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Full Length Research Paper

Environmental Determinants of Plant Colonization: A Study of Lava Flows on Mount Cameroon

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Tropical ecosystems exhibit several ecological characteristics that make their sustainable management a very difficult task. Surveys were conducted from December 2000 to December 2002 to study the influence of climate and edaphic factors on vegetation cover, species diversity and distribution on three lava flows of Mount Cameroon. On each of the lava flows, thirteen plots in the centre and 2 plots on the adjacent sides were sampled randomly, during two dry and two rainy seasons. A total of 169 plant species belonging to 55 families were identified. The Orchidaceae was the most abundant family having 16 and 19 species in 1922 and 1959 lava flows respectively. Shannon-Weaver Diversity Indices of 2.75, 3.16 and 3.61 were obtained for the 1999, 1959 and 1922 lava flows respectively. Mean annual rainfall values of 5726.7, 4938.6 and 1618.7 mm respectively, were recorded for the 1922, 1999, and 1959 lava flows. Vegetation establishment on the three lava flows was highly influenced by rainfall. 60.7% of the seeds/spores of the plant species identified are dispersed by wind. Organic carbon was found to be the main soil parameter that affected vegetation establishment on the three lava flows.

Key words: Vegetation cover, species diversity, climate and soils.

INTRODUCTION

Mount Cameroon is located in the Gulf of Guinea in south western Cameroon. This mountain is about 45 km long and 30 km wide running from SW to NE between latitudes 3°57’ to 4°27’ N and 8° 58’ to 9°24’ E. The main peak is at 4°7’N and 9°10’E (Tchouto 1996; Suh et al., 2003). It is the most active volcano in Africa, with eight eruptions in the last 100 years (1909, 1922, 1925, 1954, 1959, 1982, 1999, and 2000). During the 19th century the following eruptions were recorded; 1800 to 1815, 1825, 1838 to 1839, 1845, 1852, 1865 and 1866 (Deruelle et al., 2000; Suh et al., 2003). There are no reports regarding the places of occurrence before these eruptions. These eruptions produce lava flows that cover existing vegetation, initiating primary succession. Ndam (2003) observed that about 20 km of forest was destroyed during the 1999 flow.

This region has two main seasons: a wet season with rains from March to October and a dry season from November to February. The mean annual rainfall varies between 2085 mm near Ekona on the leeward side, to 9086 mm at Debundscha on the windward side of the mountain (Fraser et al., 1998).

The soils of Mount Cameroon are mostly andisols, formed by the weathering of volcanic rocks (Leamy,

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1984). The volcanic activity of Mount Cameroon has influenced, to a great extent, the recent geological history of the region and is responsible for the remarkable fertility of its soils (Payton, 1993). The increase in soil fertility has resulted in an increase in the human population density in this region, with large plantation farms employing about 13000 workers (C.D.C, 1997). It has been shown that these soils have poor water holding capacities (Cheek, 1992). The soil temperature at depth of 10 cm varies from 25°C at 200 m above sea level (a.s.l.) through 20°C at 1100 m altitude to 15°C at 2200 m altitude (Payton, 1993). Richards (1963) remarked that in the grassland, where the forest cover is absent, these shallow soils tend to dry out rapidly in dry weather. This may have important ecological consequences in encouraging dry season fires.

Tropical ecosystems exhibit several ecological characteristics that make their sustainable management a very difficult task. The vegetation in the ecosystem affects the following environmental factors: soil chemistry, the soil texture and vegetation types. Soil chemistry and rainfall are some of the factors that influence the type of vegetation that is found in an ecosystem (Sunderland et al., 2003; Sunderland, 2000; Ndam, 1998; Ndam et al., 2002; Wilson, 1994; Fraser et al., 1998; Chadwick et al., 2003). Hence, it is likely that different vegetation communities could be found on different soil types, which are weathered products of rocks (Odhiambo, 2003). There is also a mosaic vegetation community caused by different volcanic ages (Cable and Cheek, 1998; Fonge, 2004; Fonge et al*.,* 2005). Very few detailed vegetation studies have been carried out on the old and recent lava flows of Mount Cameroon. The bare rocks resulting from the lava flows are continuously undergoing physical and chemical weathering and are being re-colonized by plants of different taxa. Fraser et al. (1999) worked on plant succession on the 1922 lava flow of Cameroon and Ndam et al. (2002) reported on plant species diversity (concentrating mostly on higher plants) in the 1922 and 1959 lava flows. Fonge et al. (2005) worked on the vegetation of the 1922 lava flow. Focho et al. (2010) reported on the distribution of the Orchidaceae on three lava flows on Mount Cameroon at different altitudinal levels. Very little work has been done on the effects of climate and edaphic factors on vegetation establishment on this mountain. In order to study this, the following questions are needed to be answered: (1) Does rainfall pattern or amount influence vegetation cover and types on Mount Cameroon? (2) Does the variation of temperature on the different lava flows affect vegetation cover and types? (3) Do the soil chemical properties of the different lava flows influence vegetation establishment? For a sustainable management of this area there is the need to study the effects of climate and edaphic factors on vegetation, species diversity and distribution on the different lava flows.

MATERIALS AND METHODS

Study sites

Three lava flows were selected based on accessibility and size of flow (Figure 1). In all the selected lava flows the chemical composition was in the order SiO_2 > Al_2O_3 > CaO > FeO > Fe_2O_3 (Fitton et al*.,* 1983; Deruelle et al., 2000).

The 1922 lava flow is located between latitude 4°1' N, and longitude 9°1' W, 2 km south of Idenau and 10 km north of Debundscha (west of Mount Cameroon). It consists of pahoehoe (smooth pavelike surface) lava. Annual rainfall at Idenau ranges between 3303 and 12449 mm, with a mean of 8,392 mm. At Debundscha, it ranges between 4153 and 16965 mm, with the mean annual of 9086 mm (Fraser et al., 1998). The lava emerged from a crater at about 1500 m above sea level and moved 10 km from the crater to the sea. The flow is 1.5 km wide until it divides at 170 m above sea level into two arms that continue to the sea. At the flanks of the lava flow about 200 m above sea level, are oil palm plantations (*Elaeis guineensis).* Above these plantations are remnants of rainforest. The soil texture ranged from sandy loam to silt loam.The 1959 lava flow at Ekona (East coast) is located at 9°18' W and 4°14' N. The lava emerged from a crater at about 1500 m above sea level and flowed down covering a distance of about 4 km to 490 m and stopped. It is 300 m wide around the vent, narrowing to a rounded base about 100 m wide. It is an a'a lava type (rough, surface with large boulders). The annual rainfall of this region ranges between 2085 and 2887 mm. The soil texture ranged from sandy loam to loam. The 1999 lava flow is found in Bakingili, West of Mount Cameroon. This flow is located at 4°8' N and 9°6' W covering a distance of about 12 km from the crater. It is about 1.4 km wide and 20 m high and is an a'a lava type. It ends 200 m from the sea (Suh et al., 2001, 2003). The soil texture ranges from sandy loam to silt loam. Both the 1922 and the 1999 lava flows are located on the west coast region. The temperature in this region is between 24° to 30°.

Plant sampling

Sampling was done from December 2000 to December 2002 using the Braun-Blanquet scaling method (Bullock, 1996) to determine the vegetation cover (Table 1). The Whittaker method was used to measure species diversity and abundance. Fifteen plots of 20 by 50 m at a distance of 100 m from each other were sampled on each lava flow. Two of these plots were located on the edges and thirteen in the centres of each flow. The lava flows were selected after reconnaissance surveys in December 2000 because they covered extensive areas and were accessible. Plots were completely sampled in July 2001 (rainy season), December 2001 (dry season), June 2002 (rainy season) and December 2002 (dry season). Plant species found in each plot on each of the three lava flows were identified and their growth forms and distribution patterns recorded. For each species, the number of individuals encountered in each plot was recorded. Voucher specimens were prepared, identified and deposited at the Limbe Botanic Garden herbarium (SCA). Information on modes of seed/spore dispersal of the various species encountered was obtained from collections at the Limbe Botanic Garden.

Climatic data

Data from 1982 to 2002 were collected for temperature, rainfall and relative humidity from C.D.C weather stations for the west coast region where the 1922 and 1999 lava flows are located. Data for the 1959 lava flow were collected from the Institute of Research in

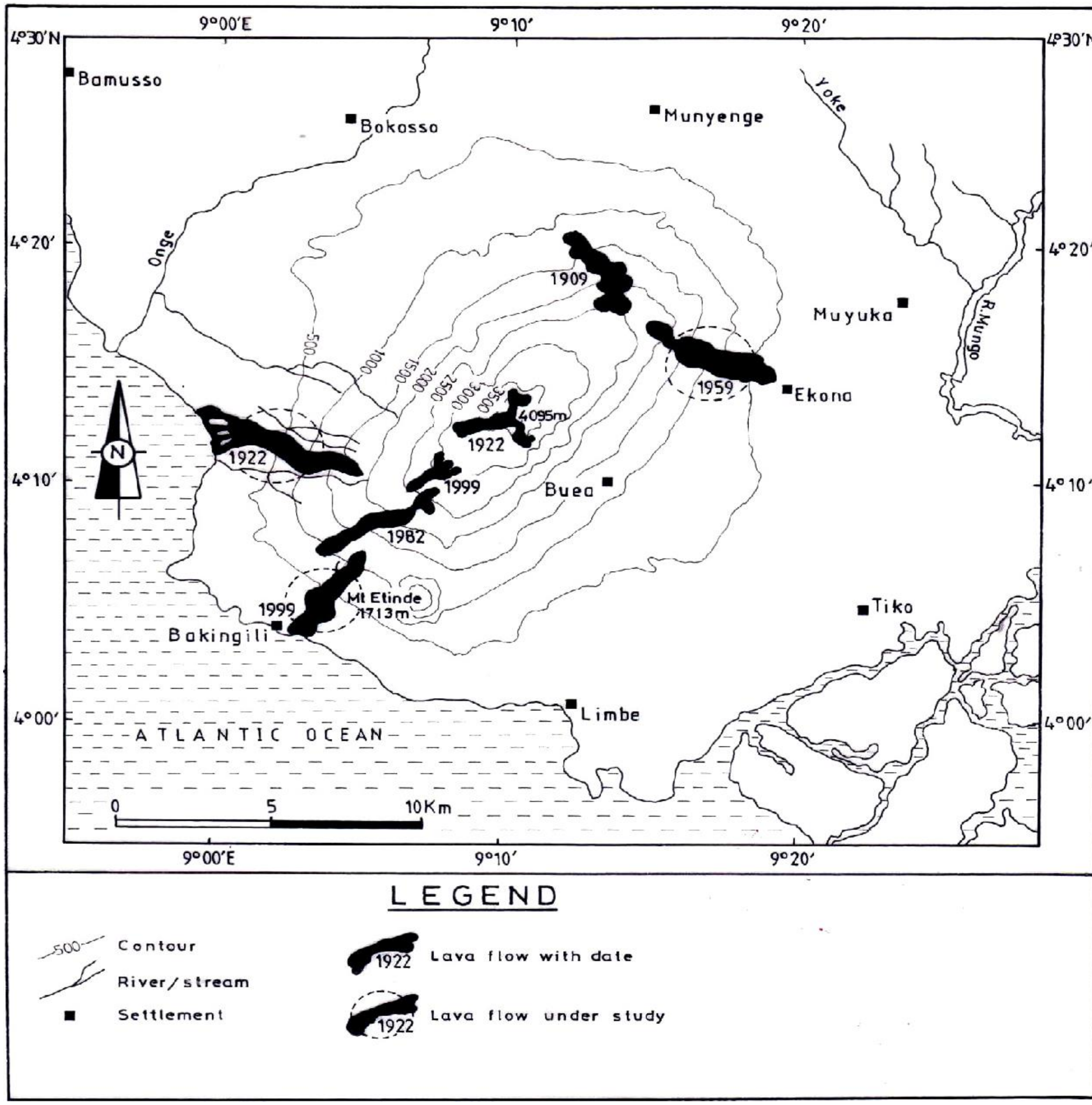

Figure 1. Site of Study. Source: Suh et al. (2003).

Geology and Mining (IRGM)-Ekona weather stations.

Soil sampling

Topsoil samples (0 to 5 cm) were collected from each of the plots in triplicates and bulked to have homogeneous samples. The soil samples were air dried, sieved with a 2 mm sieve and analysed for pH in water and KCl, organic carbon, total nitrogen, and available phosphorous and exchangeable bases as described by Cottenie et al. (1982)

Data processing and analysis

Plant species were sorted out into different life forms. The Shannon weaver diversity index of plant species within the different lava flows was determined using (Magaurran, 1988):

$$H^1 = \sum (P_I)(\log_{NI} P)$$

where, H^1 = Index of species diversity (information content of sample, bits or individuals), Pi = Proportion of total sample belonging to i^{th} species, and i = Number of species.

Table 1. Braun Blanquet scaling method.

Percentage range of species cover	Class
<<1	1
< 1	+
<1–5	1
6–25	2
26 –50	3
51–75	4
76 – 100	5

Source: Bullock (1996).

The effect of soil on the vegetation cover, diversity and abundance on the different lava flows was determined using a multivariate analysis [Principal component analyses (PCA)]. This is a statistical procedure where the effects of several factors under investigation are ranked based on their magnitudes of interaction.

RESULTS

Vegetation cover

The Braun – Blanquet method revealed that the vegetation cover ranged from <<1% (r) (rare) for fungi on bare rocks to 80% (5) for ferns in the wet season and from r for lichens to 40% (3) for trees, orchids and shrubs during the dry season (Table 2).

Species abundance

A total of 169 species belonging to 55 families were identified from the three lava flows (Table 3). The Orchidaceae was the most abundant family having 16 species in the 1922 and 19 species in 1959 lava flows respectively. No orchids and fungi species were encountered on the 1999 lava flow while parasites were absent in 1922 and 1999 lava flows. Only one parasitic species was found on the 1959 flow. On the 1922 lava flow the Rubiaceae had the highest number of shrubs while the Euphorbiaceae had the highest number of shrubs in the 1959 flow. No shrubs or tree species were recorded on the 1999 flow. However, on the peripheries, the Moraceae recorded the highest number of tree species. Diversity increased with flow age as follows: 1999 (2.75), 1959 (3.16) and 1922 (3.61). Seed/spore dispersal was mostly by wind (60.7%) and least by birds (1.2%) (Table 4).

Climate

The climate data obtained from C.D.C, and IRGM- Ekona for the period of 1982 to 2002 (20 years) showed that the mean monthly temperature of the area ranged between 24.8 to 27.7°C 26.7 to 27.6°C, 25 to 29.9°C at Idenau, Ekona and Mokundange respectively (Table 5). Annual rainfall on the west coast region that has the 1922 and 1999 lavas ranges between 4936.8 and 5726.7 mm while that of Ekona is 1618.7 mm.

Soil analysis

Table 5 shows some physico-chemical properties of soils collected from the fronts, edges and centres of the lava flows. The pH of the different lava flows at the centres showed that 1922<1959<1999 while the east flank of the lava flows was in the order 1922<1999<1959 that of the west flank was in the order 1999<1922<1959.

The centre of the 1922 lava flow had the highest organic carbon (11.10%). The lowest value (0.74%) was recorded at the centre of the 1999 lava flow. Comparison of the different lava sites showed that the organic matter increased with age. The total nitrogen was highest in the 1922 lava flow (3.53%) and lowest in the 1999 lava (0.29%). Comparing the different sites, the west flank of the 1999 lava had the highest nitrogen (3.9%).

Exchangeable cations in the centres increase with age. The 1922 lava had the highest value for the individual cations (4.8) while the 1999 lava had the lowest (1.77). On the 1922 lava, Ca content was highest (2.89 meg/100) on the east flank and lowest (2.42 meg/100) on the west flank. In the case of Mg it was highest (0.46 meg/100) at the centre and lowest (0.16 meg/100) at the east flank.

The highest amount (27.13%) of available P was observed on the west flank of the 1922 lava flow while the lowest amount (11.38%) was recorded the east flank on the 1999 lava flow.

Eigen-analysis (Table 6) shows that the first three components, PCl, PC2 and PC3 explain 71.13% of the total variation. PCl is most strongly affected by CEC, Ca, Mg, K, and organic carbon. PC2 is strongly associated

Table 2. Plant surface cover (dry and rainy seasons) on the 1922, 1959 and 1999 lava flows.

Plant life forms	1922				1959				1999			
	Dry season		Rainy season		Dry season		Rainy season		Dry season		Rainy season	
	Sp cover (%)	Class	Sp cover (%)	Class	Sp cover (%)	Class	Sp cover (%)	Class	Sp cover (%)	Class	Sp cover (%)	Class
Trees	40	3	40	3	5	1	5	1	<<1	r	<<1	r
Ferns	50	3	60	4	75	4	80	5	5	1	3	1
Orchids	30	3	40	3	40	3	20	2	<<1	r	<<1	r
Herbs	20	2	20	2	50	3	30	3	1	1	<1	+
Climbers	5	1	25	2	5	1	1	1	2	1	1	1
Shrubs	40	3	40	3	5	1	5	1	1	1	<<1	r
Fungi	1	1	1	1	1	1	1	1	<<1	r	<<1	r
Moss	25	2	30	3	40	3	40	3	30	3	10	2
Lichens	1	1	<1	+	30	3	30	3	20	2	20	2
Bare rock	<1	+	5	0.1	20	2	50	3	80	5	90	5

Table 3. Number of species/family for the different life forms found on 1922, 1959, and 1999 lava flows.
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Life forms	1922		1959		1999	
	No. of families	No. of species	No. of families	No. of species	No. of families	No. of species
Flowering plants						
Trees	13	21	13	25	05	08
Shrubs	07	12	08	09	03	04
Parasite	00	00	01	01	00	00
Herb	12	22	11	22	09	10
Climbers	05	07	07	09	01	01
Orchids	01	16	01	19	00	00
Total	38	78	41	85	18	23
Cryptogamic plants						
Ferns	08	16	08	14	02	04
Mosses	01	03	01	05	01	03
Lichens	01	04	01	11	01	10
Fungi	02	02	01	02	00	00
Total	12	25	10	32	04	17
Grand total	50	103	51	117	22	40

Table 4. Plant diversity on the selected lava flows during the 2000 to 2003 survey.

Plant No.	Names	Family	Code	Life form	1922*	1959	1999	Seed dispersal mechanism
1	*Ipomoea batatas* (L.) Lam.A	Convolvulaceae	Ipba	Climber	+	+	-	Mammal
2	*Ipomoea* sp	Convolvulaceae	Ipsp	Climber	+	-	-	Mammal
3	*Bambekea racemosa* Cogn.	Cucurbitaceae	Bara	Climber	-	-	+	Mammal
4	*Tetracera alnifolia* Willd.	Dilleniaceae	Teal	Climber	+	-	-	Mammal
5	*Leea guineesis* G.Don A	Leeaceae	Legu	Climber	+	-	-	Mammal
6	*Vigna* sp A	Papilionaceae	Visp	Climber	-	+	-	Wind
7	*Adenia cissampiloides* (Planch. Ex Benth) Harms	Passifloraceae	Adci	Climber	-	+	-	Wind
8	*Adenia lobata* (Jacq.) Engl	Passifloraceae	Adlo	Climber	+	+	-	Wind
9	*Mussaenda tenuiflora* (Benth.)A	Rubiaceae	Mute	Climber	+	-	-	Wind
10	*Paullinia* sp L	Sapindaceae	Pasp	Climber	-	+	-	Wind
11	*Smilax kraussiana* Meisn	Smilacaceae	Smkr	Climber	-	+	-	Wind
12	*Urera* sp	Urticaceae	Ursp	Climber	-	+	-	Mammal
13	*Clerodendrum* sp	Verbenaceae	Clsp	Climber	-	+	-	Wind
14	*Ipomoea involucrata* P.Beauv. A	Convolvulaceae	Ipin	Climber	+	+	+	Mammal
15	*Pityrogramma* sp	Adiantaceae	Pisp	Fern	-	+	-	Wind
16	*Pityrogramma calomelanos* (L.) link var	Adiantaceae	Pica	Fern	-	+	-	Wind
17	*Asplenium barateri* Hook	Asplenaceae	Asba	Fern	+	-	-	Wind
18	*Ctenitis dimidiota* A.	Dryopteridaceae	Ctdi	Fern	+	+	-	Wind
19	*Ctenopteris elstica* A.	Grammitidaceae	Ctel	Fern	-	+	-	Wind
20	*Trichomanes borbonicum* Bosch	Hymenophyllaceae	Tribo	Fern	+	-	-	Wind
21	*Trichomanes africanum* H. Christ	Hymenophyllaceae	Traf	Fern	+	-	-	Wind
22	*Anapeltis lycopodioides* (L.)J.Sm	Oleandraceae	Anly	Fern	+	+	-	Wind
23	*Arthropteris cameroonensis* Alston R,K,A	Oleandraceae	Arca	Fern	+	+	+	Wind
24	*Nephrolepis biserrata* (sw.)Schott R,SK,A	Oleandraceae	Nebi	Fern	+	+	+	Wind
25	*Nephrolepis cordiflora* A	Oleandraceae	Neco	Fern	+	+	-	Wind
26	*Nephrolepis pumicicola* Ballard R,K,A	Oleandraceae	Nepu	Fern	+	-	-	Wind
27	*Ophinoglossum reticuletum* L	Ophinoglossaceae	Opre	Fern	+	+	-	Wind
28	*Athyrium* sp	Polypodiaceae	Atsp	Fern	-	-	+	Wind
29	*Microgramma owariensis* (Desv.) Alston R,Sk,A	Polypodiaceae	Miow	Fern	+	-	-	Wind
30	*Microsoruim punctatum* (L.) Copel.R, sk,A	Polypodiaceae	Mipu	Fern	+	+	+	Wind
31	*Microsoruim scolopendria* (Burn.) Ching	Polypodiaceae	Misc	Fern	+	+	-	Wind
32	*Polypodium punctatum* A.	Polypodiaceae	Popu	Fern	-	+	-	Wind
33	*Selaginella abyssinica* Spring.	Selaginellaceae	Sesp	Fern	-	+	-	Wind
34	*Sellaginella* sp	Sellaginellaceae	Sesp	Fern	+	-	-	Wind
35	*Antrophum mannianum* Alston	Vitariaceae	Anma	Fern	+	-	-	Wind
36	*Loxogramme abyssinica* (Baker) M.G Price	Vitariaceae	Loab	Fern	+	+	-	Wind
37	*Daedaleopsis* sp.	Polyporaceae	Dasp	Fungi	+	+	-	Wind
38	*Lenzite* sp.	Polyporaceae	Lesp	Fungi	+	+	-	Wind
39	*Achyranthes aspera* L.	Acanthaceae	Acas	Herb	-	-	+	Mammal
40	*Asystasia gangetica* (L) T.Anders R,K,SA,	Acanthaceae	Asga	Herb	-	+	-	Mammal
41	*Anchomanes difformis* (Blume.)Engl.	Araceae	Andi	Herb	-	+	-	Mammal
42	*Stellaria media* (L.) Vill.	Caryophyllaceae	Stme	Herb	-	+	-	Wind

Table 4. Contd.

43	*Commelina benghalensis* L.Var. benghalensis	Commelinaceae	Cobe	Herb	-	+	+	Mammal
44	*Commelina diffusa* Burm.f.	Commelinaceae	Codi	Herb	+	+	-	Mammal l
45	*Ageratum conyzoides* L.	Asteraceae	Agco	Herb	+	-	-	Wind
46	*Crassocephallum creepidioides* (Benth.) S.Moore A	Asteraceae	Crcr	Herb	+	+	-	Wind
47	*Emilia coccinea* (Sims) G.Don R,K	Asteraceae	Emco	Herb	+	+	+	Wind
48	*Melanthera scandens* (Schumach.&Thonn.)Roberty	Asteraceae	Mesc	Herb	+	+	+	Mammal
49	*Mikania scandens* (L.) Willd.	Asteraceae	Misc	Herb	-	+	-	Wind
50	*Synedrella nodiflora* Gaertn	Asteraceae	Symo	Herb	-	+	-	Mammal
51	*Mariscus alternifolius* Hooper	Cyperaceae	Maal	Herb	+	-	-	Mammal
52	*Croton hirtus* A.	Euphorbiaceae	crhi	Herb	+	+	-	Mammal
53	*Phyllanthus amarus* Schum.&Thonn A	Euphorbiaceae	Pham	Herb	+	+	+	Mammal
54	*Axonopus compressus* P.Beauv.R,A	Poaceae	Axco	Herb	+	+	-	Wind
55	*Eragrostis manni* A	Poaceae	Erma	Herb	-	+	-	Wind
56	*Hyparrhrenia ruffa* (Nees) Stapf.	Poaceae	Hyru	Herb	+	+	-	Wind
57	*Imperata cylindrica* (Anderss.) c .E Hubbard	Poaceae	Imcy	Herb	+	+	-	Animal
58	*Panicum maximum* Jacq	Poaceae	Pama	Herb	+	+	-	Wind
59	*Paspalum conjugatum* Berg. R,sk	Poaceae	Paco	Herb	+	-	-	Wind
60	*Paspalum paniculatum* L.A	Poaceae	Pape	Herb	+	-	-	Wind
61	*Pennisetum hordeoides* (Lam.) Stand.A	Poaceae	Peho	Herb	-	+	+	Mammal
62	*Solenostemon monostachyus* (P.Beauv.)Briq.Subsp. Monostachyus	Lamiaceae	Somo	Herb	+	-	+	Wind
63	*Pueriaria phaseolioides* (Roxb.) Benth	Mimosaceae	Puph	Herb	+	+	+	Wind
64	*Centrosema virginianum* Benth.A	Papilionaceae	Cevi	Herb	+	-	-	Mammal
65	*Sida acuta* Burm.f.subsp. *Carpinifolia*	Malvaceae	Siac	Herb	-	+	-	Mammal
66	*Megaphryanin macrostallyum* (Benth.) Milne- Redh	Maranthaceae	Mema	Herb	+	-	-	Mammal
67	*Dissotis erecta* (Guill.&perr) Dandy A	Melastomataceae	Disp	Herb	+	+	-	Mammal
68	*Dissotis rotundifolia* (S.M) Triana A	Melastomataceae	Diro	Herb	+	-	-	Mammal
69	*Piper umbellatum* L.	Piperaceae	Pium	Herb	+	+	+	Mammal
70	*Oldenlandia* sp	Rubiaceae	Olsp	Herb	-	-	+	Wind
71	*Diodia sarmentosa* D.Brevisecta, Benth.	Rubiaceae	Disa	Herb	+	-	-	Mammal
72	*Coccocarpia* sp	Lichen	Cosp	Lichen	+	-	-	Wind
73	*Cladonia flaverkaena*	Lichen	Clfl	Lichen	-	+	-	Wind
74	*Dictyonema* sp	Lichen	Disp	Lichen	+	-	+	Wind
75	*Dirina massiliensis* F. *Aponina* (Mussal.) Fehler	Lichen	Dima	Lichen	-	-	+	Wind
76	*Hypotrchyna* sp	Lichen	Hysp	Lichen	-	-	+	Wind
77	*Leptogium* sp	Lichen	Lesp	Lichen	-	+	+	Wind
78	*Parmelia laevigata*	Lichen	Pala	Lichen	+	+	+	Wind
79	*Parmotrema* sp	Lichen	Pasp	Lichen	-	+	+	Wind
80	*Rhizocarpa* sp	Lichen	Rhsp	Lichen	-	+	-	Wind
81	*Solenopsura caudicans*	Lichen	Soca	Lichen	-	+	+	Wind
82	*Steroocaulon* sp	Lichen	Stsp	Lichen	-	+	+	Wind
83	*Theliduim incavatum* Mudd-Krain & Bultmann	Lichen	Thin	Lichen	+	+	+	Wind
84	*Usea florida*	Lichen	Usfl	Lichen	-	+	-	Wind
85	*Cladonia convolute* (Lam.) Cout.	Lichen	Clco	Lichen	-	+	-	Wind
86	*Pyxine* sp	Lichen	Pysp	Lichen	-	+	+	Wind

Table 4. Contd.

87	*Campylopus dusenii* C.M	Musci	Cadu	Moss	-	+	+	Wind
88	*Campylopus horridus* welw.&Duby	Musci	Caho	Moss	+	+	-	Wind
89	*Ectopothecium afro-molluscum* (C.M) Broth.Keay FH1 28676	Musci	Ecaf	Moss	-	+	+	Wind
90	*Ectopothecium regulare* (Brid.)Jaeg	Musci	Ecre	Moss	+	+	+	Wind
91	*Semantophyllum calspitosum* (sw) Mitt Sensu lato H.n.Dixon	Musci	Seca	Moss	+	+	-	Wind
92	*Bulbophyllum* sp2	Orchidaceae	Busp2	Orchid	-	+	-	Wind
93	*Diaphananthe bueae* (Schltr.) Schltr.	Orchidaceae	Dibu	Orchid	+	-	-	Wind
94	*Centrostigma occultans* Schltr.	Orchidaceae	Ceoc	Orchid	-	+	-	Wind
95	*Chamaengis odoratissima* (Rchb.f.) Schilr.	Orchidaceae	Chod	Orchid	-	+	-	Wind
96	*Chamaengis* sp	Orchidaceae	Chsp	Orchid	+	-	-	Wind
97	*Ancistochitus rothschildians* 0'Brien	Orchidaceae	Anro	Orchid	+	+	-	Wind
98	*Ancistrochynchus cephelotes* A.	Orchidaceae	Ance	Orchid	+	-	-	Wind
99	*Angraecum birrimenae* Rolfe	Orchidaceae	Anbi	Orchid	+	+	-	Wind
100	*Angraecum superbum* Lindl.	Orchidaceae	Ansu	Orchid	-	+	-	Wind
101	*Ansella africana* Lindl.Lindl.	Orchidaceae	Anaf	Orchid	-	+	-	Wind
102	*Bulbophyllum biaferium* Hook.f.	Orchidaceae	Bubi	Orchid	+	+	-	Wind
103	*Bulbophyllum calvum* Summerh	Orchidaceae	Buca 2	Orchid	+	+	-	Wind
104	*Bulbophyllum falcatum* (Lind.) rchb.f.Var *falcatum*	Orchidaceae	Bufa	Orchid	+	+	-	Wind
105	*Bulbophyllum intertextum* Lindl.	Orchidaceae	Buin	Orchid	+	-	-	Wind
106	*Bulbophyllum josephii* (Kuntze)Summerh.Var.*josephie*	Orchidaceae	Bujo	Orchid	+	-	-	Wind
107	*Bulbophyllum porphyrostachys* Summerh	Orchidaceae	Bupo	Orchid	-	+	-	Wind
108	*Bulbophyllum simonii* Summerth	Orchidaceae	Busi	Orchid	+	-	-	Wind
109	*Calyptrochylum emarginatum* Schltr.	Orchidaceae	Cach	Orchid	-	+	-	Wind
110	*Cyrtorchis chailluana* (Hook.f.) Schltr. A	Orchidaceae	Cych	Orchid	+	+	-	Wind
111	*Habenaria gabonensis* Rchb.f	Orchidaceae	Hesp	Orchid	-	+	-	Wind
112	*Liparis epiphytica* Schltr	Orchidaceae	Liep	Orchid	-	+	-	Wind
113	*Polystachus affinis* Lindl.A	Orchidaceae	Poaf	Orchid	+	-	-	Wind
114	*Polystachya luxiflora* Lindl. R	Orchidaceae	Polu	Orchid	+	+	-	Wind
115	*Polystachya tesseleta* (Jacq.)garay &H.R. Sweet	Orchidaceae	Pote	Orchid	+	-	-	Wind
116	*Schroartzkopffa lastic*	Orchidaceae	Scla	Orchid	-	+	-	Wind
117	Unidentified sp	Orchidaceae	Unsp	Orchid	-	+	-	Wind
118	*Bulbophyllum calyptratum* kraenzl.	Orchidaceae	Buca 1	Orchid	+	-	-	Wind
119	*Bulbophyllum* sp1	Orchidaceae	Busp1	Orchid	-	+	-	Wind
120	*Phargmanthera capitata* (Sprengel) Balle A	Loranthaceae	Phca	Parasite	-	+	-	Bird
121	*Sorindeia mibroedi* Engl.&Brehmer	Anacardiaceae	Somi	Shrub	-	+	-	Mammal
122	*Tabenaemontana crassa* (Benth.)Hiern	Apocynaceae	Tacr	Shrub	-	+	-	Mammal
123	*Voacanga africana* Stapf	Apocynaceae	Voaf	Shrub	-	+	-	Mammal
124	*Maytemus* sp	Celastraceae	Masp	Shrub	+	-	-	Mammal
125	*Chromolaena odorata* (L.)R.M.King&H. Robinson	Asteraceae	Chod	Shrub	+	+	+	Mammal
126	*Vernonia cinerea* (L.) Less	Asteraceae	Veci	Shrub	-	+	+	Wind
127	*Costus afer* A	Costaceae	Coaf	Shrub	+	-	-	Mammal
128	*Agauria salicifolia* Zomm. Ex Lam) Hook.f.ex	Ericaceae	Agsa	Shrub	+	+	-	Mammal
129	*Psorospermum staudtis* Engl. A	Clusiaceae	Psst	Shrub	+	-	-	Wind
130	*Mimosa pudica* L.A	Miniosaceae	Mipu	Shrub	+	-	+	Mammal

Table 4. Contd.

131	*Malvaviscus arboreus* var. *drummondii*	Malvaceae	Maar	Shrub	-	+	-	Mammal
132	*Urena lobota* L	Malvaceae	Unlo	Shrub	+	+	-	Mammal
133	*Tristemma hirtum* P.Beauv	Melastomataceae	Trhi	Shrub	+	-	-	Wind
134	*Hymenodictyon biafranum* Hiern.R,K A	Rubiaceae	Hybi	Shrub	+	+	-	Bird
135	*Oldenlandia lancifolia* (K. Schum.) DC.A	Rubiaceae	Olla	Shrub	+	-	+	Wind
136	*Pauridiantha venusta* N.Hall	Rubiaceae	Pave	Shrub	+	-	-	Wind
137	*Tarenna conferta* (Benth.)Hiern	Rubiaceae	Taco	Shrub	+	-	-	Mammal
138	*Tarenna* sp	Rubiaceae	Tasp	Shrub	+	-	-	Mammal
139	*Tricalysia* discolor Brenan	Rubiaceae	Trdi	Shrub	+	-	-	Mammal
140	*Lantana camara* L	Verbenaceae	Laca	Shrub	-	+	-	Mammal
141	*Mangifera indica* L	Anacardiaceae	Main	Tree	+	+	-	Mammal
142	*Pseudospondia macrocarpa* (A.rich) Engl.var. *mocrocarpa*	Anacardiaceae	Psmi	Tree	-	+	-	Mammal
143	*Alstonia boonei* De Wild	Apocynaceae	Albo	Tree	+	+	-	Mammal
144	*Rauvolfia vomitoria* Afzel.	Apocynaceae	Ravo	Tree	-	+	-	Wind
145	*Spathodea companulata* P. Beauv	Bignomiaceae	Spco	Tree	-	+	-	Mammal
146	*Tecoma stans*.L.	Bignoniaceae	Test	Tree	-	+	-	Mammal
147	*Cecropia cecropioides* R.Br. Ex Tedlie	Cecropiaceae	Cece	Tree	+	+	+	Mammal
148	*Cecropia peltata* L.SA	Cecropiaceae	Cepe 2	Tree	+	+	-	Mammal
149	*Musanga cecropioides* R.Br.R,sk,SA	Cecropiaceae	Muce	Tree	+	+	-	Mammal
150	*Alchornea cordifolia* (Schum,andThonn)mufl.Arg	Euphorbiaceae	Alco	Tree	+	+	+	Mammal
151	*Bridelia micrantha* (Hocht)Baill.	Euphorbiaceae	Brmi	Tree	+	+	-	Mammal
152	*Macaranga occindentalis*	Euphorbiceae	Maoc	Tree	+	+	-	Mammal
153	*Harungana madagascariensis* Poiref R SK,A	Clusiaceae	Hama	Tree	+	+	-	Wind
154	*Desmodium adscendens* Dc.R.A	Papilionaceae	Dead	Tree	+	-	-	Mammal
155	*Albizia zygia* (Dco) J.F. Macbr. A.	Mimosaceae	Alzy	Tree	+	+	-	Mammal
156	*Ficus canraui* Avarb.	Moraceae	Fica	Tree	+	-	-	Bird
157	*Ficus exasperata* Vahl.	Moraceae	Fiex	Tree	-	+	+	Bird
158	*Ficus lutea* Vahl.	Moraceae	Filu	Tree	+	+	-	Bird
159	*Ficus polita* Vahl Suhsp. *Polita*	Moraceae	Fipo	Tree	-	+	-	Bird
160	*Ficus* sp	Moraceae	Fisp	Tree	-	-	+	Bird
161	*Ficus sur* Forssk.	Moraceae	Fisu	Tree	+	+	+	Bird
162	*Syzygium guineense* (Willd.) DC.var. *guineense*	Myrtaceae	Sygu	Tree tree	+	-	-	Mammal
163	*Syzyium* sp	Myrtaceae	Sysp	Tree tree	+	_	-	Mammal
164	*Psiduim quajava* L.	Myrtaceae	Psqu	Tree	+	+	+	Mammal
165	*Pycnanthus angolensis*	Myrtaceae	Pyan	Tree	-	+	-	Wind
166	*Syzyguim* sp	Myrtaceae	Sysp	Tree	-	+	-	Mammal
167	*Elaies guineense* Jacq.	Palmae	Elgu	Tree	+	+	+	Rodent
168	*Trema orientalis* (L.) Blume	Ulmaceae	Tror	Tree	+	+	-	Mammal
169	*Ceiba pentrandra* (L.) Gaertn.R.	Bombacaceae	Cepe	Tree	-	+	-	Wind

* **+** = Present; - = Absent.

Table 5. Mean Climate data (1982 to 2002) for Bibunde, Mokundange, and Ekona Palms weather stations.

MONTH	1922			1959			1999		
	Rainfall (mm)	Humidity (%)	Temp. (°C)	Rainfall (mm)	Humidity (%)	Temp. (°C)	Rainfall (mm)	Humidity (%)	Temp. (°C)
Jan.	83.10	82.20	26.80	21.60	86.70	27.30	64.30	81.70	27.20
Feb.	94.20	83.30	27.40	55.20	85.20	27.20	223.80	82.90	27.80
Mar.	150.10	81.90	27.70	77.50	86.30	27.60	164.90	83.80	27.80
Apr.	234.20	82.80	27.40	148.50	84.10	27.40	256.50	83.80	26.90
May.	366.90	84.60	27.43	176.00	85.70	27.40	348.60	85.20	29.90
June	844.50	87.30	26.80	156.60	87.40	27.60	676.70	87.20	26.10
Jul.	1052.90	89.60	25.60	237.80	87.40	27.00	858.90	89.00	25.00
Aug.	832.30	91.00	24.80	264.30	86.30	27.00	906.20	90.60	25.00
Sep.	891.50	89.80	25.90	195.50	90.00	26.70	588.50	89.90	25.40
Oct.	747.90	86.80	26.30	178.10	86.60	27.00	279.80	86.60	25.60
Nov.	365.60	85.40	26.50	79.40	87.00	27.30	125.50	86.10	26.00
Dec.	63.50	83.50	26.80	28.20	86,80	27.00	443.10	83.80	26.00
Mean monthly	477.23	85.68	26.62	134.89	86.61	27.21	411.40	85.88	26.56
Mean annual	5726.70			1618.70			4936.80		

Table 6. Chemical analysis of soil from some selected lava flows on Mt Cameroon (1922, 1959, and 1999).

Site	pH H_20			pH KCl			Organic carbon (%)			Total nitrogen (%)			Available P (%)		
	1922	1959	1999	1922	1959	1999	1922	1959	1999	1922	1959	1999	1922	1959	1999
Centre	4.2	6.53	6.87	4.31	5.39	5.80	11.10	2.22	0.74	3.53	1.24	0.29	19.30	14.38	13.57
East flank	5.31	5.74	5.46	4.66	5.10	4.85	4.44	7.78	3.33	1.65	1.84	2.20	21.88	19.69	11.38
West flank	5.05	6.60	4.80	4.55	5.80	4.48	3.70	6.76	5.14	2.40	1.85	3.90	27.13	26.67	19.25
Front	-	4.78	6.49	-	4.40	6.49	-	5.56	5.19	-	2.79	2.53	-	13.13	43.75

Site	Ca			Mg			k			Na			CEC			Base saturation (%)		
	1922	1959	1999	1922	1959	1999	1922	1959	1999	1922	1959	1999	1922	1959	1999	1922	1959	1999
Centre	2.72	1.32	1.11	0.56	0.32	0.16	1.44	0.18	0.45	0.08	0.03	0.05	4.81	1.88	1.77	9	8	8
East flank	2.89	9.84	1.01	1.16	1.32	0.14	0.28	0.59	0.07	0.01	0.03	0.04	3.34	11.78	1.31	13	25	6
West flank	2.42	9.38	1.70	0.44	2.41	0.13	0.28	1.25	0.15	0.03	0.03	0.02	3.19	13.07	2.00	11	27	7
Front	-	3.21	9.19	-	0.45	2.00	-	0.28	0.96	-	0.04	0.03	-	3.98	12.18	-	17	35

with pH, total N, and organic carbon, while PC3 was closely related to pH, CEC, total N, and available P.

The principal component analysis of soil data in relation to vegetation establishment and sites showed that the main soil parameter that affects vegetation establishment on the three lavas was organic carbon

DISCUSSION

The results of this study demonstrate that vegetation development during primary succession depends upon climate as well as the age of the substrate which in turn affect soil formation. The 1922 lava flow had the highest rainfall (5726.7 mm) with the largest vegetation cover while 1959 lava flow had the lowest rainfall (1618.7 mm). Its vegetation cover is higher than that of the 1999 lava flow with an annual rainfall of 4938.6 mm because of its age. This trend was also reflected in their temperature ranges with the highest in Ekona (1959 lava flow). The rainfall pattern in west region is mono-modal and high especially in Idenau and Debunscha. The east flank of Mount Cameroon where the 1959 lava flow (Ekona) is found has a bimodal rainfall pattern with a severe dry season in December and January. The mean annual rainfall is 1618.70 mm. The amount of rain is greatly influenced by the distance of the site from the west coast. Debunscha is 11 km from the 1922 and 1999 lava flows while it is about 40 km from the 1959 lava. Due to the high precipitations, the soils do not completely get dry in the 1922 and 1999 lava flows. This is not the case with the 1959 lava flow where succession is influenced by harsh environmental conditions of drought and /or exposure (Mathew, 1992). Surface soil properties dramatically affect establishment and survival of plants in primary succession (Jampponnen et al., 1999; Cable and Cheek, 1998).

The Orchidaceae was the most abundant family but was not recorded on the 1999 lava flow four years after the eruption (Fonge et al., 2005; Fonge, 2004). This was in contrast with the findings of Ndam et al. (2002). They reported after a survey conducted in 1995 that 90% of the orchids only disappear in the third stage of succession. The absence of orchids may be due to the fact that these plants had not had proper microsites for establishment in the 1999 flow (Focho et al., 2010). During ecosystem development on a new substrates like volcanic eruptions, all phosphorus needed by the plants are obtained from primary minerals slowly released from weathered rocks unlike nitrogen that is brought over time from biological fixation and atmospheric deposits (Aplet and Vitousek, 1994; Mvondo, 1991; Vitousek, 2004). According to Jumpponen et al. (1999) and Raich et al. (2000), primary succession is controlled by both biotic and abiotic factors, while Hulme (1997) and Houle (1992) state that it is under strict abiotic control. Jumpponen et al. (1999) reported that vegetation establishment depends on the ability of the site to trap seeds or vegetative propagules. However, there must be existing seed banks for there to be plant recruitment. Bigwood and Inouye (1988) reported that the abiotic factors in primary successional environments are also seen in the prevalence of wind-dispersed propagules whose distribution is controlled by environmental factors after the seeds have been released from the seed source.

The first re-colonization studies on lava flows on Mount Cameroon were by Rosevear in 1936 to 1937 on the 1922 lava flow (Keay, 1959). It has been reported that the rough jagged surfaces of a’a lavas provide more safe sites for germination and establishment of vegetation than the smooth, ropy surfaces of pahoe-hoe lavas. Juvik and Merlin (2001) and Jumpponen et al. (1999) reported that the type of the lava also affects colonization patterns. According to Van der Valk (1992), Juvik and Merlin (2001) and Fonge et al. (2005), the pahoe-hoe lava favours plant diversity more than the a’a lava. Jumpponen et al. (1999) found that sites with concave surfaces, coarse substrates and in the vicinity of large rocks are more likely to be colonized by pioneer plants. The 1999 and 1959 a’a lava substrate surfaces provide more safe sites than the 1922 lava. This is in accordance with our findings which report the presence of 117 plant species on the 1959 lava flow and only 103 species on the pahoe-hoe flow of 1922 in spite of the age and climate differences that would favour the 1922 lava flow. This difference in diversity can be partially due to the abundance and variation of sites provided by the 1959 lava flow (Jumpponenen et al., 1999). However, the species cover and species diversity for the 1922 lava flow were much higher than for the 1959 lava flow. Fonge (2004) and Fonge et al. (2005) reported that this could be because the cracks and fissures in the pahoe’hoe lava favour accumulation of rain water, and inorganic and organic matter. Colonization on the lava flows of Mount Cameroon follow patterns similar to those described elsewhere (Leonard, 1958; Del Moral and Wood 1993a, 1993b; Raich et al., 1997; Chadwick et al., 2003). It proceeds from low to high altitude and from old to young substrates, favouring a’a lavas. The pahoe-hoe cracks have thermal properties that are conducive for plant growth. This may be due to the persistent cloud cover and mist coupled with high rainfall, temperature and distance from the sea coast (Payton, 1993; Suh et al., 2008; Njome et al., 2008).

The continuous accumulation of organic materials on the topsoil over the years, from pioneer species (bryophytes, ferns, orchids), litter from trees and shrubs and dead macro and micro organisms could be responsible for the regeneration of the vegetation cover in the different lava flows (Wada, 1989). This fact was also supported by the principal component analyses which showed that organic carbon was the principal driving factor promoting the vegetation cover. The humic substances from the decay of organic materials aid in weathering of the parent rock and thereby increasing the amount of silt and clay in the soil. Allison (1973) also reported that increase in organic matter increases the rate of colonization.

Conclusion

The edaphic factors and climate (temperature between 24.8 to 29.9°C and rainfall between 21.6 to 1052.9 mm) play very vital roles in the colonization process on Mount Cameroon. The age, type and number of plant species tend to improve the nutrient levels of the soil although the plants are selective of the type and amount of nutrients utilized. The soil pH is slightly acidic and tends to break down parent rock materials. Growing roots of trees also tend to break down parent rock materials releasing nutrients.

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