ACTA GEOLOGICA HISPANICA, v. 28 (1993), nº 2-3, p. 45-53

Effect of the clearfelling on the water quality: Example of a spruce forest on a small catchment in France

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SUMMARY

This paper presents the variation of the hydrology and the water quality of a spruce catchment, located at Mont-Lozére (France), in a mediterranean mountain climate area , in relation to the forest status during 12 years (1981-1993). Four situations were successively examined : healthy forest (1981-84), declining stand with pest (1984-87), gradual clearfelling (1987-89) and reforestation (1989-93). An undisturbed beech catchment was used to provide reference values.

In the hydrological budgets, the P-Q value (as ETR) was slightly higher in the spruce catchment than in the beech one during the first period and decreased progressively in the following ones as a consequence of: (1) the declining stand of the forest and (2) the clearfelling.

No change was observed for cations, and NO_3 concentrations remained were very low during the whole period in the streamwater of the beech catchment , in relation to the steady state of that ecosystem. Iin the spruce catchment,the concentrations of cations and NO_3 were always higher, and increased slightly during the disease. During the clearfelling, NO_3 was strongly related to Ca and Mg. Six months after the reforestation, NO_3, Ca , Mg concentrations were respectively 11,9 , 2,6 and 3,6 higher than at the beginning of the clearfelling.They returned to previous values at the end of 1993.

The Input-Output budget of cations presented a continuous storage in the beech catchment and simultanously a permanent release in the spruce catchment . The mean loss, -expressed as the denudation cation rate, in keq.ha-1.year-1 was as follow: -0,41 (1981-84), -0,65 (1984-87), -1,60 (1987-89) and -0,82 (1989-93).The leaching was observed during more than 6 years after the clearfelling, resulting probably from the duration of the drought period , and from the mineralization of the remaining important organic matter compartment.

1. INTRODUCTION

In many european countries, large areas easing acidity and aluminium leaching (Likens et al.,1979, Stevens and Hornung,1987, Hornung et al.,1990), particularly with aluminium-rich soils. (Hultberg,1985, Adamson et al., 1987) .

In low air-polluted areas, such as in the south of Europe, where this process is of less importance, studies on the clearfelling effects have just been developped, in France (Didon-Lescot et al..,1992), or in Spain (Sabate and Gracia, 1993).

In the low air-polluted area of Mont-Lozère (Durand et al..,1991), three experimental catchments are monitored for biogeochemical functionning studies (Dupraz et al..,1984, Lelong et al..,1990).Two of them are forested catchments, one is covered by a beech coppice, the other by a spruce plantation. The spruce forest has progressively declined from 1984 to 1987. So, there was an opportunity to describe the evolution of the biogeochemical processes during the ecosystem change. The water chemistry of the spruce catchment was examined during the four successive situations of the forest, i.e, healthy forest (1981-1984), followed by 3 years of declining stand (1984-1987),then gradual clearfelling (1987-1989) and finally reforestation (1989-1994).

The aim of this paper is to present the results concerning the hydrological budgets and the evolution of cations and NO_3 concentrations in the streamwaters, as well as the Input-Output budgets in the two forested catchments. The hydrochemical and hydrological characteristics of the beech catchment are presented to provide reference values of an undisturbed ecosystem.

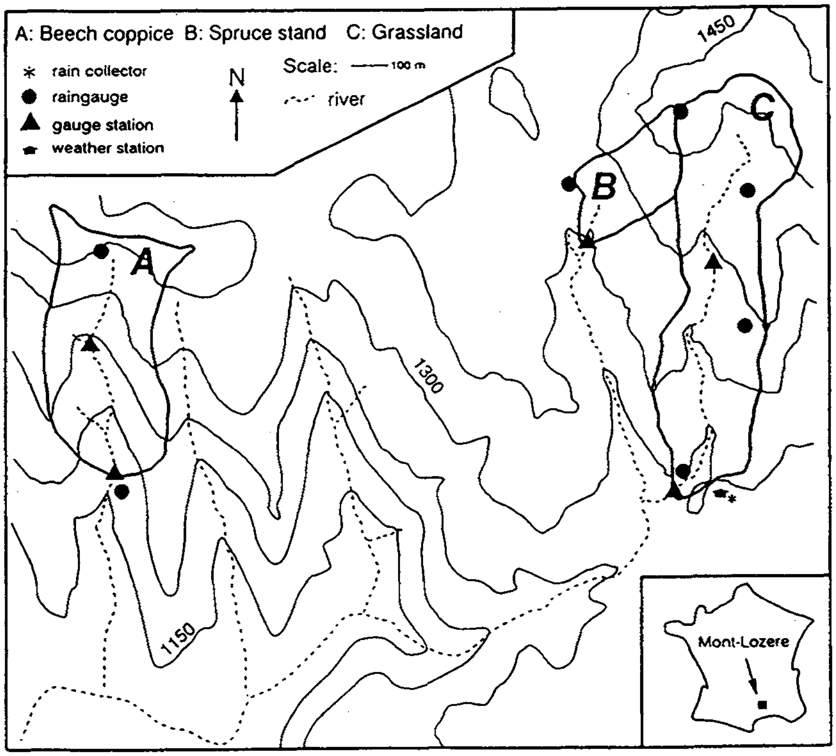

Figure 1. Site location and equipment

2. METHOD

2.1. The study area :

The Mont-Lozere research catchments (ERBFR110) are located in the National Park of Cevennes (south of Massif Central), in a M.A.B sanctuary with slight anthropic perturbation (Lelong et al..,1990) . They are 80 km distant from the Mediterranean Sea , and they range from 1150 to 1500 m of elevation.They have small surfaces, i.e. 0.20 km^2 for the spruce catchment and 0.54 km2 for the beech catchment (Figure 1).

The parent bedrock is a granite, and they have similar types of soil (dystrochrepts, i.e. acid and humiferous soils).The climate is mediterranean (rainstorms in automn and spring , possible long drought period in summer) with mountain characteristics (annual mean temperature of 6°C, and snowpack varying from 10 to 25 % of the total precipitations).

The beech, covering 80% of the surface of the beech catchment, is a coppice of low production unexploited since more than 60 years, characterized by a large number of trees (4270 boles/ha) (Hanchi, 1994). The spruce covered 85% of the second catchment, where there was 5 % of mountain pine. In the coniferous catchment, the spruce stand has been gradually attacked by a bark-beetle (Dendrochtonus sp.) probably after the drought of 1983. A gradual clearfelling was prescribed during the summers of 1987,1988,1989, and trunks of commercial value were extracted by logging mecanically. Finally young conifers were planted in automn 1989 after removing and gathering of the tree debris stored in strips parallel to the slope.The wooden area is presently restricted to the extreme-top of the catchment and to a small plot of declining trees maintained for studying the internal cycling of nutrients.

Table 1. Precipitacions (P), Runoff (Q) and P-Q (in mm). Mean for period 1 to 4 (bold); mean 1981-93 and standard deviation (italic)

	Beech				Spruce		
	P	Q	P-Q		P	Q	P-Q
81-82	1630,4	1162,9	467,5	period 1	1594,1	1210,7	383,4
82-83	2237,1	1431,7	805,4	(1/7/81	2475,0	1554,7	920,3
83-84	1440,0	877,8	562,2	30/6/84)	1506,1	928,6	577,5
	1769,2	**1157,5**	**611,7**		**1858,4**	**1231,3**	**627,1**
84-85	2137,6	1379,4	758,2	period 2	2189,2	1484	705,2
85-86	1374,7	968	406,7	(1/7/84	1469,2	1044,4	424,8
86-87	1906,2	1219,1	687,1	30/6/87)	1954,4	1297	657, 4
	1806,1	**1188,8**	**617,3**		**1870,9**	**1275,1**	**595,8**
87-88	2428,7	1639,3	789,4	period 3	2665,4	1985,5	679,9
88-89	1238,5	698,2	540,3	(1/7/87	1349,7	931,6	418,1
	1833,6	**1168,8**	**664,8**	30/6/89)	**2007,6**	**1458,6**	**549,0**
89-90	1339,6	680,4	659,2		1431,3	798,3	633,0
90-91	1394,8	938,3	456,5	period 4	1446,61071	375,6	
91-92	1431,4	688,4	743,0	(1/7/89	1490,9	798,9	692,0
92-93	2028,6	1225	803,6	30/6/93)	1954	1286,1	668,4
	1548,6	**883,0**	**665,6**		**1580,8**	**988,6**	**592,2**
Mean	**1715,6**	**1075,7**	**639,9**		**1793,9**	**1199,2**	**594,6**
S.d.	**409,5**	**317,0**	**146,9**		**447,3**	**350,2**	**164,8**

2.2. Method.

The equipment of the catchment is described in previous papers (Dupraz et al., 1984, Lelong et al., 1990).It includes , in the two forested catchments:

- 2 rain gauges with automatic recorder (CR2M-PLA),

- one bulk precipitation collector devoted to chemical analysis.

- one gauge station with a V-notch-weir and 2 stream-level recorders : one AOTT R10 and one with ultra-sonic and temperature probes connected to a data-logger (CR2M-LUS-I) for streamflow measurements.

- one water sampler .During the major hydrological events , especially during the study of the clearfelling , manual water samplings were performed.

- soil lysimeters and throughfall devices have completed the field equipment from 1986 (Vannier et al, 1993).

Chemical analyses have been performed as quickly as possible, alkalinity by Gran method, NO_3 and NH_4 by colorimetry, and cations by atomic absorption spectrometry. Bulk precipitations are collected on an event basis (about 30 samples in a year), and stream water before and after the peak flow and during the baseflow .

Fluxes of solutes were computed using the combinaison of linearized hydrograph and instantaneous concentration, giving a "chemograph" (Lelong et al.,1990). Relatives error values are +/- 10% for input and +/-5% for output . After 12 years of study, the way of calculation has been simplified and in this study, the annual input and output of elements have been calculated by multiplying the Volume Weigthed Concentration (VWC) by the annual mean value of the rainfall or streamflow average (Hanchi,1994).

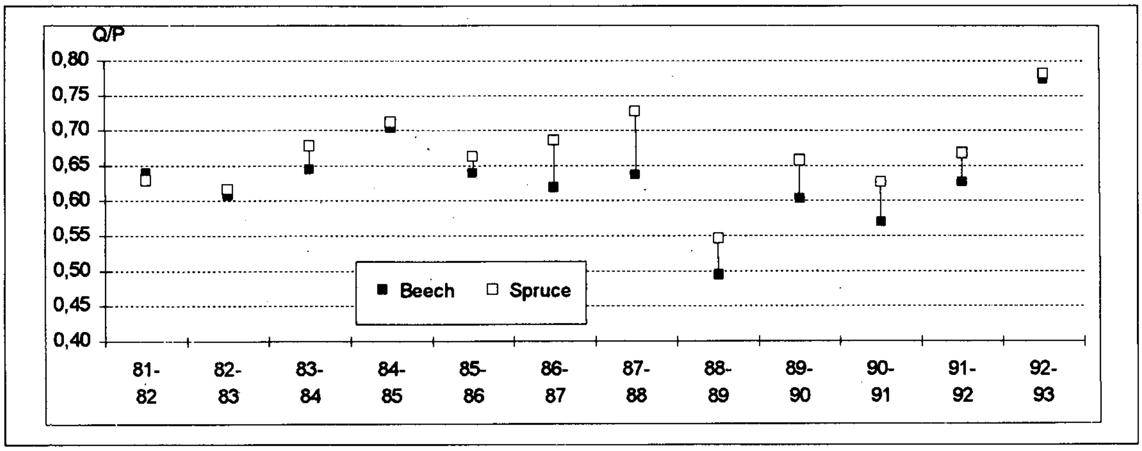

Figure 2. Variation of the early Q/P ratio for the two forested catchments. Period 01/07-03/06

3. RESULTS

3.1. Hydrological behaviour.

The hydrological budgets presented on Table1 are computed on the basis of an annual cycle (01 july to 30 june). During the 12-yrs period of study, the average of annual precipitations was lower in the beech catchment (1715,6 mm) than in the spruce one (1793,9 mm) .The greatest discrepancy between the two catchments was observed in 1982, and is related to a storm event (500 mm in 48 hours) that occurred particularly in the spruce catchment , which is more influenced by mediteranean storms (Dupraz et al..1984).

The interannual variations are important since precipitations have varied from 1094,0 mm in 1985 (civil year) which was probably the driest year of the century, to 2465,9 mm in 1984.In comparison with the long term average, established at the Villefort station by the National Meteorological Survey, the studied period may be considered as modal with contrasted, wet (1992-1993) or dry pluriannual periods (1989-1990-1991).

As it was noted before (Dupraz et al.., 1984, Lelong et al, 1990) the runoff was always higher in the spruce catchment. This appears as a consequence of more abundant precipitations and of different pathways of water circulation. A small peat bog area existing at the outlet of the spruce catchment could store more water, giving a small but permanent flood in summer. By contrast, the runoff was very low in the beech catchment and during the very dry summers, as in 1985 and 1989, the stream dried up.

The water budgets (Table 1) are calculated for a pluriannual scale. As the ground water storage is probably low in comparison with P and Q, the expression P-Q can be reasonably considered similar to ETR. In the beech catchment, the mean ETR was 674 mm for the whole 1981-1993 period, whereas in the spruce catchment , ETR was slightly higher (701 mm) during the first one (reference period). There was a progressive increase of runoff in the spruce catchment from the secund to the third period , that explains the increasing of the Q/P ratio difference observed between the two catchments (figure 2), and the maximum was found in 1987-88, the first year of the clearfelling.This could be explained not only by the reducing of the physiological activity of the trees but also by a change of the circulation speed of the soil water (Cosandey,1993) .

3.2. Water quality

3.2.1. Time variations of cation concentrations in the streamwater.

The variations with time of the element concentrations and the discharge in the streamwater are presented in the figure 3. The table 2 shows the Volume Weigthed Concentrations (VWC) for cations and NO_3.

In the beech catchment, the dominant cations are Na , Ca and Mg that represent 43%, 32% and 20% of the cationic charge respectively. The fact that Ca is dominated by Na, is probably related to the presence of Ca-depleted soils (Durand et al.,1991).

The relationship between Ca and Mg is better in the spruce catchment (g=0,609Ca+1,287; r2=0.982), (Mg=0,402Ca+9.240; r2=0,827) than in the beech catchment. Moreover this strong relation between the

Table 2. Semestrial Volume Weighted Concentrations (VWC, in µeq/1) and Runoff (Q, in mm) for cations and NO3 in the streamwater of the beech (left) and one of the spruce catchment (right). 1981-1993. 981-1=01/01/-30/06/1981; 81-2=01/07-31612/1981)

	Q mm	Ca	Mg	K	Na	NH4	Cat.	NO3	Q mm	Ca	Mg	K	Na	NH4	Cat.	NO3
81-2	513,3	37,3	24,3	4,9	48,4		114,9	3,8	522,8	63.2	40,2	5,6	52,7		161,7	1,6
82-1	649,6	35,5	22,9	3,9	44,8		107,1	1,8	687,9	60,6	38,3	5,5	50,3		154,7	11,0
82-2	683,8	34,3	23,7	7,3	46,0		11,3		791,4	61,2	39,5	7,9	49,9		158,4	
83-1	747,9	39,6	24,1	4,5	47,2		115,5		763,3	60,3	38,8	6,2	50,8		156,8	
83-2	132,5	40,7	26,6	6,4	56,8	0,5	131,0		140,3	68,3	44,1	6,9	56,3	0,3	176,0	
84-1	745,3	40,8	26,0	4,7	47,4	1,2	120,1		788,3	72,0	46,7	6,5	55,2	6,5	186,8	
84-2	921,5	39,7	24,5	7,9	48,6	0,1	120,7		1015,3	65,8	43,0	11,0	51,3	1,0	172,1	
85-1	457,9	35,7	24,7	4,1	47,9	0,0	112,4		468,7	61,7	43,4	4,4	54,6	0,2	164,2	
85-2	32,4	49,7	31,3	7,1	62,9	0,0	150,9		102,9	83,1	50,2	7,5	64,7	0,0	205,3	15,
86-1	935,6	52,9	29,4	5,2	57,0	0,3	144,7		941,5	78,2	47,4	7,4	63,1	0,0	196,2	11,0
86-2	601,9	48,0	28,9	7,3	61,9	2,3	148,5		687,3	77,1	44,8	10,8	67,9	4,6	205,3	15,8
87-1	617,2	43,5	25,3	4,9	62,1	2,7	138,4		609,7	77,7	42,9	6,7	63,1	2,0	192,4	28,4
87-2	635,1	40,8	26,1	5,1	58,1	0,7	130,8	0,7	846,9	95,5	60,1	12,0	66,7	2,1	236,4	94,5
88-1	1004,2	38,8	23,7	4,9	54,5	0,8	122,7	0,8	1138,6	102,5	61,7	8,5	71,1	0,8	244,7	157,6
88-2	253,8	41,2	26,0	5,4	59,0	1,7	133,3	2,0	524,8	114,6	72,6	12,2	74,6	2,5	276,5	170,8
89-1	444,4	53,7	29,7	4,9	53,6	0,6	142,6	2,1	406,8	160,5	102,7	11,7	80,5	1,6	357,0	238,9
89-2	250,6	46,6	29,4	10,1	58,4	1,6	146,1	1,9	366,9	194,1	111,9	19,7	84,1	3,5	414,0	304,0
90-1	429,8	45,8	28,5	5,6	58,4	2,0	140,3	1,8	431,4	203,8	132,6	13,1	91,0	1,5	442,0	337,7
90-2	294,4	40,9	23,8	4,3	61,0	1,0	131,0	0,6	402,3	193,5	117,7	11,2	91,4	0,7	414,5	309,3
91-1	643,9	46,3	25,1	4,7	52,4	1,4	129,8	2,3	668,7	191,0	101,9	14,1	76,7	1,2	384,8	292,4
91-2	184,3	53,8	30,3	5,9	65,3	1,0	156,3	0,8	272,5	178,5	107,2	11,1	77,6	3,3	377,7	243,4
92-1	504,1	52,1	26,2	4,1	59,9	59,9	1,2	1,1	526,4	145,9	77,4	7,9	69,4	0,6	301,1	192,5
92-2	626,2	40,3	26,3	3,0	44,8	1,3	115,6	0,5	738,5	104,3	57,6	10,0	53,7	1,7	227,2	109,7
93-1	598,8	39,7	25,4	2,3	54,5	1,2	123,1	1,2	547,6	86,9	52,3	3,8	60,4	2,5	205,8	82,0
93-2	695,6	37,9	23,4	4,0	55,3	1,2	121,8	0,4	924,0	70,4	44,8	14,0	50,6	2,1	181,9	42,6

two elements was not altered by the clearfelling.

The relative low K concentrations are subjected to seasonal variations,with a peak in automn, due to a rapid lixiviation of the decaying leaves and organic debris. NH_4 and NO_3 have comparable con-centrations, which remain low (0 to 2 µeq/l).

The highest values of the cationic charge (table 2) always occur after a long time of drought (1983 ,1985,1989,1991) .This can be explained by a strong mineralization of the forest floor during summer and automn when the soil moisture and temperature are still favorable to microbial activities. The leaching of the solutes occurs later at the beginning of winter once soils are water saturated (Durand et al., 1991). This process is especially obvious after the two driest automns of 1985 and 1989. By contrast, the rain storms that occur in automn and in spring, (figure 3) contribute to dilute the soil solution (exemples of spring 1988, and during the whole wet period of 1992-93).

The time variations of the cations are mainly due to the alternance of wet and dry periods, and are probably controlled by the importance of the precipitations. At a decennal scale, in the beech catchment, years of similar wetness as 1981 and 1992-93 are quite similar (Table 2).This could reflect the probable steady-state equilibrium of the forest (Lelong et al. 1990, Hanchi, 1994).

The fact that the cation concentration was higher in the spruce catchment (table 2), may be related to a greatest mobility of mineral anions. This could be partly a consequence of more important dry depositions collected

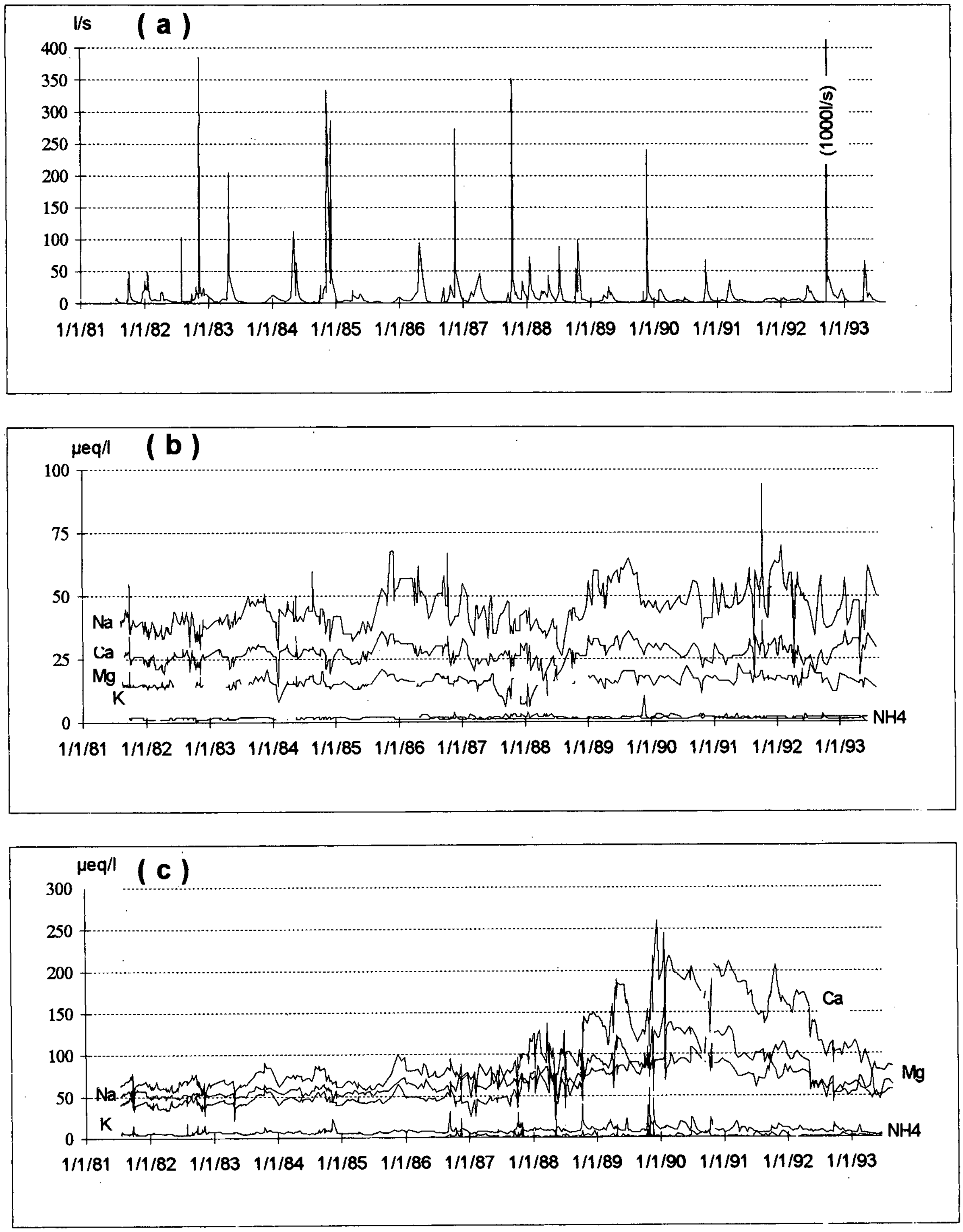

Figure 3. Time variation of discharge in the spruce catchment (a), cation concentrations in the streamwater of the beech catchment and the spruce catchment (c).

by the very efficient canopy of the conifers (Durand & al. 1991).
NO_3 increased slowly during the first and the second period and reached a VWC of 28,4 µe/l just before the beginning of the harvest (first semester of 1987, table 2).The increase was probably due to the declining stand of the trees, but it remained low and as NO_3 was not related to Ca (figure 4), we conclude that it had no effect on the leaching of this element at that moment (Didon-Lescot et al., 1992).

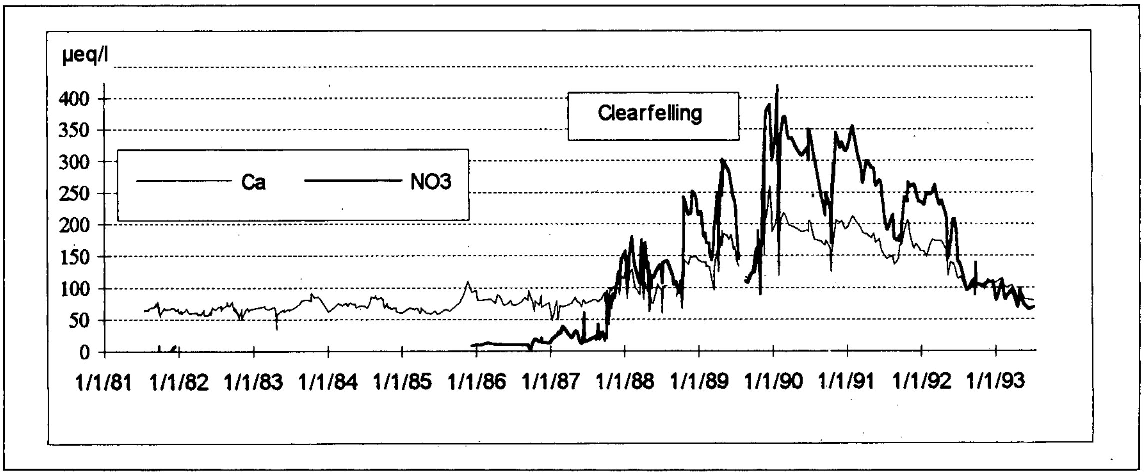

Figure 4. Time variations for Ca and NO3 in the spruce catchment. Period 1981-1993

3.2.2. Impact of the clearfelling of the spruce forest.

3.2.2.1. Time variations of concentrations from 1987 to 1993.

The clearfelling of the spruce was performed from summer 1987 (50% of trees have been cut) to summer 1989 (95%). Cations have increased gradually after the beginning of the disturbance (figure 3), strong seasonal variations appearing with lower concentrations in summer and higher in winter or spring.

The VWC (Table 2) for Ca and Mg have been multiplied respectively by 2,6 and 3,1 between summer 1987 and 1990. The maximum occurred in january 1990, 6 months after the end of the clearfelling and was of 245 µeq/l for Ca and 161 µeq/l for Mg. After early 1990, concentrations decreased regularly and reached the level before felling, 6,5 years after the beginning of the dis-tur-bance , at the end of 1993.

The Na increase was of 1,5 , with a maximum concentration in june 1990. At the end of 1993, concentrations were quite lower than in 1987. K showed high concentrations in automn such as during the important flood events of late november 1989, characterized by a peak at 41 µeq/l.

A higher value (59 µeq/l) was found at the peak flow of a very important flood, in september 1992 . NH4 which was in low concentration before the felling (0 to 5µeq/l) presented the same pattern as K. It appeared in the first flood events of automn 1989, and its maximum concentration was observed during september 1992.

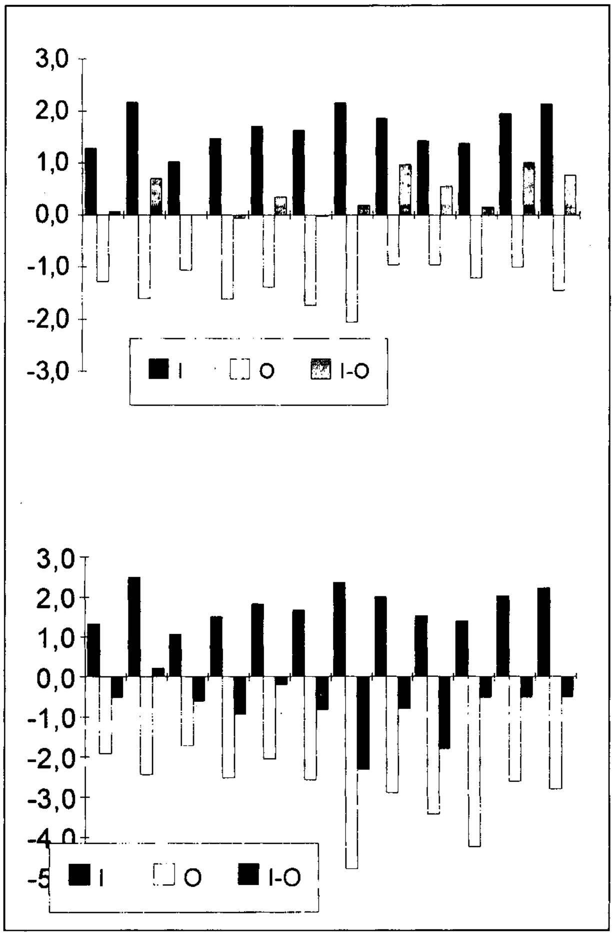

Figure 5. Input-Output budgets (in keq.ha^{-1}.yr^{-1}) for cations in the beech catchment (left), and in the spruce catchment (right) during the 1981-1993 period. (I=Input, O=Output.

The evolution of NO_3 seemed controlled by Ca (figure 4) and Mg leaching , as this can be deduced from their significative relation (NO_3 = 0,42 Ca + 61,86 , R2= 0,90 n=267, and NO_3 = 0,25 Mg+39,16, R2 = 0,85).

The maxima were observed at the same time (the VWC in 1990 was 11,9 higher than in 1987) and the concentrations returned to lower values at the end of 1993.

3.2.2.2. Input-Output budgets.

The figure 5 presents the cation (sum of Ca, Mg, K, Na, NH_4) budgets in the 2 catchments. As the clearfelling started in summer, ions budgets have been calculated from july to june.

In the beech catchment , the cationic denudation rate, expressed as the difference between the Input-Output (Hornung et al, 1990), was always positive (storage), (Dupraz,1984, Durand et al., 1991). As the cation budget is dominated by Ca, this is mainly due to the annual storage of Ca, the other elements being either quickly turned over (K) or stored in the biomass, either slightly leached (Na and Mg). The most efficient storage appeared in 1988-89 and 1990-91,due to the strong input of saharian dusts (Hanchi, 1994) .

In the spruce catchment, cations were always leached from the catchment (Dupraz, 1984, Durand et al.,1991) and Input-Output budgets were moderate (0,55 keq.ha-1.yr-1) during the period 1981-1987. With the clearfelling, the leaching of cations increased, and the most important losses occurred in the first year of treatment (Didon-Lescot et al, 1992). The important runoff (Q=1985,5mm), partly due to a large amount of precipitations, explains the level of the leaching . The magnitude of the cations losses was generally more moderate in the following years, depending of either low runoff in coincidence with relatively high input (drought period), or decreasing concentrations with much runoff corresponding to the wet years of the end of the experiment. Finally during the 4 periods of the spruce stand, the average denudation cation rates -expressed in keq.ha-1.y-1 - were as follow: -0,41 during the first period, -0,65 at the beginning and -1,60 at the end of the clearfelling, and -0,82 in summer 1993, 6 years after.

4- CONCLUSION

The Mont-Lozère clearfelling experiment corroborates the results of many other studies in North America (Bormann and Likens,1979, Feller and Kimmins,1984, Hornbeck et al., 1986, 1991) or in western Europe (Hultberg,1985, Ahtiainen,1988, Adamson and Hornung 1990).
The mecanisms involved in the different studies to produce NO_3 are the mineralisation of organic nitrogen from the ancient forest layer, the decomposition of fine roots and the drop of biological uptake. In the experiments ,the major cation losses are mainly due to the contribution of subsurface waters evacuating cations (Ca, Mg, K) that cannot be retained in ecosystems in reason of the decreasing cation uptake of the plant community (Hornung et al, 1990).

In these case studies, general attention has been allowed to the magnitude and duration of NO_3 losses that seem to be strongly exported during two or three years after the beginning of the disturbance, and return faster to previous values.

In the Mont-Lozère experiment, the period of leaching was important and lasted more than 6 years after the start of the clearfelling. This could be explained either by the effect of water stress that occured from 1989 to 1991 or by a progressive release of N and base cations associated to a compartment of organic matter which was probably sligtly mineralized.

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