University of Colorado at Boulder

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January 13, 1992

Mark Gershman
Wetlands/Wildlife Coordinator
City of Boulder
Real Estate/Open Space Department
P. O. Box 791
Boulder, CO 80306

Dear Mark,

With the completion of the Fall 1991 semester at CU, the students in my class in Soils have provided some nice data analyses for the soil sampling study we did in the North Boulder Open Space near Foothills Trail. Please find enclosed one full report on the soil results, and a part of another report to give full information on methods of analysis (both by Geography Department graduate students). Also I have included copies of the data and observations for sites sampled in the study.

I greatly appreciate your help in facilitating our class study of the soils of the open space area. The students got a great deal out of the project, and hopefully your department can use the information we came up with in your own projects. I would hope that we can continue our contact through the coming years, for future class projects of mutual interest. If I can be of any further assistance, please do not hesitate to give me a call. Thanks again.

Sincerely,

Susan

Susan W. Beatty
Associate Professor

encl. 2 reports, data sheets

Prof. S. Beatty
U. Colorado
Geography
492-6343

Included to provide more details on Methods

Data Analysis Paper: Soils

Geography 4401/5401, Fall 1991
from paper by Joy Nystrom Mast, graduate student.

Introduction

Differences along a topographic gradient and a vegetation gradient were compared in a partially burned area in Boulder County Open Space. Fine-scale soil forming factors were analyzed by field and laboratory techniques. By concentrating in a small-scale field site, we were able to control for time, climate and parent material soil forming factors. Micro-climatic variables were also examined in relation to soil processes.

Site

The field site is a designated open space area just north of Boulder, Colorado. The area is the limit of a November 1990 fire, and encompasses both burned and unburned conditions. The area is also the boundary between *Pinus ponderosa* forest, at the top of the slope, and grassland vegetation, in the valley region (Table 1). Cacti and succulents, such as yucca, not a succulent!, occur in the lower sections of the site. Grasses are the dominant vegetation of all sampling areas within the site. Some shrubs were recorded in the mid-slope region of the site. The vegetation appears to have recovered from the 1990 fire, with 35 to 90% cover in the burned areas (compared to 25 to 95 % cover in the unburned areas). The burned lower bole of one *Pinus ponderosa*, in area #5, provided direct evidence of the 1990 fire. The topography includes the margin between the plains and the foothills of the Colorado Front Range. The slope angle was between 13.5 and 16 degrees at the upper-most part of the slope, and varied from 5 to 15 degrees in the mid section of the slope (Table 2). The valley has a gentle slope of approximately 4 degrees.

The parent material should be a control factor, with the regional parent material consisting primarily of sandstone. The exact parent material under each sampling point in the site was not determined. The upper sections of the slope were quite rocky, with more pebbles recorded the valley region of the site (Table 1). Drainage gullies were observed only in the lowest valley site.

Field Methods

The soil sampling was designed to take two readings from each of 7 topographic positions along the elevation gradient, one from the unburned section and one from the area burned in 1990. The vegetation gradient follows the elevation gradient, so the forest boundary, transition zone, and grassland all had multiple samples. The site could be divided up into four basic zones: burned forest (upper slope), unburned forest (upper slope), burned grassland (lower slope and valley), and unburned grassland (lower slope and valley). The exact sampling sites within each of the 14 predetermined areas were chosen randomly, using a random numbers table.

Soil samples, taken with a trowel, were four 5 x 5 x 15 (deep) cm blocks that were placed in a labeled plastic bag for future lab analysis. Volumetric soil samples, coded by site number, were also obtained from each of the 14 areas. Observations on soil horizons were recorded for each site, including depth, color, texture, structure, and presence of vegetation roots. The physical properties of the sites, including the slope angle, slope aspect, soil temperature, litter depth, presence of surface obstacles, vegetation cover and characteristics, presence of burned material, and air temperature, were also observed at each of the 14 areas (Table 1 and 2).

Laboratory Analysis

The soil samples were analyzed air-dried, oven-dried, and ashed and summarized in Table 3. Gravimetric moisture was determined on air-dried soil samples and oven-dried soils. Percent moisture was then calculated for each area. Water holding capacity by weight and also by volume (percent pore space) were determined for each of the oven-dried soils. The pH was determined for both the air and oven-dried soil samples using 1:1 water technique. Nutrient analysis determined the milliequivalents of both NH4 and SO4 per 100 grams soil for each sample. Percent organic matter was calculated from comparing the oven-dried and ashed soils weights.

The texture of the soil is summarized on Table 4. The percent of sand, silt, and clay were determined, as well as the percent of coarse fraction material. The bulk densities were calculated from the volumetric field samples.

In order to compare the burned and the unburned areas, the four tables arranged by topographic position were rearranged by listing first the burned sites (still in topographic order) then the unburned sites (Tables 5 through 8). These tables enable comparisons within and between burned and unburned regions.

Geography 4401/5401 - Soils - Class Data - Fall 1991
ofessor Susan W. Beatty

Field samples were taken to either side of the Foothills Trail in north Boulder open space, on the west side of Hwy 36, and extending from the foot of the slope to just below the rock outcrop area above the trail. All samples were in grassland.

SOIL #	SLOPE POSITION	SITE DESCRIPTIONS BURNED/ UNBURNED	OTHER OBSERVATIONS
1	UPPER	U	rocky, oak 100 m away, mostly grass/herb
2	UPPER	B	rocky, grasses
3	UPPER-MID	U	rocky, grass, pine 50 m away
4	UPPER-MID	B	rocky, little litter, grasses
5	MID	U	rocky, grass, pine 5 m above
6	MID	B	rocky, grass, pine 65 m away
7	MID-LOW	U	rocky, grass, shrubs 5 m away
8	MID-LOW	B	rocky, grass, shrubs 30 m away
9	LOWER	U	rocky, grass & shrubs
10	LOWER	B	rocky, grass/herb
11	TOE	U	small pebbles, yucca 1 m, grass
12	TOE	B	rocky, grass
13	VALLEY	U	small pebbles, cactus, grasses
14	VALLEY	B	small pebbles, drainage area, grass & cactus

SOIL #	SLOPE ANGLE	SLOPE ASPECT	SOIL TEMP	AIR TEMP	% BARE GROUND
1	13.5	118	18	16	50
2	16	80	18	16	50
3	5	46	18	18	5
4	8	136	17	18	10
5	17	198	17	17	10
6	14	160	19	16.5	30
7	16	74	17	21	50
8	18	140	19	20	65
9	22	10	16	18	75
10	14	120	20	16.5	50
11	15	350	19	17	30
12	7	146	20	18	20
13	4.9	57	19.3	21.5	50
14	3.75	246	21	21.5	60

taken
ca. 3:30pm
Mon. Sept 30, 1991

Beatty
Geography, CU

Pw = Percent water
WHC = Water Holding Capacity
%PS = percent pore space [%PS = %WHC by volume]
meq = milliequivalents
%OM = Percent Organic matter content
NH4 = ammonium; SO4 = sulfate ions

SOIL #	Pw AIRDRY	by weight % WHC	%PS (by volume % WHC)	AIRDRY 1:1 WATER pH	OVEN DRY 1:1 WATER pH	meq/ 100 g soil NH4	meq/ 100 g soil SO4	% OM
1	15.55	31.08	28.75	6.58	6.41	0.304	0.128	8.71
2	21.77	23.33	28.58	6.93	6.54	0.092	0.069	9.16
3	20.91	42.33	42.26	7.02	6.49	0.148	0.093	10.18
4	15.04	40.61	31.1	6.78	6.65	0.000	0.048	8.02
5	19.23	46.15	36.87	6.2	5.76	1.150	0.330	10.93
6	21.17	44.07	52.26	6.95	6.73	0.120	0.133	9.74
7	19.82	44.71	32.35	7.28	6.84	0.248	0.125	8.08
8	18.03	29.41	22.78	8.47	8.2	0.020	0.080	6.24
9	15.62	28.75	35.51	7.91	7.69	0.000	0.095	6.58
10	13.58	38.88	45.07	7.19	7.31	0.000	0.089	8.85
11	16.66	44.86	40.26	8.53	8.13	0.004	0.081	7.76
12	18.22	37.99	35.2	8.49	8.42	0.940	0.101	7.69
13	15.86	7.2	9.2	6.85	6.77	1.230	0.129	6.63
14	15.9	33.3	38.5	7.74	7.94	0.380	0.149	6.95

SOIL #	BD	% COARSE	% SAND	% SILT	% CLAY	% SILT +CLAY
1	0.95	0.75	34.62	44.32	21.06	44.32
2	1.20	31.38	81.11	7.92	10.97	18.89
3	0.79	8.61	82.50	10.83	6.67	17.50
4	1.13	2.60	61.45	17.86	20.69	38.55
5	0.77	8.92	73.78	16.19	10.03	26.22
6	1.28	4.87	64.75	22.78	12.47	35.25
7	0.85	36.15	86.39	6.80	6.80	13.61
8	0.77	19.21	88.94	5.53	5.53	11.06
9	1.38	19.73	86.82	7.28	5.90	13.18
10	1.03	13.24	81.41	7.56	11.03	18.59
11	1.07	18.10	65.52	13.27	21.21	34.48
12	1.04	9.02	65.80	20.90	13.30	34.20
13	1.34	10.97	55.99	28.95	15.06	44.01
14	1.47	8.35	68.47	18.36	13.17	31.53

BD= Bulk Density [weight soil/ volume soil]

Coarse is > 2 mm
Sand is .02-2 mm
Silt is .002-.02
Clay is <.002 mm

Percentages are expressed by weight.

Geography 4461/5461
Fall 1991
Professor S.W. Beatty
492-6343

NATURE AND PROPERTIES OF SOILS

DATA ANALYSIS PAPER

SOIL VARIATION ALONG A TOPOGRAPHIC GRADIENT OF BURNED AND UNBURNED GRASSLANDS IN THE COLORADO FRONT RANGE

Thomas Kitzberger
Graduate Student, Geography

INTRODUCTION AND METHODS

The variation in soil properties and its relationship with climatic, topographic and disturbance characteristics was investigated in a grassland area of the Colorado Front Range. 14 sampling points were selected over a hill slope from the valley to the upper slope. Sample pairs were placed at similar topographic positions on areas burned on the previous summer and on areas without sign of being recently burned. At each point topographic position, slope angle, slope aspect, ground vegetation cover and distance to the nearest shrub/tree helped to characterize the sample. In situ measurements were soil and air temperature and visual structure and texture determinations as well as colorimetric pH determinations. One soil sample was extracted for most of the lab measurements. Additional fixed volume samples were taken for bulk density determinations and gravimetric water determinations. Lab measurements included air and oven dry/ water pH measurements, NH_4 and

SO_4 colorimetric determinations, organic matter measurement, water holding capacity, pore space and bulk density determinations, gravimetric water measurement and textural component determination (for procedures see Laboratory Manual for Soils).

RESULTS AND INTERPRETATION

The effect of topography

Fig. 1 shows the variation in slope angle along the chosen topographic gradient from the upper slope (samples 1 and 2) to the valley (samples 13 and 14). It can be observed that the slope is not constant and does not define a smooth gradient of one main drainage basin. In contrary, it shows a slope divided into two main slope gradients (fig. 2): ZONE 1. the upper to mid slope zone with decreasing slope angle towards samples 3 and 4, and ZONE 2. mid-low position to the valley were the slope increases again in samples 7 and 8 and decreases towards the lower valley samples. By increased weathering and material transportation it is expected that areas of steeper slope angles to have coarser material whereas we expect to find the fine material concentrated in flatter areas. Our data show a trend of increased coarse material(fig.3) and sand (fig. 4) correspondent with areas of steeper slopes of zone 1 and zone 2 (fig. 2) and increased silt (fig. 5) and clay content (fig. 6) in flatter ares of zones 1 and 2. The relationship between slope angle and texture characteristics is reflected in the trends in fig. 7 were the % coarse fraction increases abruptly at angles > 14 degrees whereas the clay content decreases.

Measured soil temperature at the time of sampling also shows a topographic influence. The altitudinal gradient apparently determined slightly higher temperatures towards lower elevations. This was particularly evident in the more homogeneously sun-exposed burned samples (fig. 8). To evidence the effect of aspect on soil temperature slopes of angles higher than 14 degrees where plotted as function of aspect. Fig. 9 shows a temperature gradient from southeast- facing slopes with high soil temperatures through east-facing slopes to cold north facing slopes.

The influence of fire and vegetation

The principal problem in assessing the influence of fire was the uncertainty of the area affected by the last fire. In addition there had been previous fires in the area as evidenced by scars and recently burned bark in the surrounding pines. Therefore, even if the samples were correctly positioned with respect to the last years fire, it is not possible to separate it from the influence of other previous fires that probably did not affect the same area.

Samples 3 to 8 are considered as the most reliable in terms of the delimitation of the most recent fire.

The main pattern found in relationship to fire is the loss of NH_4 probably via volatilization. Fig. 10 shows that most of the burned samples showed lower % NH_4 than the unburned. this is particularly true for the samples 3 through 8 where the fire limits were more marked. Within unburned plots, NH_4 was (with exception of samples 1 and 11 that may have burned) directly correlated with clay content in the soil, in other words with higher CECs (fig. 11).

As fire affects vegetation, it indirectly affects factors that are related to the vegetation. Plants by litter production have strong effect on organic matter accumulation. Fig. 12 shows the relationship between % bare ground and the organic matter present. Higher vegetation cover means higher litter input and probably slower decomposition due to lower soil temperatures. Samples 3 - 8 showed higher organic matter content in unburned samples (fig 13). This may be explained by a higher litter production in later successional stages. Directly correlated to high organic matter content, was a high SO_4 content for these unburned samples (3-8) (fig. 14). Positive charges in the organic matter may be favoring the retention of SO_4 anions.

Organic matter on the other hand has a relatively strong influence on the soil pH (fig 15). Higher organic matter contents have apparently an acidifying effect, particularly in conifer areas. Fig. 16 shows neutral or slightly acidic pHs in the higher elevations where the influence of conifer litter is probably stronger (samples 1-6). The input and accumulation of organic matter and humus in the soil may be increasing the soil's CEC. Therefore a double effect of increased acidification and increased nutrient availability takes place. Fig. 17 shows that neutral to slightly acidic soils contained higher NH_4 and SO_4 concentrations.

Finally the organic matter or indirectly the vegetative cover may be playing an important role in maintaining water in the soil. Both vegetation and litter can act as natural "mulching" and prevent loss by evaporation. Fig. 18 does not show a clear linear relationship, however it is evident that soils with organic matter percentages > 9% showed significantly higher water content.

Textural effects on water availability soil aeration

As discussed before texture is strongly influenced by topographic variables affecting weathering and transport of particles. In this part I examine the contribution of texture on soil variables, particularly those related to soil aeration and water availability. The importance of clays as contributors of the CEC of the soil and therefore being related to cation availability has been discussed earlier in this paper (see fig. 11).

An important variable that summarizes soil properties is bulk density. It gives indication of the pore space of the soil, therefore it will be affected by variables influencing pore space. Pore space can be affected by compaction or by changing soil texture. The amount of pore space should reflect the water holding capacity. Despite all this generalities most relationships were not clear in this data set. Figs. 19-21 are good examples of the lack of relationship observed. Explanation for this apparent independence among variables may be the amount of error introduced by each of the estimating methods. In addition clear sampling errors are introduced due to the lack of homogeneity in sampling procedures among the 14 different samplers. Fig. 22

shows a good example of this problem. The figure shows the relationship between bulk density and water content of each soil sample. It is expected and the general trend shows that the amount of water should be inversely correlated with bulk density as the higher the bulk density the lower the pore space and lower the volume of water that can be held. However an outlier is indicated in the figure that escapes the trend. This is sample 6 which was collected by myself and it is probable that my sampling procedure overestimated the bulk density. The reason probably due to the fact that the fixed volume sample was taken by stepping on the tube instead of just pushing with the hand as most of the other samplers did. Therefore it is evident from the graph that the point should have fallen at lower bulk densities and in this way be part of the general pattern.

One of the few slightly stronger relationships found is the positive correlation between organic matter content and % pore space (fig. 23). The fact is pointing out the importance of organic matter as a structure forming factor in soil. Organic matter is the major agent that stimulates the formation and stabilization of granular and crumb-type aggregates. A similar pattern although weaker is observed between vegetative cover and bulk density. As noted earlier (fig. 12) the vegetation cover is positively correlated with the amount of organic matter in the soil. Here, the correlation between vegetation and bulk density establishes indirectly through the organic matter (fig. 24). However, both figures 12 and 24 show a typical sampling error due to different criteria among samplers. Note the accumulation of 50% values. Probably for different samplers different vegetative covers meant "50% bare ground".

CONCLUSIONS

Fig. 25 summarizes all relationships found (thin arrows) and general controls or influences assumed (thick arrows) between main factors (large boxes) and soil variables (small boxes)(number indicate figures that depict the relationship). Regional climate and parent material are assumed to affect soil development at a scale that exceeds the scale of this sampling scheme. Therefore the relationships do not appear but are implicit. For example it is well known that the low precipitation and the sedimentary rock determines high a soil pH in the region. Similarly regional climate controls the prevailing vegetation of the area,in this case grasslands and ponderosa pine woodlands.

At the local scale several interrelationships were found. The effect of topography on soil texture appears among the most robust relationships. Probably microtopographic features such as drainage basins and steep slopes affect hydrological patterns of infiltration and runoff, modifying in this way weathering and soil particle transportation patterns. Fire seems to affect soil by at least to different ways on one hand, there seems to be volatilization of NH_4 during a fire, on the other fire set up a new successional pattern and therefore modifies the vegetation mosaic. I found a relatively strong influence of vegetation cover and type on organic matter and SO_4 content of the soil. In addition the organic matter content increased pore space and therefore proved to improve soil structure.

PH appeared to be one of most consistent variables as it could be related to influence from both influence from vegetation and organic matter content. The presence of pine vegetation and high organic matter contents promoted low soil pH due to probably the influence of organic acids.

Although many expected relationships became somewhat evident many important known relationships did not appear. For example the relationships between textural components and soil water relationships were weak or inexistent. This lack of relationship may be due to the fact that the sampling and experimental error was higher than the natural variation of the variable values measured. Therefore the noise introduced masked the range of variation of the variables. As mentioned before, high levels of error are introduced when the samples are taken and processed by different persons with different criteria. Another possibility is that the spatial variability is so high, that any pooling of samples by any factor gives high variability. A third possibility for not finding causal relationships is the lack of dynamic range of certain variables in the scale considered. This may be the case of SO_4 where except for sample 5 there was a very low variability. Another complicating factor here is that we tried to consider the effect of several variables a the same time. However, our sampling design did include all combinations of variables. For example burned areas were all located on more sun-exposed slopes. For this purpose factorial sampling designs considering all combinations of factors are necessary. Another consideration is the lack of replication in the sampling design. It could have given information about internal variability and experimental error if we had taken more than one sample in each plot or if we had repeated (we did it in some procedures) some measurements.

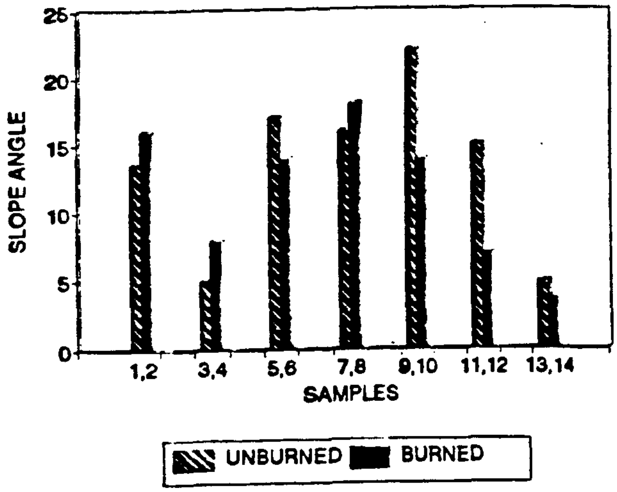

Fig. 1. Slope variation along the topographic gradient.

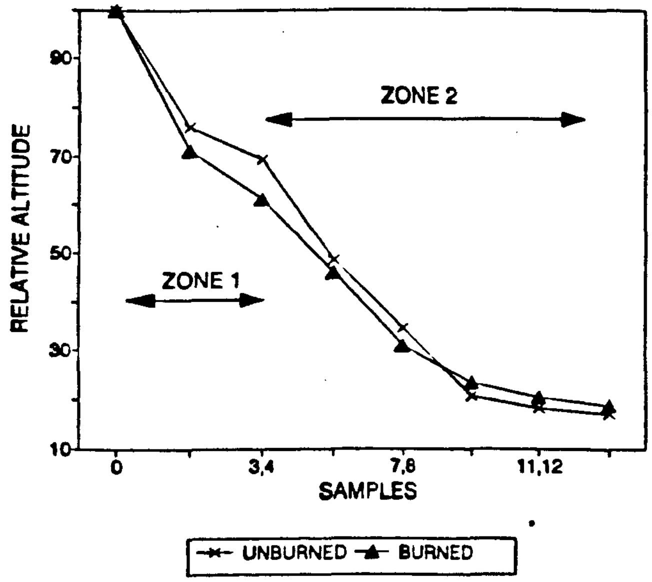

Fig. 2. Profile representing relative slope variation along the sampling points.

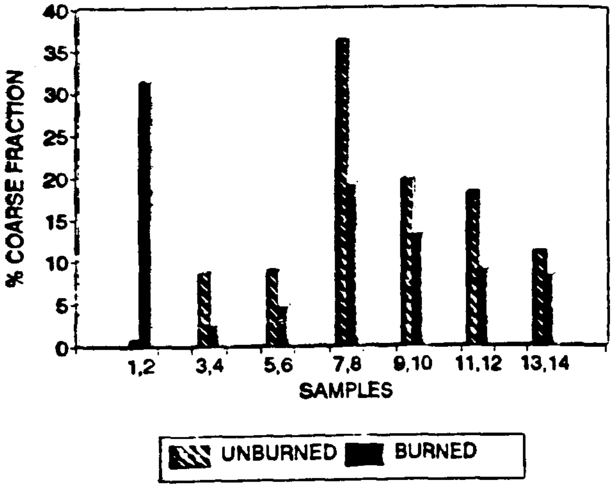

Fig. 3. Coarse fraction variation along the topographic gradient.

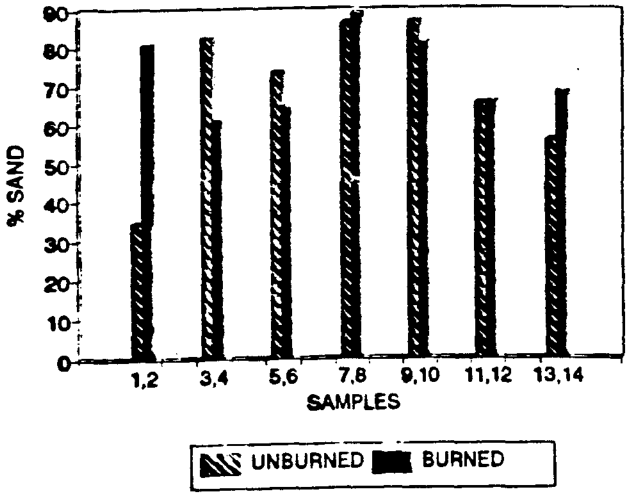

Fig. 4. Sand fraction variation along the topographic gradient.

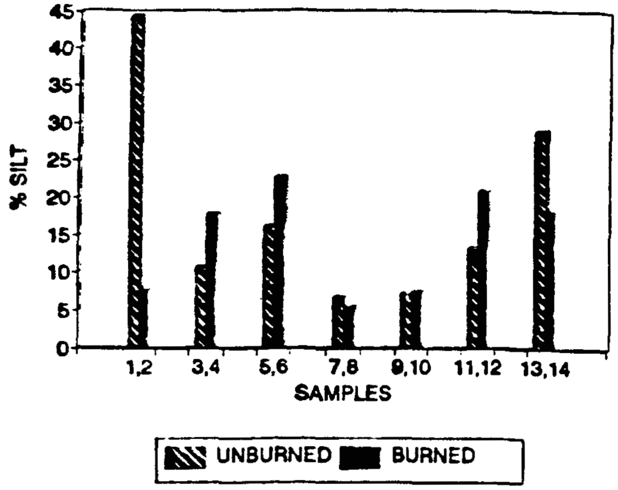

Fig. 5. Silt fraction variation along the topographic gradient.

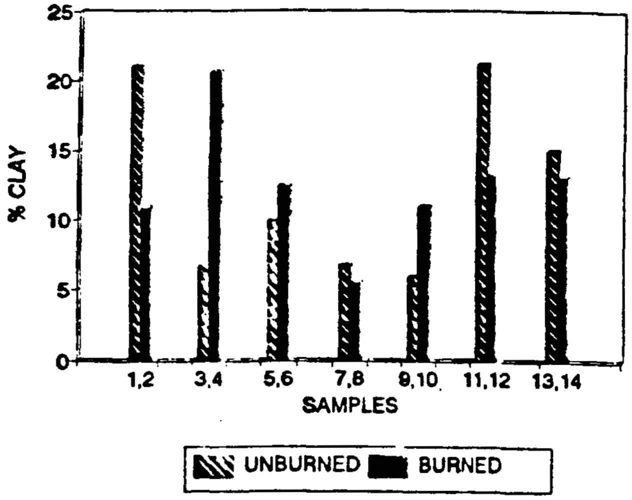

Fig. 6. Clay fraction variation along the topographic gradient.

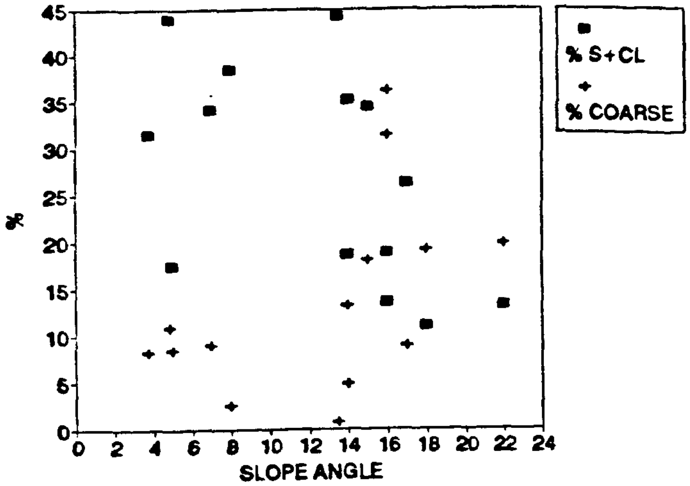

Fig. 7. Relationship between slope angle (degrees) and the percentages of coarse and fine particles (% silt + % clay).

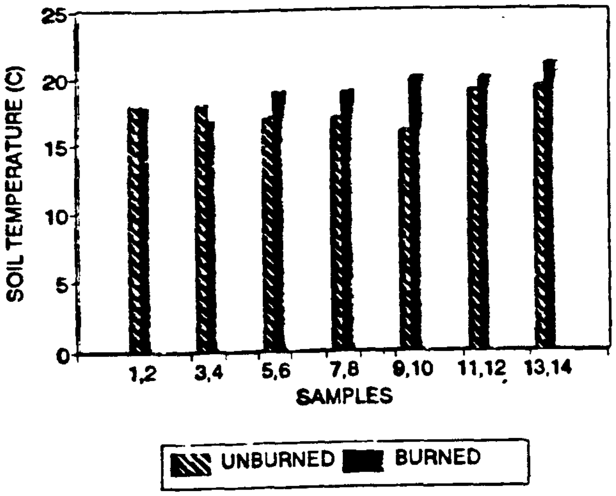

Fig. 8. Soil temperature variation along the topographic gradient.

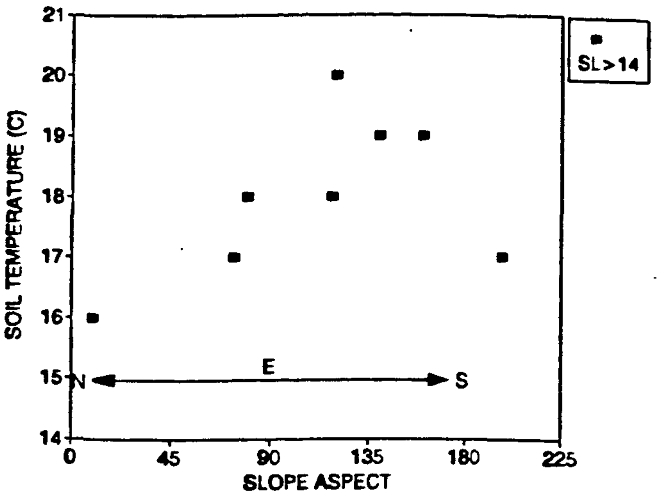

Fig. 9. the relationship between soil temperature and the slope aspect gradient. Only samples with slope angles >14° are plotted.

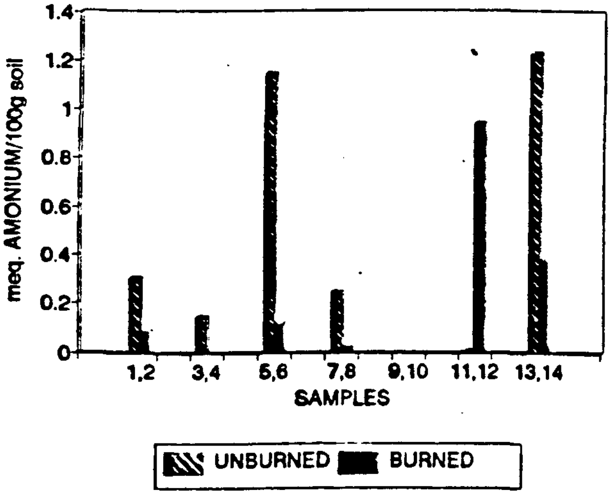

Fig. 10. Ammonium concentration variation along the topographic gradient.

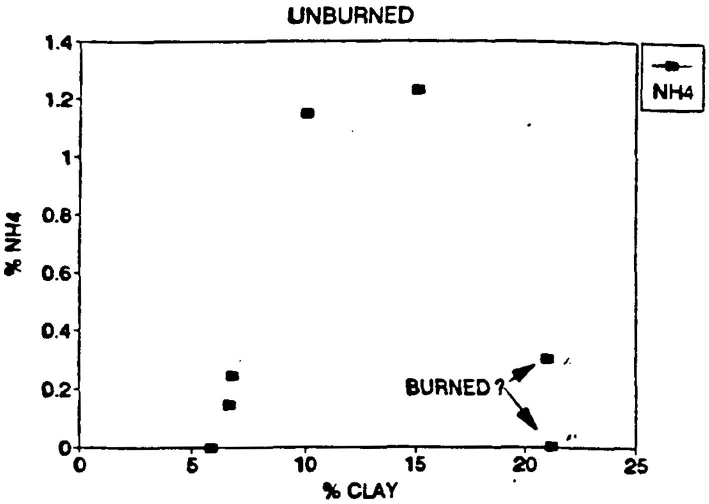

Fig. 11. Ammonium concentration relationship with clay content. Only unburned samples are plotted. Note that two samples may have been wrongly classified as unburned (samples 1 and 11).

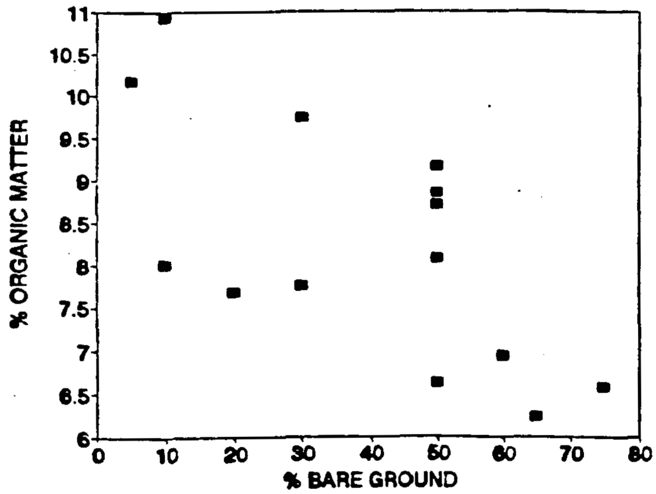

Fig. 12. Relationship between organic matter content and the % of bare ground.

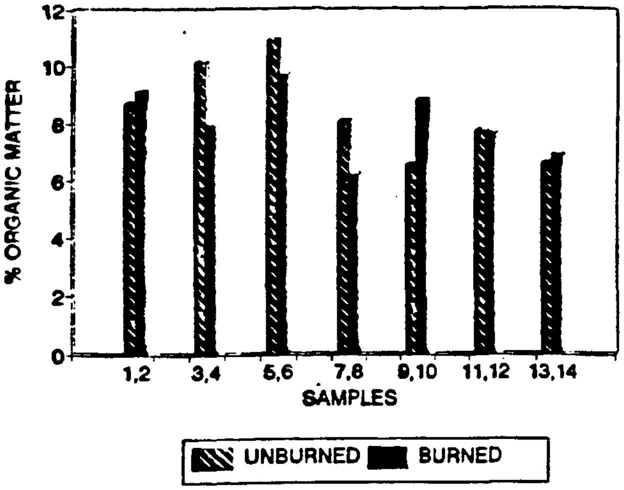

Fig. 13. Organic matter variation along the topographic gradient.

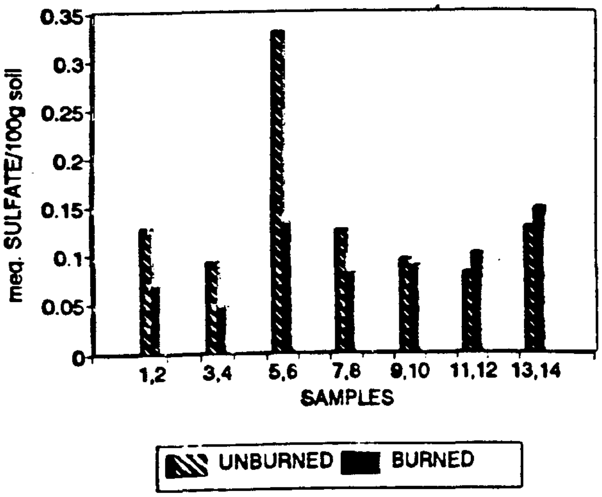

Fig. 14. Sulfate content variation along the topographic gradient.

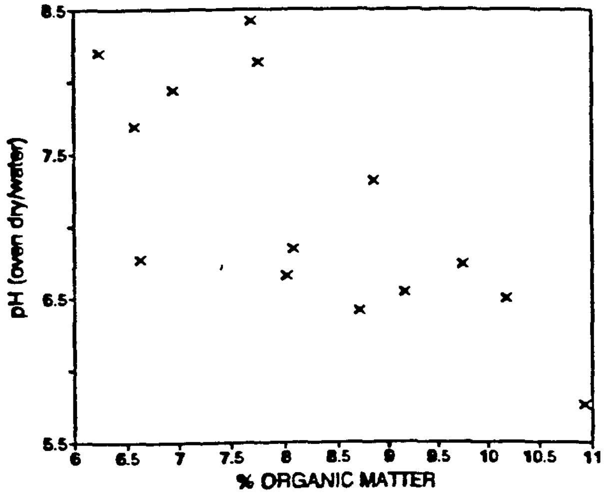

Fig. 15. PH variation with organic matter content of the soil.

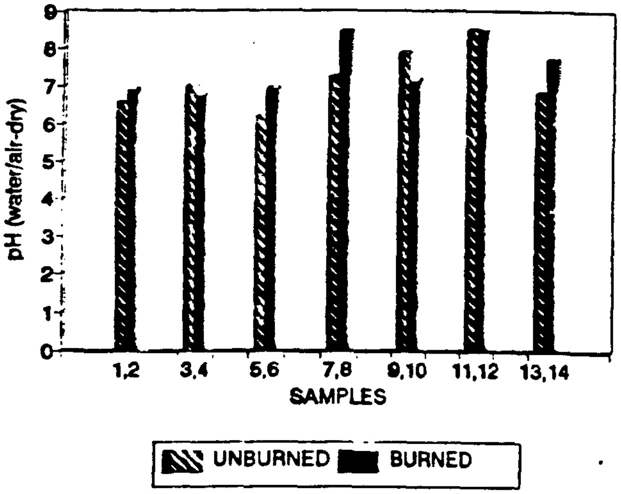

Fig. 16. PH variation along the topographic gradient.

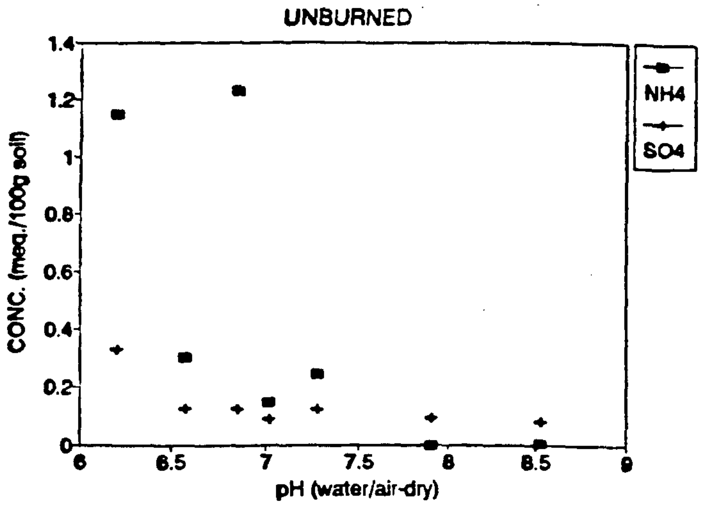

Fig. 17. Nutrient concentration variation along a pH gradient.

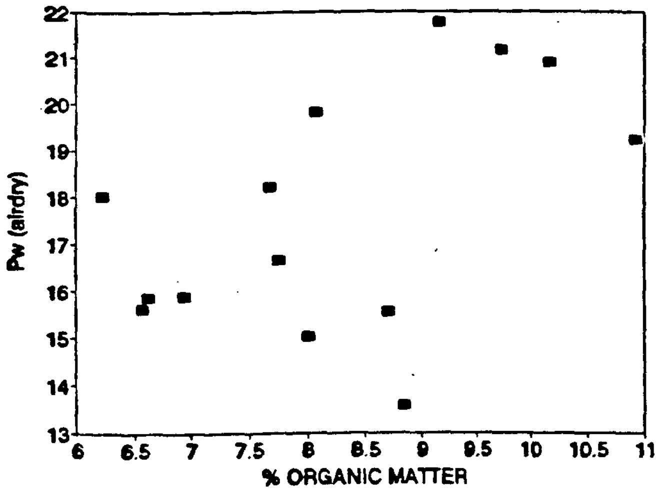

Fig. 18. Relationship between organic matter content and water content of the soil (gravimetric method).

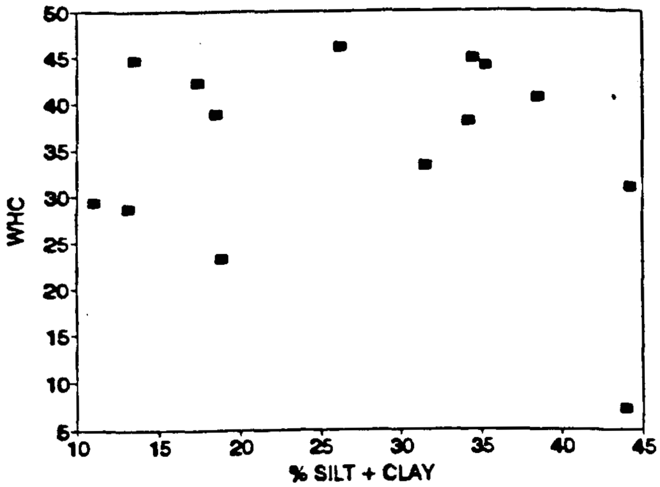

Fig. 19. Water holding capacity as a function of silt and clay content. Note the lack of relationship.

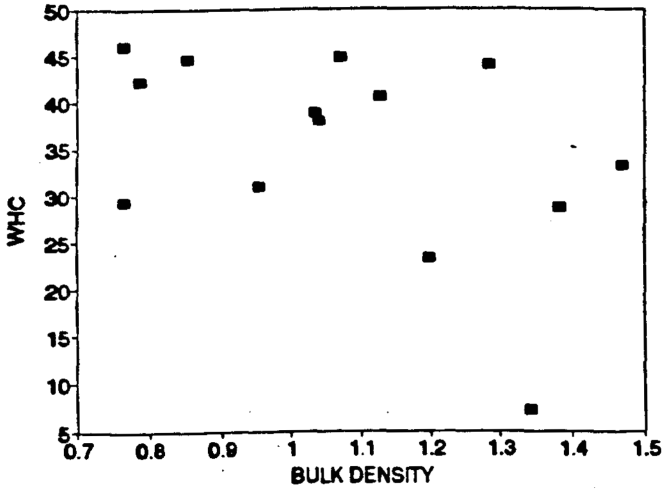

Fig. 20. Water holding capacity as a function of bulk density. Note the lack of relationship.

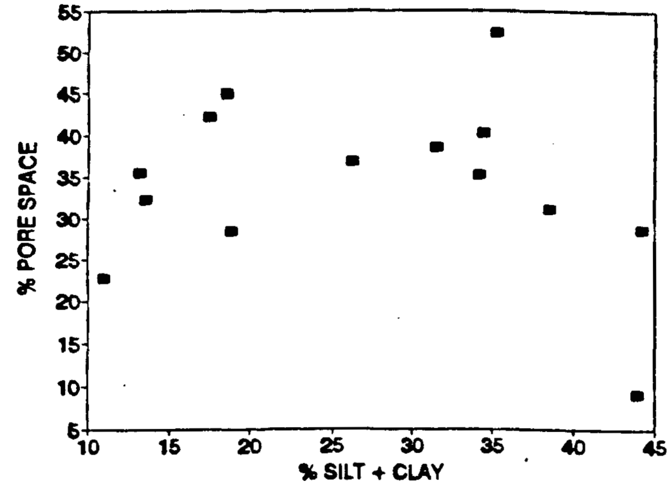

Fig. 21. % pore space as a function of silt and clay content. Note the lack of relationship.

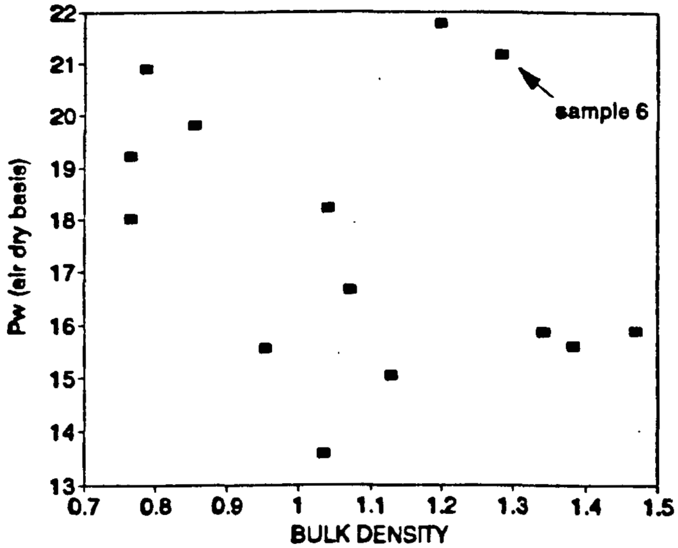

Fig. 22. Water content as a function of bulk density. Note the outlier position of sample 6 (see text for explanation).

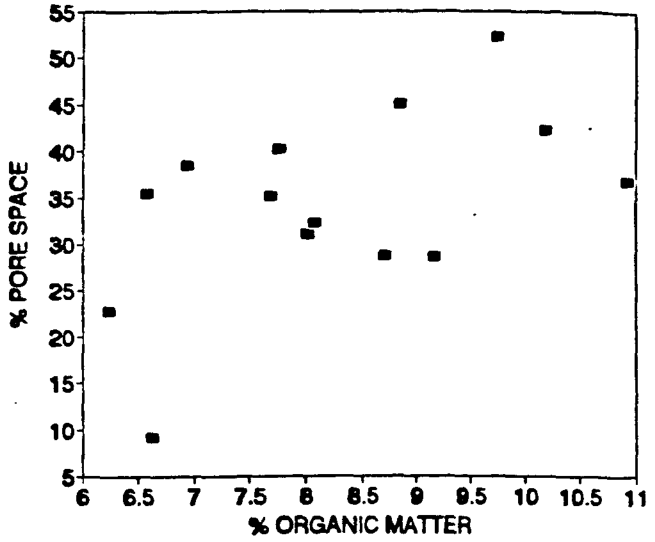

Fig. 23. Relationship between % pore space and the amount of organic matter in the soil.

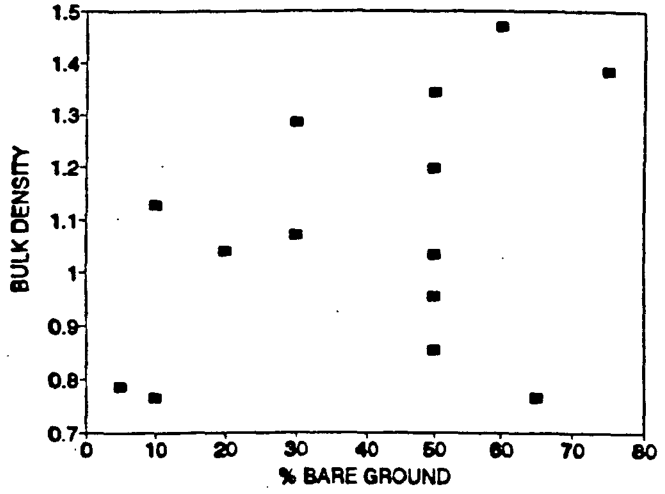

Fig. 24. Relationship between bulk density and the percent bare ground cover. Note the concentration of 50% values of % bare ground.

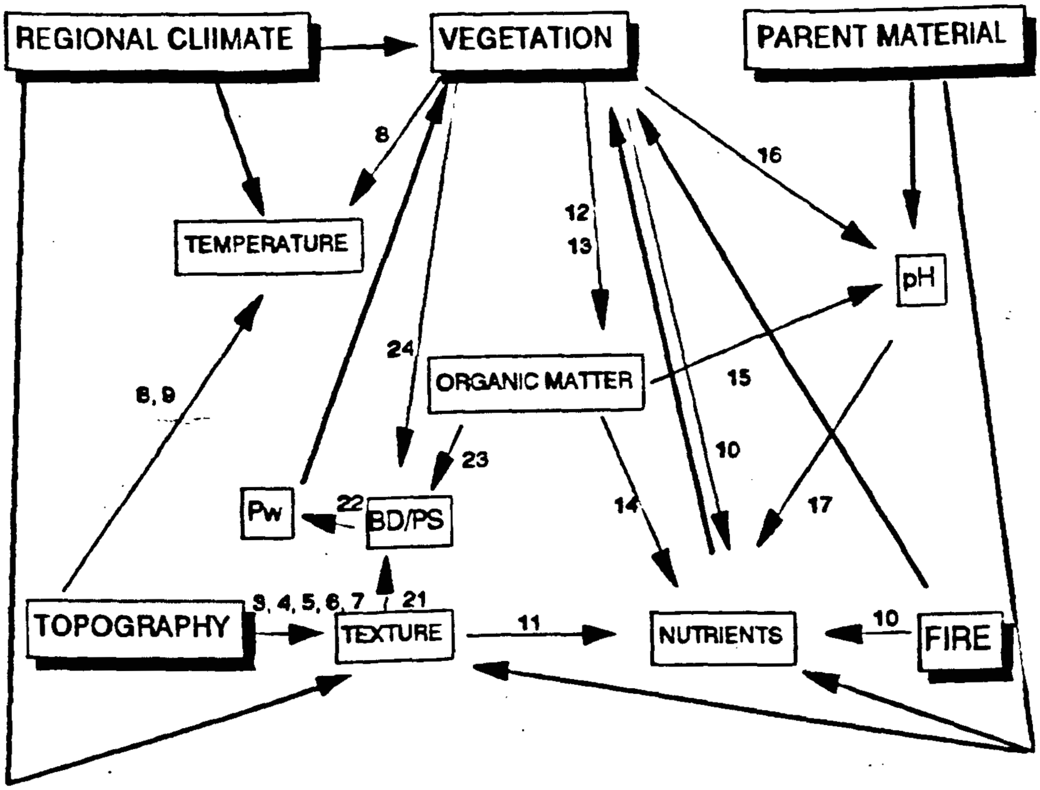

Fig. 25. Relationships among controlling factors (large boxes) and soil properties (small boxes). Thick arrows indicate assumed relationships. Thin arrows show found relationships and numbers refer to the figures depicting the relationship.