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Interception of rainfall, input and leaching of nutrients within two *Castanea sativa* Mill stands at the Etna volcano

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Abstract. Rainfall, throughfall and stemflow were studied within two sweet chestnut (*Castanea sativa* Mill.) stands located on the flanks of the Etna volcano (Sicily).

Interception amounted to 18 and 25% of rainfall and was directly correlated with the stem density of *Castanea sativa* at the sites. The same factor also induced differences with the stemflow and throughfall levels at both sites.

Cumulative rainfall input amounted to 203 and 149 kg ha^{-1} $year^{-1}$ of the analyzed elements (Cl, Ca, Mg, S, P and N). In contrast to most forest stands, canopy leaching within throughfall and stemflow was very low, except for magnesium and sulphur at one site. This was probably related to the volcanic environment, as the Etna volcano is well known for high magnesium levels in the lava and for its more or less continuous emission of sulphur.

Key-words: *Castanea sativa*, throughfall, stemflow, interception, nutrients

Introduction

Precipitation reaching and passing through a forest ecosystem follows several pathways before arriving to the forest floor (Rapp and Romane, 1968; Rutter *et al.*, 1971, 1975; Rutter and Morton, 1977; Rapp and Ibrahim, 1978, Niziński and Saugier, 1988).

Incident rain passing through the forest canopy can be divided into two fluxes. One flux, quantitatively greater than the other, falls directly through the canopy, or drips down from the leaves, this is the *throughfall*. Rain repartition, under the forest canopy, is more heterogeneous than in open areas. The other part flows down along the branches and trunks and reaches the stumps of trees in this way, this is the *stemflow*. A third part never reaches the soil, but is reevaporated from the forest canopy, this is the *interception*.

Whilst passing through the canopy, the rain-water becomes a carrier for various nutrients. Indeed, the rain-water dissolves elements from particles in suspension in the low atmosphere and from dry deposition on the vegetation, especially on leaves, occurring between precipitations. The mechanisms involved in the transfer of nutrients and their role in nutrient cycling have been reported by Parker (1983).

Two aspects, therefore, need to be considered in studies of the precipitation fluxes within a forest ecosystem such as (1) the physical aspect which involves the quantification and distribution of the various pathways of rain-water reaching the soil, and (2) the chemical composition of these different pathways. It is essential to investigate how these elements can affect the input as well as the transfer of substances and nutrients within the vegetation cover. The input is related to climate (quantity, intensity, frequency of each rainfall) or to vegetation (deciduous or evergreen, broadleaved or resinous), together with a number of other environmental factors which affect the amounts of materials and elements available for transfer.

The present work deals with two coppices of *Castanea sativa* Mill., aged approximately 10 years and located in the Etna volcano massif at altitudes of 1,000 and 1,600 m respectively. These two stands are representative of extreme conditions of the *Castanea sativa* coppices at the Etna massif. These include both the climatic factors, related to altitude and exposure, and a different location in relation with the crater of the volcano (distance, orientation).

As this work was done within the framework of a more general study of productivity and biogeochemical cycling within the *Castanea sativa* stands in Sicily, it also aims at determination of the input through precipitation and leaching within a volcanic area.

Study areas and methods

1. *The Castanea sativa sites*

The stand located at Fossa la Nave, at the upper limit of the sweet chestnut growing area (1,600 m) was clear-cut in 1982; the other stand was located at Piano Porcheria at a lower altitude and was clear-cut in 1983.

The forestry characteristics of the study sites are summarized in Table 1. Whereas the number of trunks per hectare was similar for both stands, the number of shoots per hectare, height, and mean DBH differ.

2. *Experimental equipment*

The study sites were equipped identically: Two rain-gauges were placed in clearings, next to study sites.

In the both sites, 10 rain-gauges, similar to the ones used for rainfall collection in the clearings, were placed randomly under the canopy of trees. Using 10 gauges yielded a more statistically significant result in relation with the heterogeneity of the canopy.

Six trees, representative of the different DBH of all the individuals of each study site were selected. A gutter was put round each tree, at 1.50 cm above ground, and sealed to the trunk so that all the water that flowed down the trunks could be collected.

The different water samples were collected weekly after each rainy event, and individual volumes were recorded for all collectors.

	Fossa la Nave	Piano Porcheria
Number of stools (ha^{-1})	258	288
Number of shoots (ha^{-1})	1895	5668
Mean height (m)	7	5
DBH (cm)*	1 - 20	1 - 10

Table 1. Characteristics of the two study sites (*With the exception of the "matricine", some older trees remaining in the stands in accordance with local forest management practices).

3. Water flux estimations

It is easy to determine water heights of incident rain and throughfall by dividing the volumes collected, expressed in cm^3, by the interception area of each collector in cm^2. Calculation is more difficult in the case of the stemflow. Indeed, in order to estimate the amount of water reaching the soil by way of surface stemflow, we calculated, after each rainy period, a regression curve between the diameters of the different trees included in the study and the volumes of rain water collected by the different trees. Applying this equation to all the DBH classes of the trees of each study site, and multiplying by the number of individuals for each class, we obtained the total quantity of water, in litres per hectare, reaching the soil by stemflow. This result could then easily be expressed in terms of height, as was the case with the values obtained for incident rain and throughfall.

4. Chemical analysis

Aliquots of rainfall, throughfall and stemflow water were taken to the laboratory, stored in polyethylene bottles and frozen until analysis. The different fractions collected were analysed for chloride, sulphate, phosphorus, calcium and magnesium contents. Total, nitric and ammonium nitrogen contents, were also determined.

Calcium and magnesium were analysed titrimetrically in presence of EDTA, using Murexide as an indicator for Ca, eriochrome black for Ca and Mg.

Phosphorus was determined colorimetrically following mineralization with sulphuric acid, in presence of ammonium molybdate.

Chlorides were analysed using the Mohr method, in presence of silver nitrate; sulphates determination was obtained by photometric measurement of the absorbance at 420 nm following precipitation with baryum chloride.

Total nitrogen was determined using the Kjeldahl method, and ammonium nitrogen was determined colorimetrically with Nessler reagent. Nitric nitrogen was determined by distillation in presence of Dewarda and titration in return with 0.01 N H_2SO_4 .

Date	Rainfall	Stemflow		Throughfall		Interception	
	mm	mm	%	mm	%	mm	%
06.12.91	164.7	10.0	6.1	118.3	71.8	36.4	22.1
20.12.91	26.7	1.1	4.0	16.8	62.9	3.3	33.0
15.01.92	61.7	2.3	3.8	44.3	71.8	15.1	24.4
23.03.92	163.2	14.2	8.7	117.2	71.8	31.8	19.5
03.04.92	0.7	0.0	0.0	0.0	0.0	0.7	100.0
15.04.92	77.6	5.5	7.0	42.0	54.1	30.1	34.8
24.04.92	24.5	0.8	3.4	17.3	70.6	6.4	25.9
04.05.92	87.3	2.5	2.8	72.9	83.5	11.9	13.7
11.05.92	0.7	0.0	0.0	0.0	0.0	0.7	100.0
22.05.92	23.9	1.5	6.2	16.4	68.6	6.0	25.1
30.05.92	101.4	9.6	9.5	65.5	64.6	26.3	25.9
22.06.92	26.6	1.2	4.6	15.4	57.9	10.0	37.5
10.07.92	24.2	2.0	8.3	15.6	64.5	6.6	27.3
11.08.92	4.3	0.8	18.6	3.3	76.7	0.2	4.6
06.10.92	28.9	1.9	6.7	18.3	63.3	8.7	30.0
27.10.92	133.7	7.0	5.2	95.4	71.3	31.3	23.4
18.11.92	13.6	0.4	3.2	4.8	35.3	8.4	61.5
TOTAL	963.7	60.9	6.3	663.5	68.8	239.3	24.8

Table 2. Piano Porcheria: rainfall,throughfall, stemflow and canopy interception in a Castanea sativa stand during twelve consecutive months. Results in mm water and % of incident rainfall

Results

All the measurements made in the two study sites of *Castanea sativa* during 12 consecutive months are summarized in Tables 2 and 3.

The following values expressed per year were found:

	Fossa la Nave	Piano Porcheria
Incident rain	667 mm	964 mm
Throughfall	526	663
Stemflow	18	61
Rain reaching soil	544	725
Interception	123	239

The water supply at the Piano Porcheria study site was noticeably better than at Fossa la Nave. However, these differences were not so significantly different for the amounts of water reaching the soil due to a higher in-

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Date	Rainfall	Stemflow		Throughfall		Interception	
	mm	mm	%	mm	%	mm	%
27.11.91	66.5	0.8	1.2	53.3	80.1	12.4	18.6
18.12.91	112.9	0.6	0.5	91.9	81.4	20.4	18.1
17.01.92	59.6	1.2	2.0	47.5	79.7	10.9	18.3
17.04.92	13.5	1.5	11.1	11.1	82.2	0.9	6.7
04.05.92	125.0	1.4	1.1	102.8	82.2	20.8	16.6
11.05.92	3.4	0.0	0.0	2.5	73.5	0.9	26.5
22.05.92	30.0	0.9	2.8	25.1	83.7	4.0	13.5
01.06.92	50.6	3.7	7.3	37.2	73.5	9.7	19.1
22.06.92	24.0	0.8	3.1	15.0	62.5	3.3	34.4
10.07.92	58.0	1.1	1.9	46.2	79.7	10.7	18.4
30.07.92	3.3	0.5	14.8	2.7	81.8	0.1	3.3
11.08.92	7.3	0.4	5.9	3.8	52.0	3.1	42.0
21.08.92	7.8	0.5	6.3	5.7	73.1	1.6	20.6
18.09.92	24.5	1.1	4.5	18.3	74.7	5.1	20.8
06.10.92	59.1	0.8	1.4	47.1	79.7	11.2	18.9
27.10.92	13.6	3.0	22.0	10.3	75.7	0.3	2.3
18.11.92	8.4	0.2	2.3	5.6	66.7	2.6	31.1
TOTAL	667.5	18.4	2.8	526.1	78.8	123.0	18.4

Table 3. Fossa la Nave: rainfall,throughfall, stemflow and canopy interception in a Castanea sativa stand during twelve consecutive months. Results in mm water and % of incident rainfall

	Cl	Ca	Mg	S	P	N
Piano Porcheria						
Rainfall	113.2	27.3	12.7	18.6	8.2	23.2
Throughfall	96.3	21.9	13.8	18.3	7.0	16.6
Stemflow	16.5	3.7	6.3	4.3	1.2	0.8
Total under canopy	112.8	25.6	20.2	22.6	8.2	17.4
Leaching	-0.4	-1.7	+7.5	+4.0	0.0	-5.8
Fossa la Nave						
Rainfall	81.5	21.0	12.7	15.9	5.4	12.6
Throughfall	75.6	20.4	16.0	15.8	5.0	10.2
Stemflow	4.4	1.5	1.8	1.0	0.2	0.5
Total under canopy	80.0	21.9	17.8	16.8	5.2	10.7
Leaching	-1.5	+0.9	+5.1	+0.9	-0.2	-1.9

Table 4. Nutrient input to soil through rainfall and canopy leaching of two Castanea sativa stands during twelve consecutive months. Results expressed in kg ha-1 year-1.

terception rate at Piano Porcheria: 25% of incident rain compared with 18% at Fossa la Nave. A graphical representation of the results and the corresponding regression equations between rainfall and throughfall, stemflow and interception are shown in figures 1 and 2.

The results of nutrient fluxes within the different pathways of the rain running through the canopy during the 12 month period of the study are summarized in Table 4. With the exception of nitrogen, there was a small increase of leachates for all elements at Fossa la Nave; this was not the case at Piano Porcheria, where magnesium and sulphur contents were higher in leachates.

Incident rain represented an input of 203.2 kg ha^{-1} and 149 kg ha^{-1} of the elements analysed at Piano Porcheria and Fossa la Nave respectively, with the following values:

	Piano Porcheria	Fossa la Nave
chloride	113.2 kg ha^{-1}	81.5 kg ha^{-1}
calcium	27.3	21.0
magnesium	12.7	12.7
sulphur	18.6	15.9
phosphorus	8.2	5.4
nitrogen	23.2	12.6

Rainwater collected under the forest canopy, including respectively 209.9 and 149.0 kg ha $^{-1}$ of the same elements in the two same sites, indicate minimal uptake with rain passing through the foliage and practically no leaching.

Discussion

The rain-water distribution patterns are different at the two sites. This was essentially due to the density of shoots within the stands. Stemflow represented 8.5% of water reaching the forest soil under the 5,668 shoots per hectare at Piano Porcheria (or 6.3% of incident rain), but only 3.4% or 3% of incident rain at Fossa la Nave (1,895 shoots ha^{-1}). While the former value was quite high, it was still within the limits reported by the authors who have already studied this process, in resinous and broad leaved trees. *Fagus silvatica* is an exception however. Stemflow for this last species represents approximately 10 to 25% of incident rain, depending on the local conditions (Ettehad *et al.*, 1973; Likens *et al.*, 1977; Rapp and Ibrahim, 1978; Khanna and Ulrich, 1981; Olson *et al.*, 1981; Wittig and Neite, 1983, Cape *et al.*, 1991).

The interception rates of 18% (Fossa la Nave) and 25% (Piano Porcheria) were also within the limits found by other authors (Olson *et al.*, 1981). At Piano Porcheria, however, the values were close to the highest limit, due to the high density of the stand.

The nutrient uptake can be determined, either in gross values per area unit, or in relation with the height of incident rain (964 and 667 mm), or through rainfall reaching the soil (725 and 544 mm), and thus expressed in concentrations. The values found by that method are summarized in Table 5.

Concerning the incident rain, the concentrations of phosphorus, calcium and chloride were similar within the two study sites. The concentrations of sulphur and magnesium were slightly higher at Fossa la Nave than at Piano Porcheria. For nitrogen, it was the opposite, the concentrations were slightly higher at Piano Porcheria than at Fossa la Nave.

Concerning the concentrations of leachates the re-

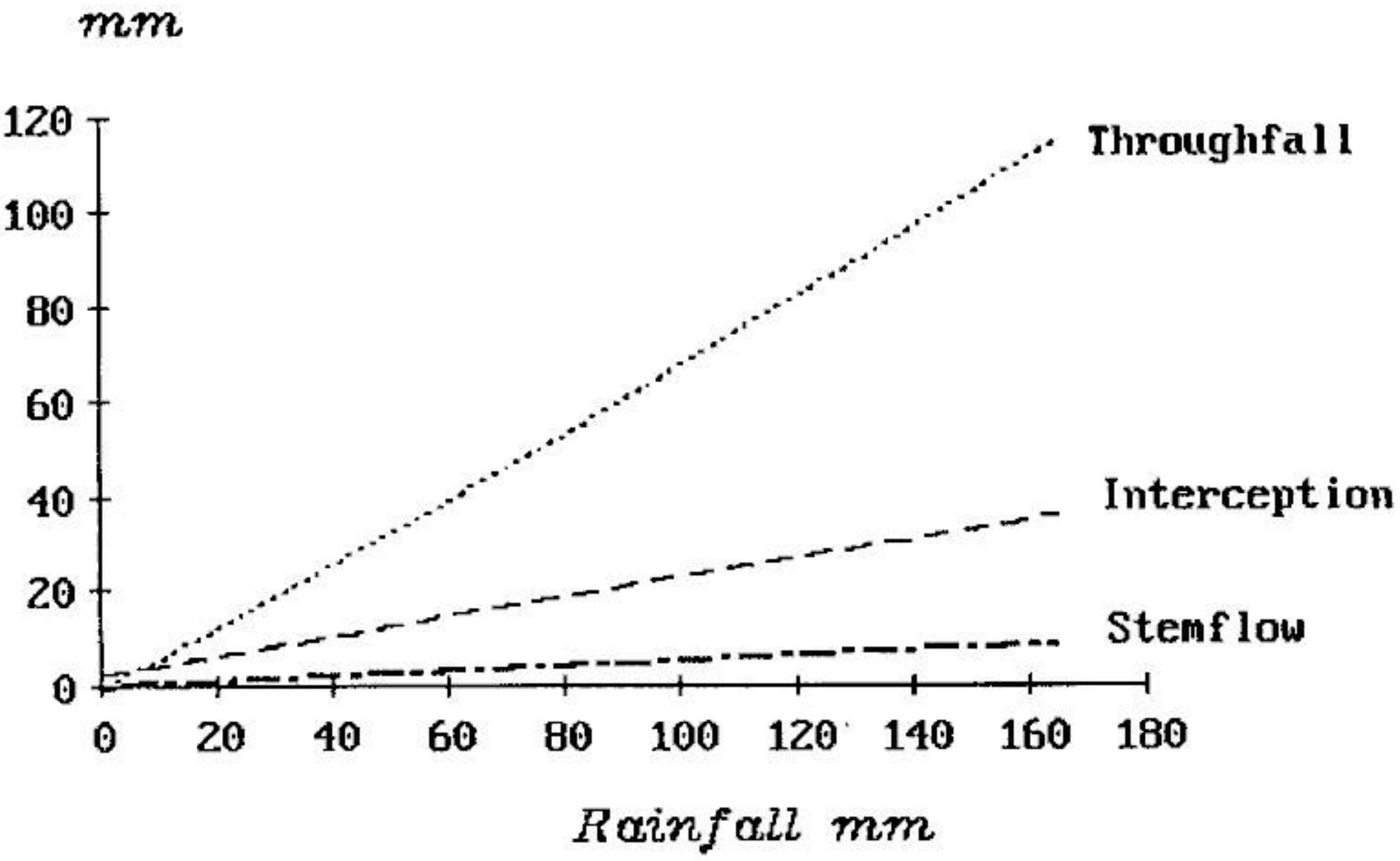

Fig. 1. Piano Porcheria: variation of throughfall, stemflow and interception of precipitations in relation with incident rain. The regression equations are the following in mm:

Throughfall	1.3732 + 0.8231 (IR)	r = 0.999	n = 17
Stemflow	0.1006 x $(IR)^{0.614}$	r = 0.951	n = 17
Interception	0.4409 + 0.1730(IR)	r = 0.977	n = 17

(IR) = incident rainfall (mm)

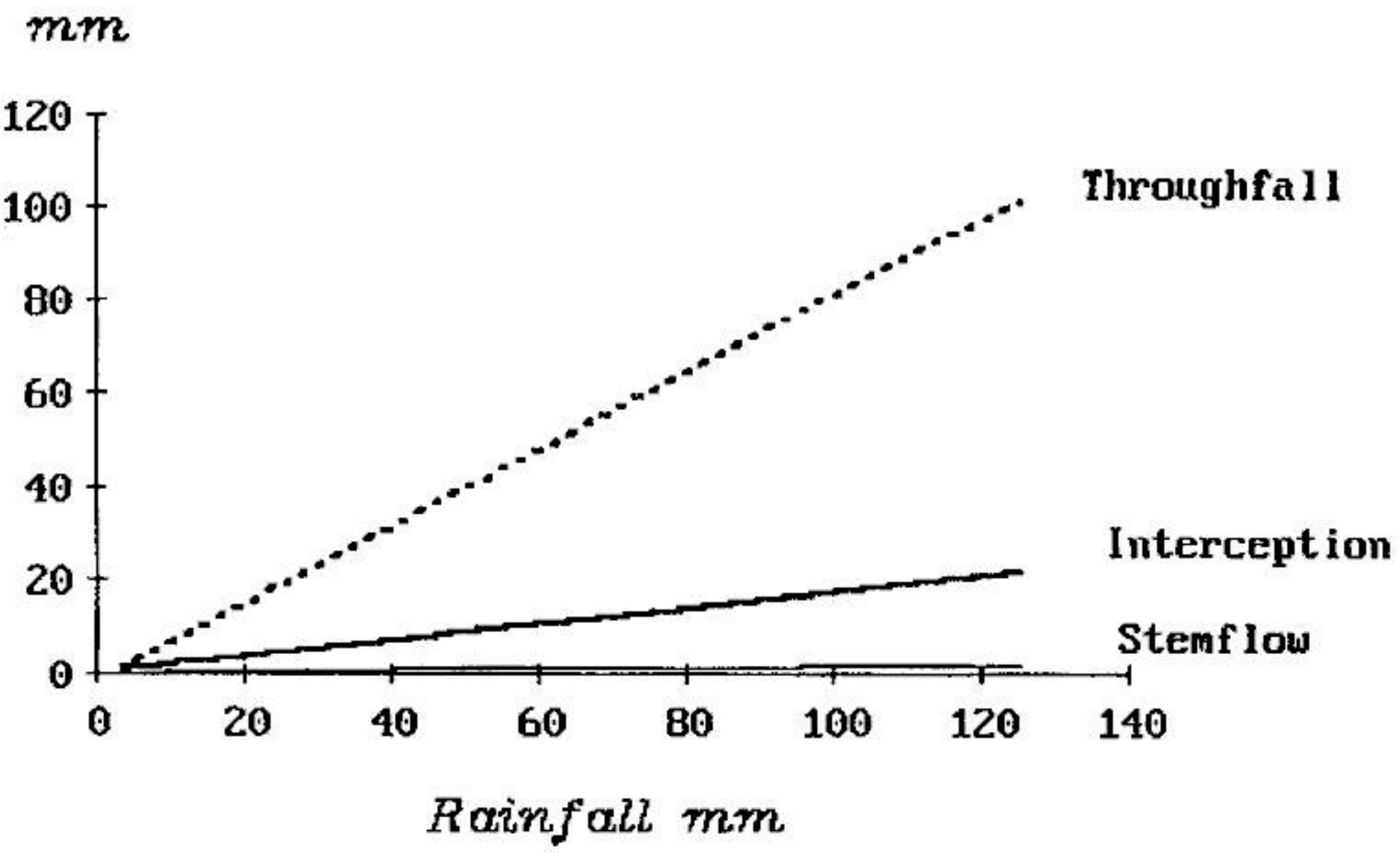

Fig. 2. Fossa la Nave: variation of throughfall, stemflow and interception of precipitations in relation with incident rain. The regression equations are te following in mm:

Throughfall	0.5295x$(IR)^{1.064}$	r = 0.993	n = 17
Stemflow	0.0682x$(IR)^{0.952}$	r = 0.927	n = 17
Interception	2.3648+0.2066(IR)	r = 0.940	n = 17

(IR) = incident rainfall (mm)

sults were different. Magnesium enrichment of rains was greater at Fossa la Nave as the site is found closer to the crater of the volcano; chloride and phosphorus leaching concentrations were lower, probably because the stand is located at a higher altitude and farther away from the sea.

Leaching of all analysed elements amounted to lower values at Fossa la Nave in comparison to Piano Porcheria for chloride, phosphorus and nitrogen. Large amounts of magnesium were also found in leachates. At Piano Porcheria, sulphur and magnesium leaching and retention of calcium, chloride and especially nitrogen was noted.

Nitrogen loss as rain water passes through the canopy has been reported for many years (Carlisle *et al.*, 1966, 1967). Indeed, nitrogen is absorbed and used by the epiphytes (Benzing, 1990) and microorganisms (algae and fungii) living on bark and trunks of trees.

Magnesium input to soil, through the incident rain and leaching, is directly related to local conditions. Indeed, the lava of the Etna volcano contains large amounts of magnesium. Small particles are constantly dispersed into the atmosphere. Given the local conditions, the low sulphur contents are more surprising. Large quantities of this element are constantly emitted by the Etna volcano. Haulet *et al.* (1977) estimated that sulphur emissions amounted to 3,740 Mg day^{-1}, a value which is considerably higher than in other volcanoes. Considering that this study was done during an active phase of the volcano, one could easily have expected higher values than those reported, which are within the lower limits of Western European regions submitted to sulphur pollution. At Piano Porcheria the highest input of this element was directly related to the activity of the volcano: on the one hand, a recent eruption gave birth to a secondary crater nearby, and furthermore this station is directly underwind from the emissions of the main crater (Carbonnel and Zettwoog, 1982).

Strangely, however, suspension enrichment of the high and low atmosphere on the Etna massif due to the gazeous volcanic eruptions does not lead to an increase of elements within rain water or within the deposits on the vegetation between the rainy events. Recent observations have reported that particles and mineral elements emitted from the crater were blown off far beyond the volcanic massif itself and found as far away as the Alps (R. Romano, personal communication).

	Fossa la Nave		Piano Porcheria	
	incident rain	leaching	incident rain	leaching
chloride	12.22	14.70	11.74	15.56
calcium	3.15	4.02	2.83	3.50
magnesium	1.90	3.27	1.32	1.79
sulphur	2.38	3.09	1.93	3.09
phosphorus	0.91	0.95	0.85	1.12
nitrogen	1.89	1.97	2.41	2.38

Table 5. Concentration (ppm) of incident rainwater and canopy leaching rainwater

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