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Dynamics of nutrients in slash and burn agroforestry in Koli National Park

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PAGE OF CONTENTS

ABSTRACT

The results and conclusions of a pro gradu thesis about slash and burn management "Kaski" of Koli are presented here as a summary. The aim of main study was to get to know if and how the fire modifies the quantity of available nutrients (P, K, Ca, Mg, Mn, Fe, Al, Cu, and Zn), total N, organic matter contents and if it produces a change in the pH. Finally, differences and analogies between this Finnish boreal forest slash and burn system and the tropical ones are showed, emphasizing in the Amazonas basin's cases. In this presentation the effects on pH, total N and Ca are reported and discussed more in details.

Keywords: Agroforestry, slash and burn, swidden agriculture, fire, boreal forest, kaski, soil nutrients, nitrogen, pH, calcium.

1. INTRODUCTION

1.1 Background

Agroforestry is an age-old land use that has been practised for thousands of years by farmers over the world (MacDicken and Vergara 1990). Between its different definitions, Nair (1993) relates the following that International Centre for Research in Agroforestry ICRAF considers the most useful and is wide accepted. Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management unit as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economic interactions between the different components (Lundgren and Raintree 1982, Nair 1993).

Research about slash and burn agroforestry is mainly done in the tropics. Nye and Greenland (1960) review nutrient cycle in tropical soils, restoration of fertility under the fallow and changes in soil fertility during and after shifting cultivation. Other representative publications on different aspects of tropical soil rehabilitation and soil properties include issues of Sanchez (1976), Toky and Ramakrishnan (1983), Jordan (1985), Uhl (1987), Brubacher et al. (1989), Nakano and Syahbuddin (1989), Proctor (1989), Van Reuler and Janssen (1989), Moberg (1990), and Szott et al. (1999).

There are some studies about that topic in boreal conditions too. Viro (1969) studied the effect of prescribed burning on soil properties in Finland. Kuusela (1990) studied the dynamics of boreal coniferous forests with special attention to the effect of fire in them. Finer (1989) and Piirainen et al. (2000) studied leaching processes of different nutrients in boreal conditions. Salo (in this proceedings) is studying the effects of fire on soil and biodiversity of flora and fungi on a "huuhtakaski"-type slash and burn area in Koli National Park.

Slash and burn, called also as swidden cultivation, in Finnish “kaski”, was a common practice in Europe during the prehistoric age. References about it are presented in the stories of Kalevala, Finno-Ugrian mythology (Lönnrot 1876). Slash and burn agriculture in Finland was used in the past until the beginning of 20’s century. It can be divided into two main types: the so-called “huuhta” slash and burn (mainly spruce forest) and deciduous forest slash and burn agriculture (Salo 1997).

The process begins in one year before the fire when the forest (spruce forest in “huuhta” or deciduous species) is cut down in the best position to favour the burn. After one year, during next summer around the Midsummer-day called in Finland as “Juhannus” -day, 24^{th} of June, the area is burned and planted with rye or swidden turnip during the next 1-2 years. After that the area is abandoned and grasses, hay and a new forest begins to grow composed mainly of pioneer species like birch (Betula sp.), aspen (Populus tremula) and alder (Alnus incana). Later this area is grazed with cattle and burned again after 20-30 years or more depending on the site fertility and the availability of land and forest in the area (Sarmela 1987).

In this work it is necessary to consider that I study one short time period (fires between 1994-2000) of slash and burn in Koli National Park. On other hand, because I used also different areas outside the time range of latest fires for comparison, it means that it is not a temporal sequence and we could find some variations due to the spatial characteristics of each area.

1.2 Aims of the study

The aim of this study was to investigate the effects of slash and burn as a landscape management method upon the dynamic of nutrients. The main hypothesis of the study reported here was as follows:

(1) Fire in connection to slash and burn agriculture has an effect in the quantity of available nutrients (N, Ca), organic matter contents and produces a change in the pH (Viro 1969).

2. DESCRIPTION OF THE STUDY AREA

The studied area lies in the Northern part of the Koli National Park in municipality of Lieksa, Region of North Karelia in eastern Finland (figure 1). The area has been under slash and burn cultivation until early 20th century. The Finnish Forest Research Institute has started a new cultural heritage program here with annual burnings in the year 1994. The chosen areas are located at four different locations in the Koli NP area (figure 2).

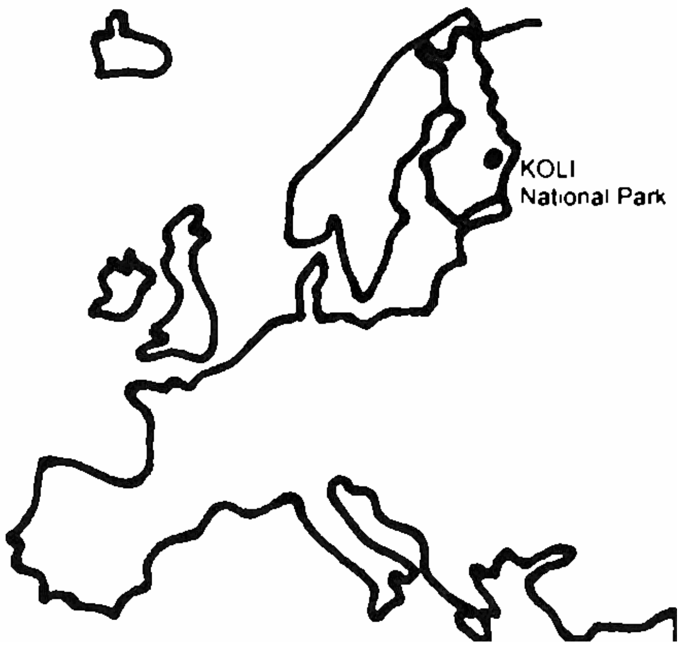

Figure 1. Study area: Koli National Park in eastern Finland.

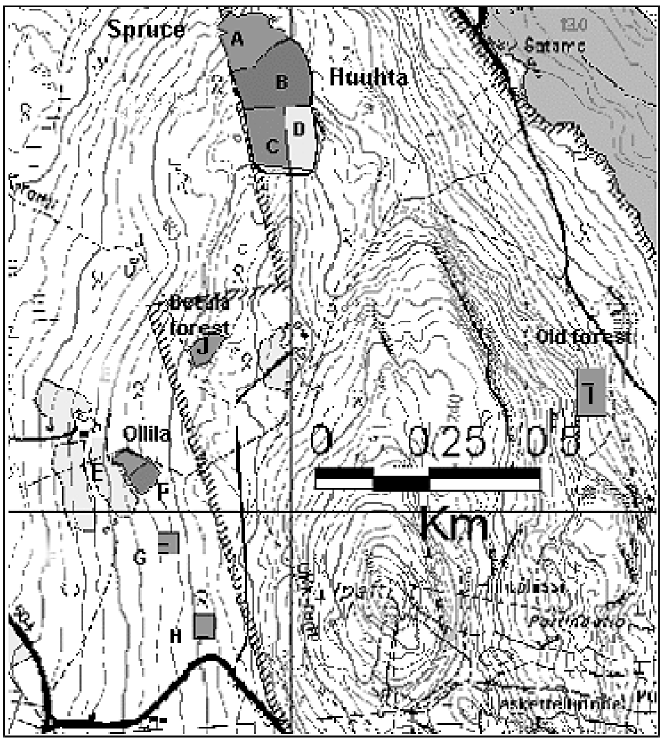

Figure 2. Study areas in Koli National Park.

Table 1. Description of the studied sites.

Subareas Number-code	Name of site	Year of burn	Orientation	Area ha	Slope %	Dominant tree species	Site type	Burned timber m^3/ha	Swidden cultivation
1-A	Spruce	Appr. 1880	N	-	5	Spruce	Myrtillus	-	-
2-B	Huuhta	1998	N	1,9	10	Spruce	Myrtillus	100	Rye
3-C	Huuhta	1994	N	1,1	5	Spruce	Myrtillus	100	Rye
4-D	Huuhta	1996	N	0,9	25	Spruce	Myrtillus	100	Rye
50-E 51-E	Ollila	<1880 2000	W	0,2	5	Spruce	Oxalis-Myrtillus	60	Rye
6-F	Ollila	1999	W	0,3	5	Spruce, birch	Oxalis-Myrtillus	60	Turnip
7-G	Ollila	<1880	W	-	10	Spruce, birch	Oxalis-Myrtillus	-	-
8-H	Ollila	<1880	W	-	10	Spruce	Oxalis-Myrtillus	-	-
9-I	Old forest	<1800 or never	NE	-	30	Spruce	Oxalis-Myrtillus	-	-
10-J	Betula	1995	NW	0,3	15	Birch	Oxalis-Myrtillus	-	Rye

3. METHODS

3.1 Soil sampling

The soil samples were taken of all the 10 subareas in June of 2000. From area E, which was burned in that year, another sample was collected in October on the same year. There were ten repetitions per each area or slash-and-burn status (area E which was burned in 2000), which means a total of 110 holes. Material was taken from the two mineral layers (eluvial and illuvial) and the humus layer.

In the laboratory of the Finnish Forest Research Institute, Joensuu Research Centre, pH, N, Organic Matter, P, K, Mg, Ca, Mn, Fe, Al, Zn and Cu were analysed. I am going to present in this report just pH, N and Ca. The pH was measured from dry material in water suspension by Radiometer PHM220 pH-meter, total N was analysed with the Kjeldahl method using Tecator 2020 digestor, Gerhardt Vapodest 3S Distilling unit, and titration with METROHM 645 Multi-dosimat. Exchangeable cations were analysed by flame atomic absorption spectrophotometer Perkin Elmer “Ms Elisabeth”, from acid ammonium acetate (pH 4.65) extract.

3.2 Statistical work

For analysing the effect of burning, the subareas were divided into three groups having different time periods from the last burning (table 2). The statistical analyses were done with the program SPSS 1999 for Windows.

The statistical hypothesis was that there are significant differences between the groups in every nutrient because of the fire. The histogram show that the distribution was not normal for every nutrient and so the test used was non-parametric Kruskal-Wallis and the Mann-Whitney test for testing the differences between the group averages. Other calculations and graphics were done by using Microsoft ® Excel 97 SR-2.

Table 2. Studied areas in groups of burning age.

Old burnt or non-burnt areas	Middle time burnt areas	Recently burnt areas
Old growth forest, burnt before 1850 or never	Area burnt in 1996	Area burnt in 2000 after fire
One hundred years old pure spruce stand, burnt before 1880	Area burnt in 1995	Area burnt in 1999
One hundred years old mixed stand, burnt before 1880	Area burnt in 1994	Area burnt in 1998
Spruce forest burnt in 1880´s		
Spruce forest to be burnt in 2000, burnt earlier before 1880, status before the fire in 2000		

4. RESULTS

4.1 Changes of pH

In the Ollila -area the pH of humus layer increased in the area E after fire 0.24 pH units compared to measurements before burning. This was 0.38 units higher level compared to unburned spruce dominated subarea 9-I (table 3). Looking at the variability of pH, an increase in the amplitude of values was found after the fire. In the eluvial or illuvial layers no effect of fire could be found in Ollila -area just after the fire (table 3).

Table 3. pH and its variation in different soil horizons in the subareas of Ollila area and never burnt old forest stand.

Area		**Humus**		**Eluvial soil**		**Illuvial soil**	
Code	**Status of burn**	**x**	**s**	**x**	**s**	**x**	**s**
50-E	Before burning in 2000	4,16	0,10	4,15	0,14	4,51	0,22
51-E	After burning in 2000	4,40	0,32	3,91	0,10	4,13	0,13
6-F	Burnt in 1999	4,20	0,35	3,98	0,09	4,32	0,17
7-G	Burnt before 1880	4,43	0,13	4,28	0,16	4,81	0,18
8-H	Burnt before 1880	3,80	0,10	3,93	0,11	4,43	0,33
9-I	Never burnt	4,02	0,18	3,87	0,17	4,69	0,18

In the Huuhta -area (table 4), the values of pH and their variability in the recently burned subareas (1998, 1996, and 1994) are higher than in the unburned area (Area 9-I) and the subarea burned in 1880´s (Area 1-A). The difference in humus layer was about one pH unit between the most recently (1998 and 1996) burned subareas and the subareas burned in 1880´s or the values in the old forest. The variation of the pH values was highest in the subareas where also the pH was highest.

Table 4. pH and its variation in different soil horizons in the subareas of Huuhta -area and never burnt old forest stand.

Area		**Humus**		**Eluvial soil**		**Illuvial soil**	
Code	**Status of burn**	**x**	**s**	**x**	**s**	**x**	**s**
2-B	Burnt in 1998	4,93	0,32	4,18	0,10	5,17	0,32
4-D	Burnt in 1996	5,18	0,49	4,38	0,20	4,66	0,15
3-C	Burnt in 1994	4,55	0,43	4,90	0,48	4,68	0,15
1-A	Burnt in 1880´s	3,83	0,21	3,94	0,13	4,65	0,14
9-I	Never burnt	4,02	0,18	3,87	0,17	4,69	0,18

In the illuvial layer pH was higher than in eluvial layer, as usual. Concerning the effect of fire, nothing special was detected in Ollila (table 3). The subarea burned in 1998 in Huuhta-area (table 4) showed a higher pH value than the other areas. The mixed species stand (7-G) presented higher pH values than pure spruce stand (8-H) in all the layers.

4.2 Nitrogen

The results showed that there were significant differences in nitrogen concentration between all the three age groups in humus layer (table 5). The highest average was 1.81 % in recently burned subareas and lowest in some years ago burned subareas.

Table 5. Average values of soil characteristics of humus layer in different burning age groups and their statistical comparison.

Characteristic	Unit in dry matter	Burning age group			Kruskal-Wallis Test		Significant differences Mann-Whitney Test(2)
		Old (a)	Middle (b)	New (c)	Chis-Square	AS Kruskal-Wallis Test(1)	
N	%	1,29	0,88	1,81	23,863	0	ab, bc, ac
Ca	g/kg	1,66	4,33	3,94	33,699	0	ab, ac
OM	%	58,72	41,88	63,95	14,278	0,001	ab, bc
N/OM	% in OM	2,23	2,39	2,72	10,379	0,006	ac
OM	kg/ha	49961	35158	59507	9,038	0,11	
N	kg/ha	1207	912	1797	6,135	47	

(1) Asymp. significance (p) between all groups.
(2) Significant differences (p<0,05) between pairs of groups.

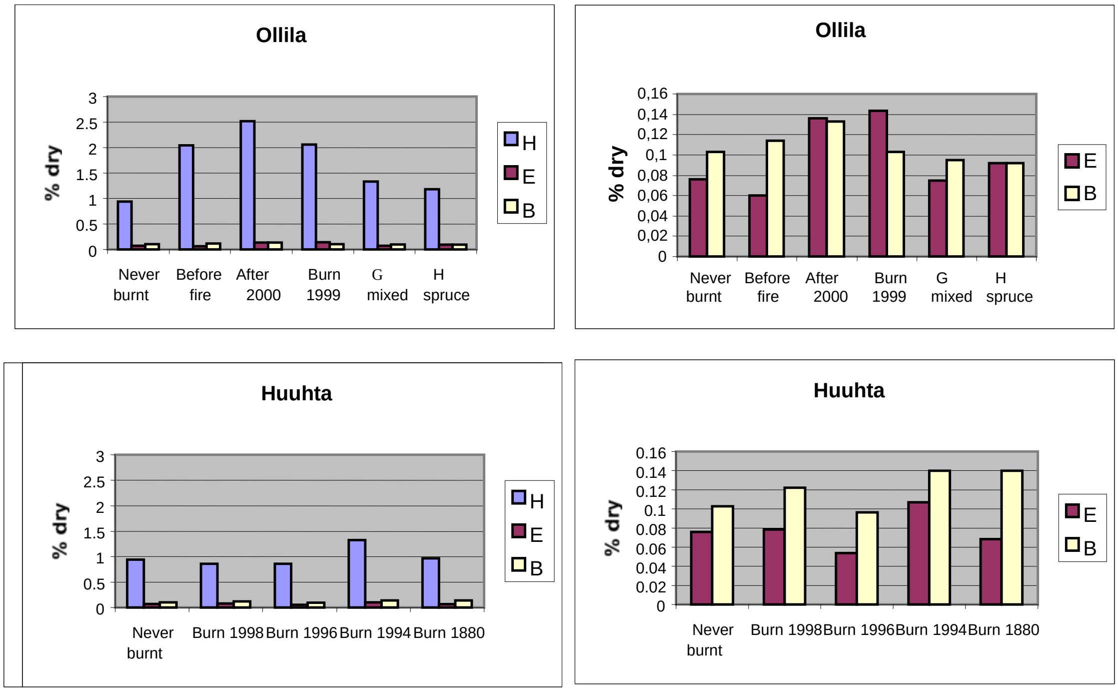

Figure 3. Concentration of total Nitrogen (% of dry matter) in humus (H), eluvial (E) and illuvial (B) layers in different subareas of the areas, Ollila and Huuhta, and in the never burnt old forest stand.

In Ollila -area, it was found an increase of N concentration from 2 % to 2,5 % because the fire. One year after the fire, the concentration level was the same than before the fire (figure 3). In the other area (Huuhta) the percents were even lower than in the old forest in the 1998 and 1996 burnt subareas and there was a higher concentration at 1.3 % in the subarea that was burned in 1994. Finally in 1880's subarea, the level was again near the old forest situation, around 1 %.

It is more clear to present the results in kg of nitrogen per hectare in the humus layer (table 4, figure 4). Significant difference could only be found between some years ago burned subareas group and recently burned subareas group, which were also located on separate areas and had different site conditions and efficiency in burning.

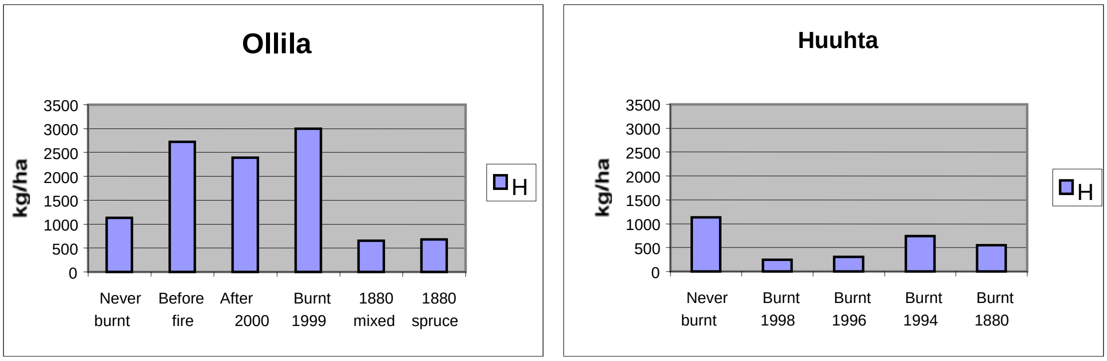

Figure 4. Total Nitrogen (kg/ha) in humus (H) layer in different subareas of Ollila and Huuhta, and in the never burnt old forest stand.

In the eluvial horizon, in Ollila (figure 3), the new burned subareas presented higher levels of N in dry material than the others, with the highest value in 1999's one with 0,14 %. The lowest was in the situation just before fire in 2000 with 0.06 %. In Huuhta -area, there existed no important differences, only with the lowest concentration in 96´s one.

In the illuvial horizon, no significant difference between the groups was registered. Nitrogen contents were about the same level than in eluvial horizon.

4.2.1 Calcium

In the humus layer, the results showed a high increase in exchangeable calcium content just after the fire (figure 5). Calcium content did not differ very much from the recently burned subareas to the some years ago burned subareas, but in all of them it was significantly higher than on reference groups (table 5).

For all the layers, in the forests where fire had not been visiting during at least the latest 120 years, higher contents of calcium could be found in mixed than in pure spruce stands. In the eluvial layer, Calcium showed an increase from 0,02 g/kg before fire, to 0,04 g/kg just after the fire and 0,065 g/kg one year after the fire in Ollila area. In the Huuhta -area, the trend showed a continuous increase till 1996's one with the peak of 0,15 g/kg. After that, it begun a decrease to 0,1 % in 1994 burnt subarea. This decrease continued and in the 1880´s burned subarea the contents were 0,01 grams of calcium per kilogram of dry soil. It is important to notice here the high calcium content in the never burned forest, which can probably be a sign of different parent material of the soil in this area (figure 5).

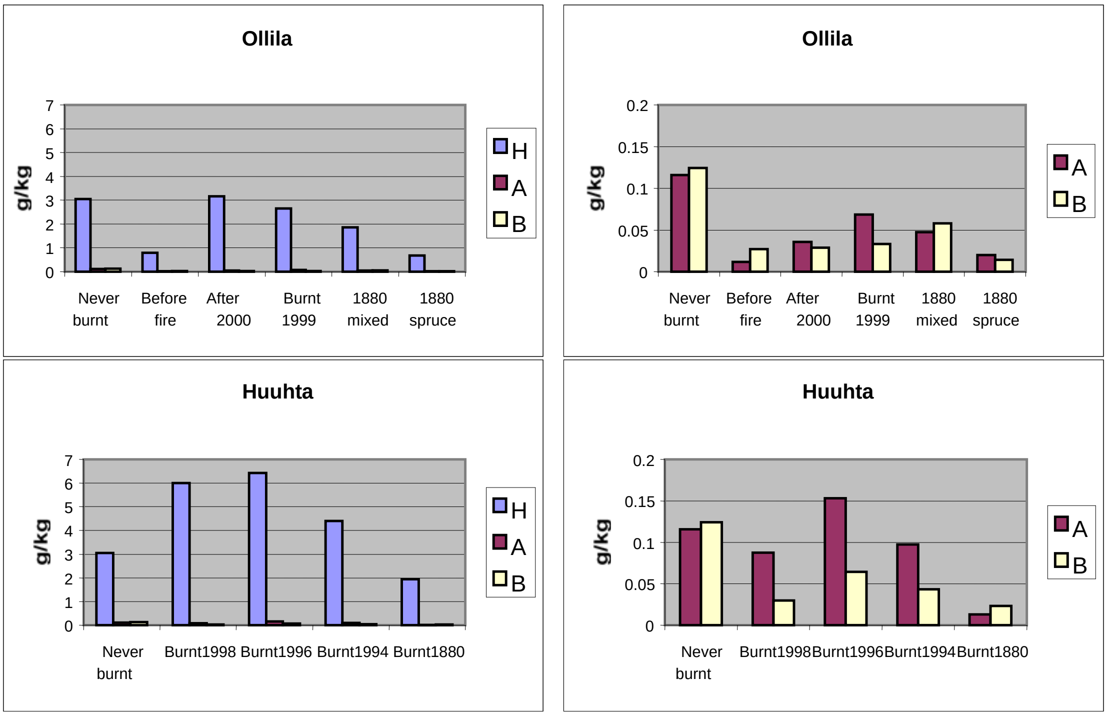

Figure 5. Concentration of soluble Calcium (g/kg in dry matter) in humus (H), eluvial (E) and illuvial (B) layers in different subareas of the areas Ollila and Huuhta, and in the never burned old forest stand.

In illuvial layer there were not any important differences in Ca in Ollila. In Huuhta area, we found an increase of Ca some years after burning (figure 5).

5. DISCUSSION

5.1 Burning process

The effectiveness and rate of mineralization of the fire depends on the previous conditions of the site and the burning process itself. Sanchez (1976) reported that farmers in the Amazon assess the quality of the burn and predict how god the crop will be on that basis. In Huuhta, especially on the years 1996 and 1998, the fire was very strong and there was a high reduction (20-30 mm) of the thickness of the humus layer. The quantity and concentration of organic matter after fire was lower than before fire. In Ollila, the burning process was less effective because of the lower amount of burned wood, more residues were left unburned and the higher humidity of the humus during the burn (only 4 dry days without rain) and consequently the ratio of mineralization of organic matter was lower and there was only a weak increase of pH and nutrient contents.

The thickness of the initial humus layer of the site before burning is an important factor because of its effect on the moisture retention. High moisture in humus produces extra need of energy for drying the material and decreasing the final quantity of humus layer that will be burned (Viro 1974). In Ollila the depth of humus layer originating mostly needles of spruce averaged about 8 cm. This caused very high retention of water. In Huuhta -area the thickness of humus was lower. Viro (1974) showed that in prescribed burning, the humus layer became slightly thinner as a direct result of burning, decreasing from 5.3 to 4.1 cm. In Huuhta –area this effect was even stronger because of the 100 m^3/ha timber plus the cutting residues left on the area for burning.

The previous weather of the burning episode is other very important factor mainly because it determines the wetting status of the material in the area at the time of burn. Finally the amount of previous biomass determines the burning process and the final quantity of nutrients because more of the biomass before the fire, the more energy for fire and higher quantity of nutrients released and go to the soil (Jordan 1985).

5.2 Changes of pH

The burning process affects strongly to the changes in the pH values. In Ollila because of the conditions before fire, the increase of pH due to fire was very slight. In the area of Huuhta, there was a strong increment (1,3 units) of the pH because of the fire. After that, a trend of decrease in the values for pH was observed in the area burned in 1994 after six years from the burning and this trend may continue at least to the level noticed in the area burned in 1880´s. Notable is that Viro (1974) found the similar trend in prescribed burning, an average increase of about 2 units in pH after fire, and after that the trend was decreasing, faster in the first 7 years after fire and then gradually later. Viro noticed that after 30 years the pH values were similar to the situation before fire. Sanchez (1976) found same trend in tropical conditions.

This trend is due to the process of uptake of the nutrients by the plants, especially cations like calcium, potassium and magnesium, the leaching of cations and because aluminium becomes soluble Al^{3+} (Whitmore 1998). In boreal conditions, the increase of organic matter in the soil, especially spruce needles, contributes to the decrease of the pH in older burned forests (Viro 1974).

The conditions for fire produces an increase in the variability of pH values. The effectiveness of the burning process varies between several subareas, but even more in short distances inside a subarea. It was possible to find a place, where the humus was deeply burned and just some centimeters around, the humus was totally unburned. This fhenomenon conditions the values of pH and creates differentiated microsites making feasible that different species can live there increasing the biodiversity. In Ollila the increase of variability was less than in Huuhta -area because the burning processes were less intense. In Huuhta this effect was found also in the eluvial layer.

The process of leaching of the cations from the top of the humus layer to the deeper soil layers produces a delayed effect in mineral layers compared to the humus. In Ollila it was not detected. However in Huuhta -area, the effect of the fire was clearly visible in deeper layers like in humus layer, but two years delayed.

5.3 Nitrogen

Nitrogen is most often the limiting nutrient in the boreal forest ecosystem (Kuusela 1990). The dynamics of nitrogen in the cycle of slash and burn is very much connected to the cycle of organic matter.

There is a decrease of the quantity (kg/ha) of N after the fire. The fire produces the gasifying of high quantities of nitrogen. Nye and Greenland (1960) had found same trend in tropical conditions, mainly lost from the biomass of the cut trees and the humus burned. Viro (1974) found that in humus there is a decrease of total nitrogen about 100 kg/ha due to the fire in prescribed burning.

With respect to the concentration, an increase of nitrogen was noticed in slash and burn on Koli National Park. The unburned lower part of the humus layer is more decomposed and nitrogen richer than the whole humus layer before burning. Sanchez (1976) observed that not all the nitrogen is lost in the process of burning because not all the vegetation is completely burned in tropical conditions. After that, the downward movement of nitrogen from the decomposing primary trunks and roots replaced nitrogen that had been lost from the soil (Vitousek et al. 1979).The hypothesis that burning has a favourable effect on nitrification was put forward by researchers so from boreal as from tropical conditions such as Heikinheimo (1915) and Hesselman (1917, cit. Viro 1974), Eneroth (1928, cit. Viro 1974), Nye and Greenland (1960) and Jordan et al. (1983). As a whole, the fire increases the nitrogen available for plants and improves site fertility (Viro 1974, Kuusela 1990).

One year after the fire, the content of nitrogen begins to decrease and this trend continues during at least four years after the fire as was found in the present study, in the Huuhta -area. Viro (1969) found that the rapidly decomposing nitrogen compounds disappeared quickly and afterwards the nitrogen compounds were decomposing more slowly than those not containing nitrogen.

Nye and Greenland (1960), Nakano and Syahbuddin (1989) and Wadsworth et al. (1990) described the decline in N levels until the age of 10 years, after which the levels started to increase steadily ending after 50 years of age at values similar to their initial level. In contrast, Toky and Ramakrishnan (1983) found the opposite on soils in North-East India.

In boreal soils the leaching process is not so important like in tropics because the soil is frozen much of the year and the fluxes are not so important like in other lower latitudes (Brinkmark 1980, cit. Helmisaari 1995). Only during the time of snow melting in the spring and some summer storms is leaching active (Helmisaari and Mälkönen 1989).

Fire produces an improvement of the quality of organic matter higher in the eluvial layer. The increase in the pH and the fire produces mineralization of the organic nitrogen that is more soluble and easily leaching to the mineral soil. But in Ollila -area this effect disappeared just one year after fire.

Six years after the fire the analysis showed an increase of the nitrogen in the humus and mineral layers because of the activity of the plants that produces new nitrogen rich humus and the biological nitrogen fixation effect by mycorrhizas (Viro 1969).

5.4 Calcium

Fire produces a high increase of all of the nutrients in the humus layer coming directly from the quantities that were stored in the biomass. All of these materials are deposited in the top of the soil such as oxides of potassium, calcium or magnesium with small amounts of phosphates. There are not losses like in nitrogen or organic matter by gasifying.

Cations showed a cycle in the Huuhta -system very similar to each other with variations due to the different mobility capacity. In general, monovalent nutrient cations, such as potassium, move more quickly than divalent cations, such as Ca and Mg, which in turn move more quickly than polyvalent cations (Sanchez 1976, Jordan 1985).

Just after fire, a leaching of the cations begins. This movement is helped by the big amount of different cations in the topsoil and the absence of high plants that can uptake and store it. When forests are cut and the inhibition mechanisms destroyed, nitrate becomes relatively important in leaching processes. Organic acids are more important in leaching processes in high latitudes (Johnson et al. 1982).

When the disturbance is short-lived, newly establishing vegetation may take up some nutrients in the soil before they are leached. However, if the disturbance is long-term and vegetation regrowth suppressed, nutrient loss through leaching can be significant (Sanchez 1976).

There was a decrease of soluble calcium in the humus layer already one year after the fire but not with the levels found in other cations. Also the increase of soluble calcium in the mineral layer did not begin till later than one year after fire.

Viro (1969) and Piirainen et al. (2000) pointed out similar results, calcium was leached from the humus layer very slowly, only reverting to the control level after 50 years. Viro established a high positive correlation between the amount of calcium and fertility of the site, probably due to the effect of calcium on nitrogen mobilisation. The calcium contents in mineral soil begin to decrease first in the eluvial layer because the processes of uptake in one direction and leaching in the other till recover the original levels. Only after six years of the fire the decrease of calcium becomes significant and at this time the effect of uptake by high plants begins to store the cation obstructing the leaching process. In tropical conditions, researchers such Jordan (1985), Wadsworth et al. (1990) and Szott et al. (1999) found similar trends but with a speeder movement.

Viro (1969) pointed out that there were no increases in the total amounts of calcium and magnesium as there was for potassium in the oldest burned sites. The reason is that new vegetation takes up relatively more potassium than calcium and magnesium, and the liberation of potassium from decomposing new vegetation is faster than that of the latter two nutrients.

The final levels of calcium in the different horizons depend on the species that are in the forest, if there are broadleaf tree species like birch, the levels will be higher in all of them but especially in the humus (Booker tropical… 1984).

6. SUMMARY AND CONCLUSIONS

Agroforestry systems with different particularities are extended around the world from arctic to equatorial ecosystems. An example of that systems in high latitudes is “Kaski”, a slash and burn agroforestry system used in boreal forest area Eastern Finland until the beginning of 20’s century. Now in Koli National Park, lying in North Karelia Region in Eastern Finland, there has been a revival of a new cultural heritage program with annual burnings from the year 1994.

The burning process greatly affected the results of this management, determined by the initial characteristics of the site; amount of biomass, previous weather and thickness of humus layer. Being the fire proper, pH is going to increase about one unit or more and decreasing after that due to leaching processes and uptakes of cations. The amount of total nitrogen per hectare decreases and soluble phosphorus increases after fire. The concentration of soluble cations in the humus layer is increasing due to fire and the increase is going down in the soil profile depending on their mobility.

- The burning process greatly affected the results of the management.
- When the fire and burning biomass is proper, the pH of the humus layer is going to increase about one unit or more.
- The fire produced an increase in the variability of the microsites that can improve biodiversity.
- Fire produced an increase in the concentration of cations in the humus layer.
- The dynamics of the cycle of nutrients is slower in boreal conditions than in tropical ones.
- There was a decrease in the amount of total nitrogen per hectare because of the fire, when the fire had been successful enough.

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