996, 2000; Hseu *et al.* 2000). The soil solution is intermediary between input and output of forest ecosystems (Wu *et al.* 2007). Soil solution chemistry is strongly influenced by both soil properties and by the total load of atmospheric chemical input. The soil solution is intermediary between input and output of forest ecosystems (Baeumler and Zech 1998). The Fushan subtropical Forest Dynamics Plot (FDP), as the first subtropical 25 ha FDP, was established in northern Taiwan in September 2004 (Su *et al.* 2007). The forest within the plot is an old-growth montane rain forest which is composed of broadleaf trees, featuring lush ferns and epiphytes. Alpine and subalpine ecosystems are very sensitive to such influences, and we must understand the multiple interactions within mountain ecosystems after any kind of interference for future risk assessment or minimization. The objectives of this study are to characterize the element dynamics in the soil solution of mountain forest ecosystems of Fushan FDP, and the impact of acidic atmospheric deposition.

Methods
Study site
The Fushan FDP is located at 24 45'40''N, 121 33'28''E, and the plot is square in shape and measures 500 m (north-south) by 500 m (east-west) (Su *et al*. 2007) (Figure 1). The elevation of the Fushan FDP ranges from 600 m to 733 m above sea level. The topographic components of hills, ridges, slopes, gullies, flats, and the creek constitute a complex relief for the plot. The bedrock in this area is a metamorphosed sedimentary rock from the Oligocene and Miocene, containing argillite and slate (Tang and Yang 1976). The climate of Fushan FDP is strongly influenced by the northeastern monsoon in winter and by typhoon in summer, with an average temperature of 18.2°C, a mean annual precipitation of 4271 mm, and a mean relative humidity of 95%. In the first survey of the 25-ha Fushan FDP, 110 woody species belonging to 67 genera and 39 families were recorded. The total flora of the plot includes 328 vascular plant species of 206 genera and 92 families (Su *et al.* 2007).

Collection and analysis of throughfall, surface water, and soil solution
The former studies indicated that soils in the Fushan FDP are extremely acidic (pH 3.3~4.3) with low organic carbon content, low base saturation, and low soil fertility (Su *et al.* 2007). Two major soil groups can be found in the Fushan FDP, Dystrudepts (Inceptisols) and Hapludults (Ultisols). Inceptisols were mainly distributed on steep slopes and well-drained areas while Hapludults were formed only in the relatively level

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portions of the plot. In this study, two sites each have three separate soil profiles are selected to understand the spatial variability, one is located on steep slope with Inceptisols, and the other is located at gentle slope with Ultisols (Figure 1). Throughfall, surface water, and soil solution of A (about 10 cm depth) and lowest layer of B horizon (about 60-100 cm depth) in each profile were collected monthly. The study period ranged from January 2008 to February 2009 (14 months). Throughfall, surface water, and soil solution of A and B horizons were filtered by Whatman No.42 filter paper, and the analyses of items, cations and anions are listed as: pH, EC, DOC (Total Organic Carbon Analyser, Aurora Model 1030W), Ca, Mg, K, Na, Fe, Al, Mn, Si (ICP-AES, Perkin-Elmer 2100 DV), and NO_3, PO_4, SO_4 and Cl ions (Metrohm, 792 Basic IC).

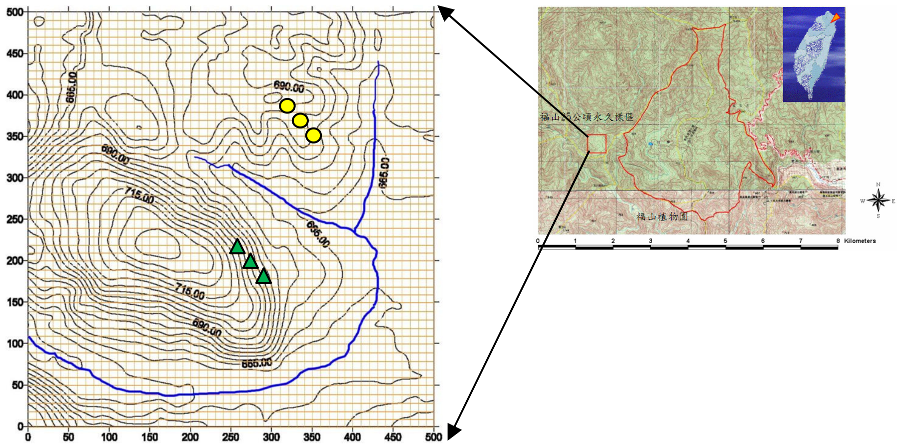


Figure 1. Location and the contour map of the Fushan FDP drawn with 5-m intervals in elevation. The axis labels denote the horizontal distance (m) from the southweastern corner of the plot. The blue line indicates the creek (Su *et al*. 2007). Sampling location of soil solutions are indicated by triangles for profiles of Inceptisols (I1, I2, and I3) and indicated by circles for profiles of Ultisols (U1, U2, and U3).

Results

Charge balance

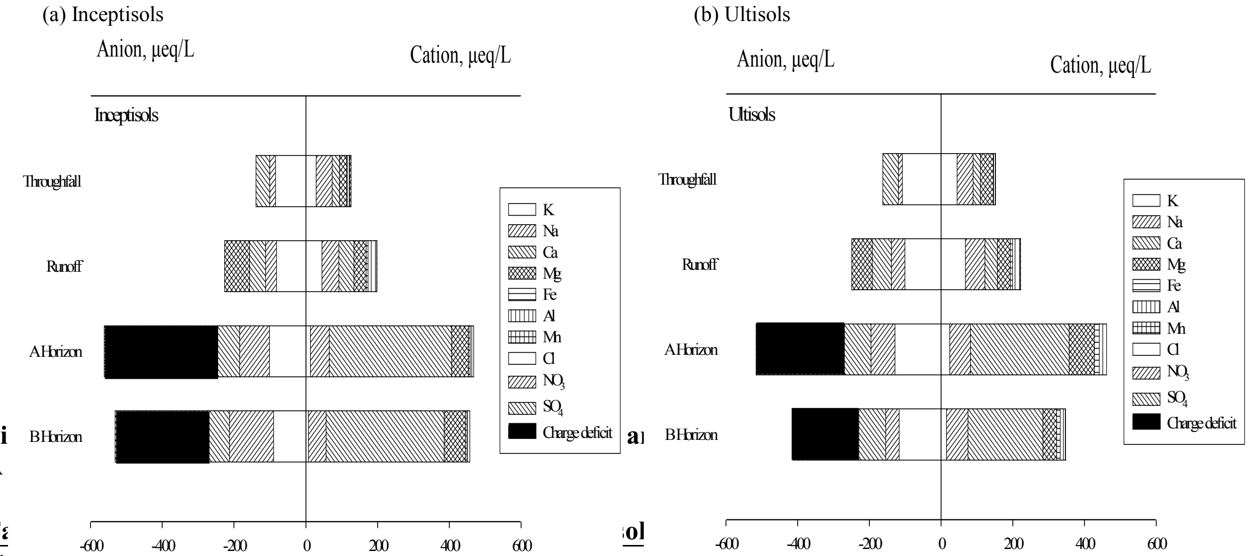
The volume-weighted equivalent mean the values of element concentration in throughfall, surface runoff, and soil solution of A and B horizons were showed (Figure 2). In general, total ion concentration of soil solution increased from throughfall to A horizon, and decreased from A to B horizon. The concentration of potassium ion (K) was in decreasing order: surface runoff > throughfall > soil solution. Berg and Staaf (1987) suggested that K ion is the most mobile cation, and it could be fast eluviated in the initial stage of litterfall decomposition. Highest K concentration in the surface runoff can be attributed to the decomposition of litterfall at soil surface. The rate of K cycling was fast, and K ion of soil solution was easily absorbed and reused by plant roots resulting in lower concentration in soil solution (Sposito 1984; Grimaldi *et al.* 2004). The concentration of Cl^- and Na^+ ion are both higher in throughfall, surface runoff and soil solution. The mean equivalent concentration of soil solution ranged from 44 to 60 µeq Cl/L and 82 to 120 µeq Na/L. Higher content of Cl and Na in soil solution suggested that sea salt significantly affect the soil solution chemistry in Fushan FDP. Moffat *et al*. (2002) also indicated that sea salt events are important at sites close to the coast, and influence chemistry for short periods. Calcium is the dominant cation in soil solutions of A and B horizons; hence the response to acidic anion or proton input would be through Ca mobilization in Fushan forest. Comparisons between Inceptisols and Ultisols showed that obviously lower content of cations and anions in B horizon in Ultisols, which suggest that the strong leaching effects occur.

Nutrient budget estimation

The amount of input was estimated from the element concentration and collection the quantity of throughfall, and the amount of output was evaluated including soil surface runoff and soil solution collected in the lowest layer of B horizon. Elemental inputs of K, Na, Mg, Cl, and SO_4 are obviously higher in the Ultisols area than those of the Inceptisols area (Table 1). The Ultisols are located at the northeastern side of the Fushan FDP receive more rainfall during the monsoon season in winter. In contrast, Inceptisols are located at the southwestern side and cannot handle as much rainfall. Robson *et al.* (1994) suggested that spatial variation greatly influence the chemical composition of throughfall, and the variations change with the characteristics of study area, such as stand and landscape position.

In the Inceptisols area, the budget of Si, Ca, and NO_3 has showed net loss, but K, Na, Cl, and SO_4 ions are net gain in soil. The other elements, including Mg, Fe, Al, and Mn, are almost balanced in soil. Only Si and

Ca have showed net loss, K, Na, Mg, Cl and SO_4 are net gain, and Fe, Al, Mn, and NO_3 are almost balanced in soil system of Ultisols. The introduction of strong mobile acid anion (SO_4^{2-}) into these soil systems may enhance soil acidification via leaching of base cations from the exchange complex. Liu *et al*. (2008) investigated the soil solutions in three different horizons located on the upper slope, middle slope, and lower slope of a natural hardwood in Fushan forest from 2001 to 2004. Liu *et al*. (2008) also indicated that except for H^+ when precipitation passed through the canopy, total ion concentration was increased, and concentrations of Na, K, Ca, Mg, F, Cl, PO_4^{3-}, SO_4^{2-}, and HCO_3^- in the throughfall generally exceeded the soil solution at the upper and middle slopes, whereas at the lower slope, Na, Ca, Mg, F, and Cl concentrations were highest at the 15 cm depth. This study has similar results to another study in Fushan FDP (Liu *et al.* 2008).



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ions	Inputs	Outputs	Inputs - Outputs
		Inceptisols	
K	60.6	16.6	44.0
Na	54.6	20.9	33.8
Ca	22.4	81.8	-59.3
Mg	12.6	11.2	1.44
Fe	1.81	1.88	-0.07
Al	2.86	2.38	0.48
Mn	0.58	0.19	0.39
Si	4.84	7.51	-2.68
Cl	160	56.0	104
NO_3	52.0	101	-49.2
SO_4	99.3	49.5	49.8
		Ultisols	
K	105	17.7	87.5
Na	62.6	19.6	43.0
Ca	24.4	51.3	-26.9
Mg	26.0	8.02	18.0
Fe	1.41	2.68	-1.27
Al	2.31	2.44	-0.13
Mn	0.69	0.13	0.6
Si	4.35	7.29	-2.94
Cl	231	62.2	169
NO_3	40.6	40.5	0.03
SO_4	127	54.6	72.2

Notes: The elements budget was calculated from the data collected from January 2008 to February 2009.

Uncertainty of nutrient budget estimation

In this study, the estimation of nutrient budget in the Fushan FDP was established and calculated based on evaluated database. For this reason, errors or uncertainties could occur, including (1) the limitation of sampling number and replication; (2) the difference of spatial distribution of soil properties and tree species; (3) the different nutrient concentration of tree species; (4) the estimation method of forest biomass and litterfall amount; (5) the lateral mobile of soil solution in soil layer; (6) the frequently effect and disturbance by typhoon; (7) the amount of increase from dry precipitation (input) and loss from evaporation (output); and (8) the overestimation of nutrient output based on the amount collected from the soil solution in B horizon.

Conclusion

The mean pH value of rain water and throughfall in the Fushan FDP during the study period is 4.6 and 4.7, respectively. The pH of soil solution has raised 1.5 pH units (pH 6.4 in average) after the throughfall percolation into the soils. Calcium is the dominant basic cation in soil solution, with a mean concentration of 341 μeq/L and is much higher than in throughfall and surface runoff. The response to acidic anion or proton input would be through Ca mobilization in Fushan forest. The budget of Si, Ca, and NO_3 in the Inceptisol area and Si and Ca in the Ultisol area show a net loss. The input amount of K, Na, Cl and SO_4 are much higher than those of output, and suggest the net gain in soils. Iron, Al and Mn have similar input and output contents. In this study, the estimation and evaluation of nutrient budget based on throughfall, surface runoff, and soil solution (located in A and B horizon) seem that it is not sufficient and has many uncertainties factors. The long-term monitoring of precipitation inputs of nitrate and sulfate in the Fushan forest is important.

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