

Geography 440/5461  
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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

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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,  $\text{NH}_4$  and

SO<sub>4</sub> 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 where 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 areas of zones 1 and 2. The relationship between slope angle and texture characteristics is reflected in the trends in fig. 7 where 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 were 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  $\text{NH}_4$  probably via volatilization. Fig. 10 shows that most of the burned samples showed lower %  $\text{NH}_4$  than the unburned. this is particularly true for the samples 3 through 8 where the fire

limits were more marked. Within unburned plots,  $\text{NH}_4$  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  $\text{SO}_4$  content for these unburned samples (3-8) (fig. 14). Positive charges in the organic matter may be favoring the retention of  $\text{SO}_4$  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  $\text{NH}_4$  and  $\text{SO}_4$  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 vegetative 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~~ <sup>two</sup> different ways. On one hand, there seems to be volatilization of  $\text{NH}_4$  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  $\text{SO}_4$  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  $\text{SO}_4$  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 at 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.

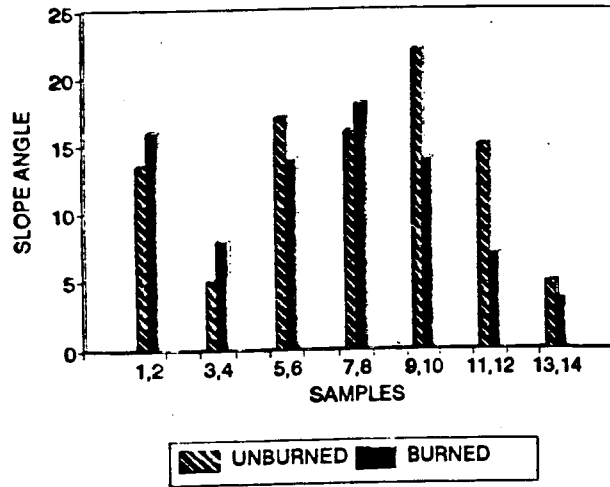


Fig. 1. Slope variation along the topographic gradient.

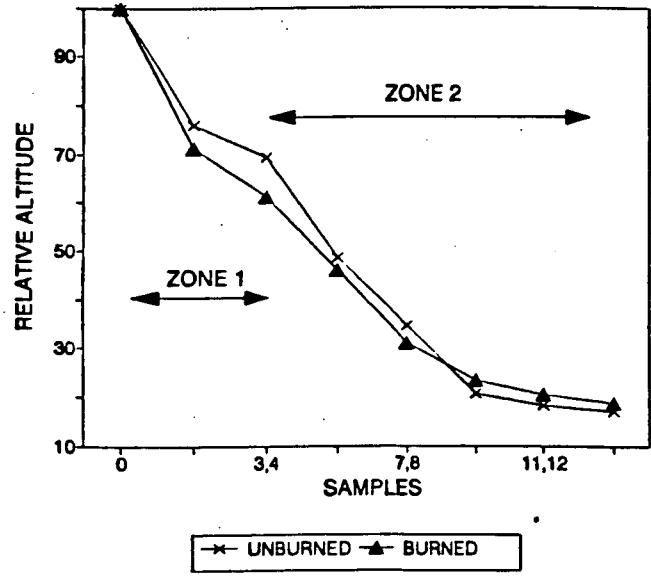


Fig. 2. Profile representing relative slope variation along the sampling points.

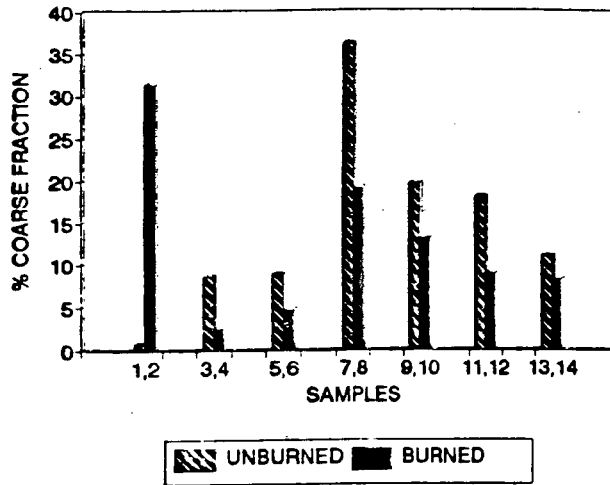


Fig. 3. Coarse fraction variation along the topographic gradient.

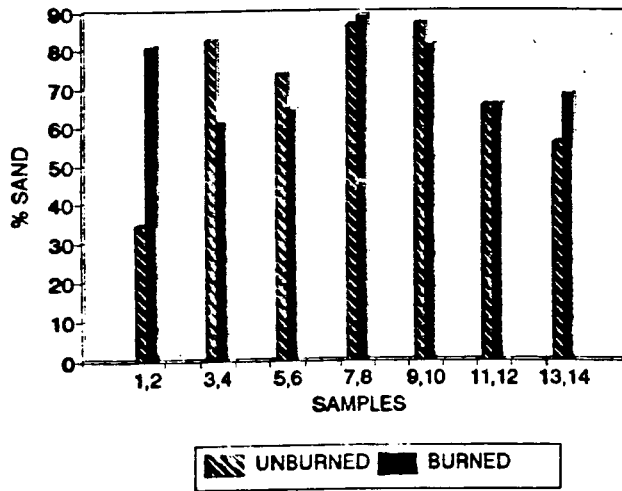


Fig. 4. Sand fraction variation along the topographic gradient.

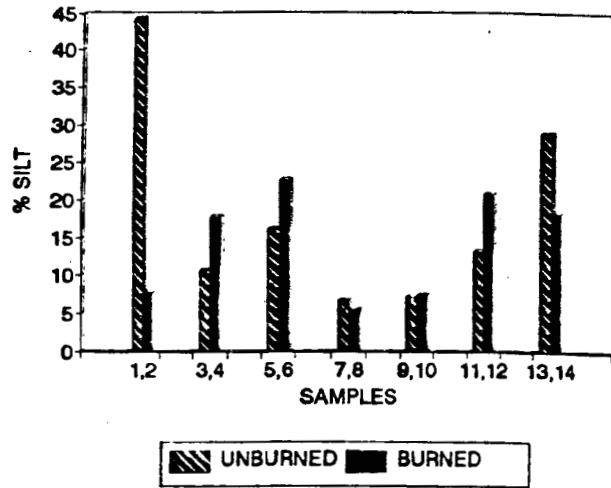


Fig. 5. Silt fraction variation along the topographic gradient.

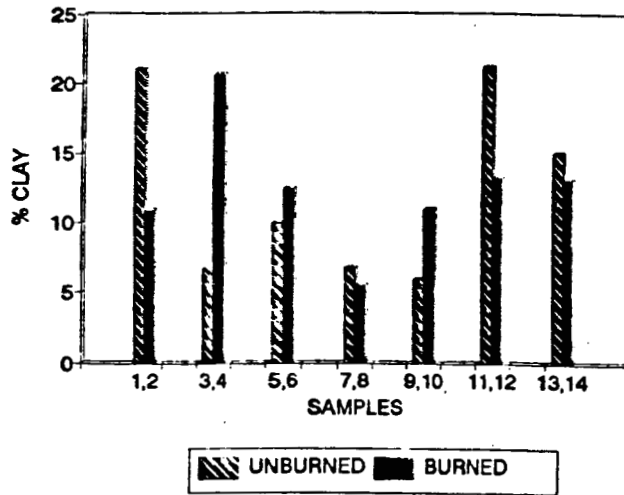


Fig. 6. Clay fraction variation along the topographic gradient.

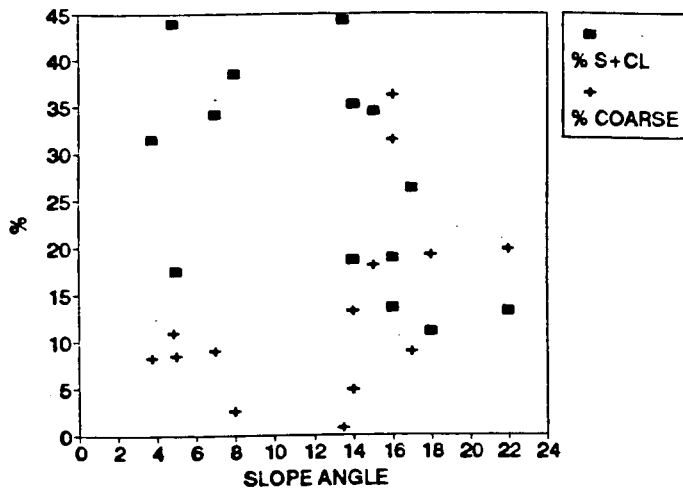


Fig. 7. Relationship between slope angle (degrees) and the percentages of coarse and fine particles (% silt + % clay).

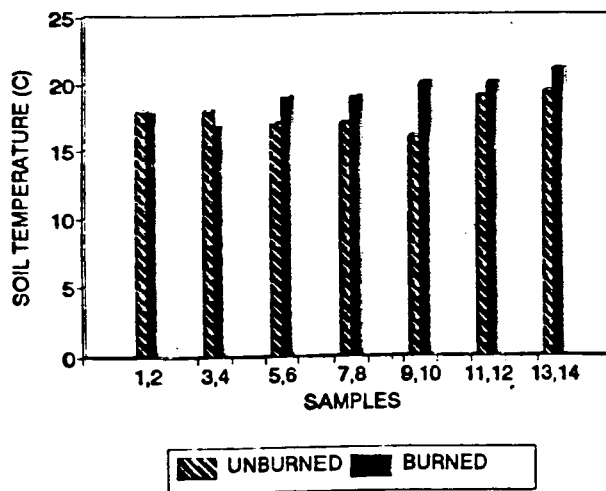


Fig. 8. Soil temperature variation along the topographic gradient.

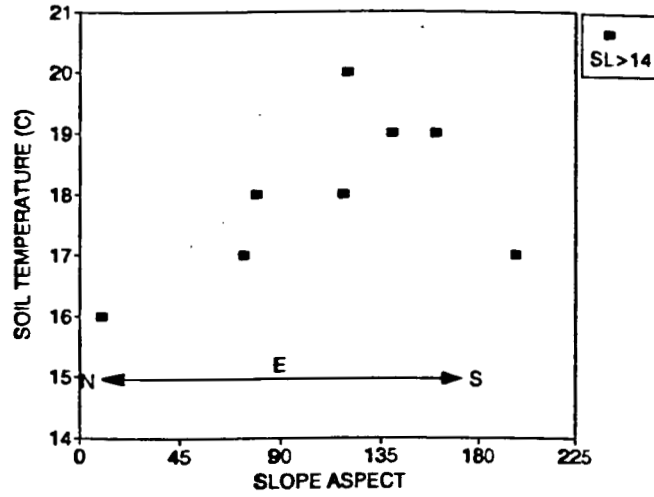


Fig. 9. the relationship between soil temperature and the slope aspect gradient. Only samples with slope angles  $>14^\circ$  are plotted.

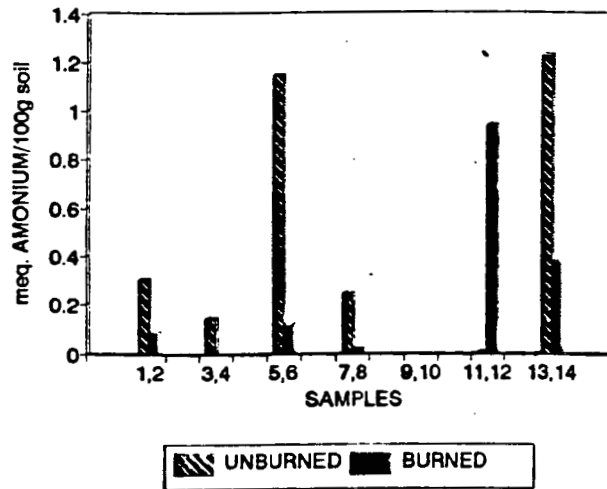


Fig. 10. Ammonium concentration variation along the topographic gradient.

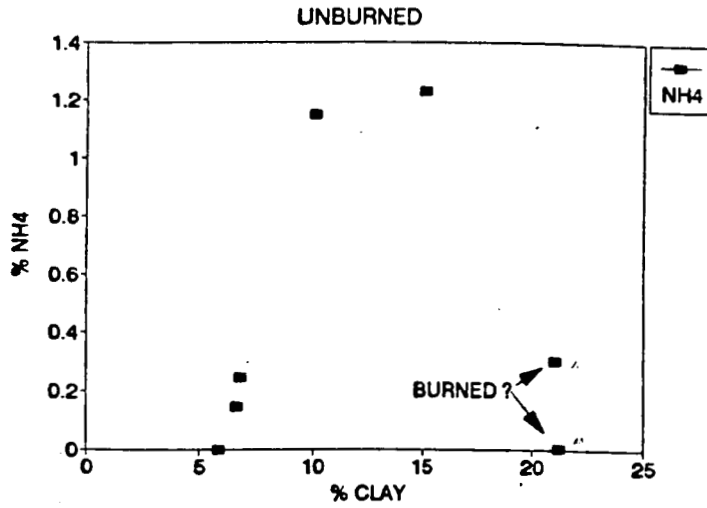


Fig. 11. Ammonium concentration relationship with clay content. Only unburned samples are plotted. Note that two samples may have been wrongly classified as unburned (samples 1 and 11).

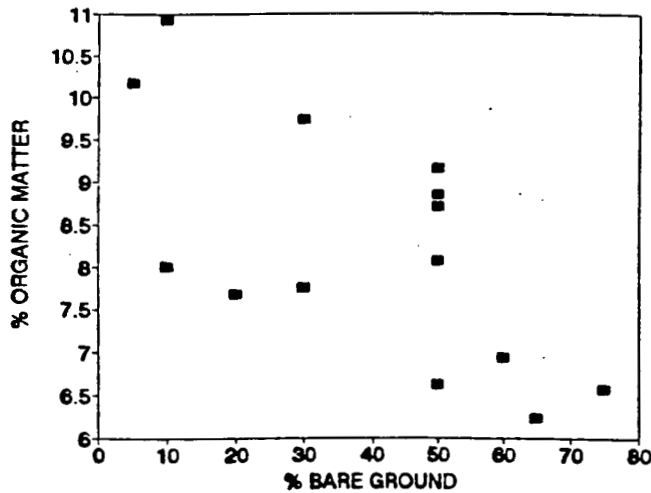


Fig. 12. Relationship between organic matter content and the % of bare ground.

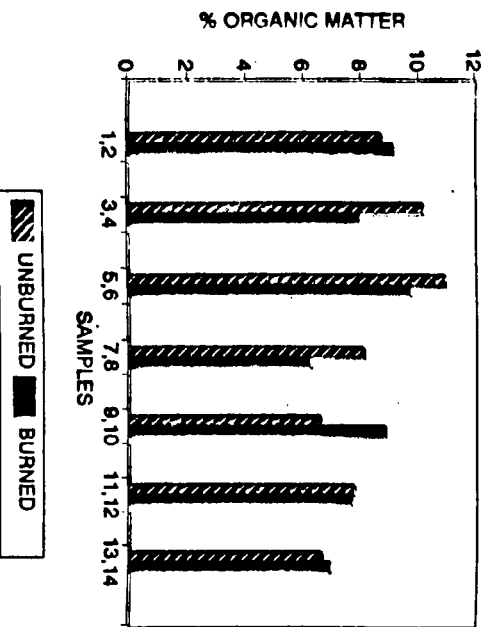


Fig. 13. Organic matter variation along the topographic gradient.

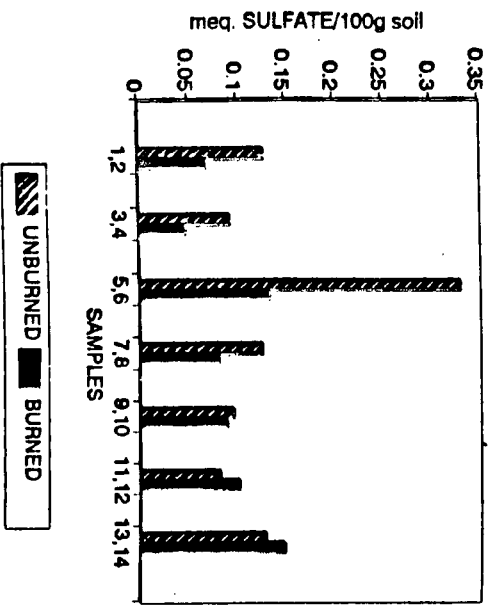


Fig. 14. Sulfate content variation along the topographic gradient.



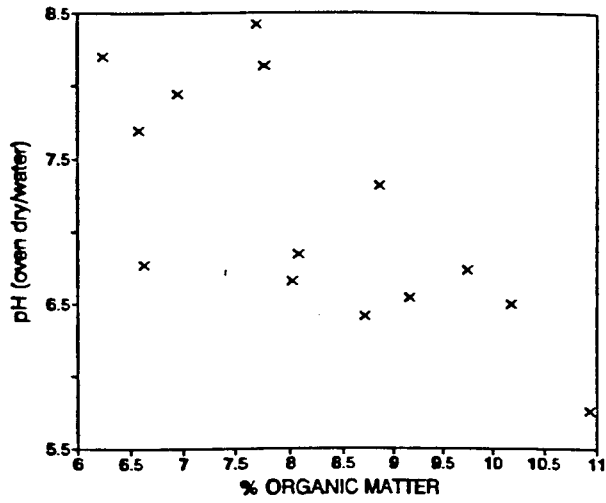


Fig. 15. PH variation with organic matter content of the soil.

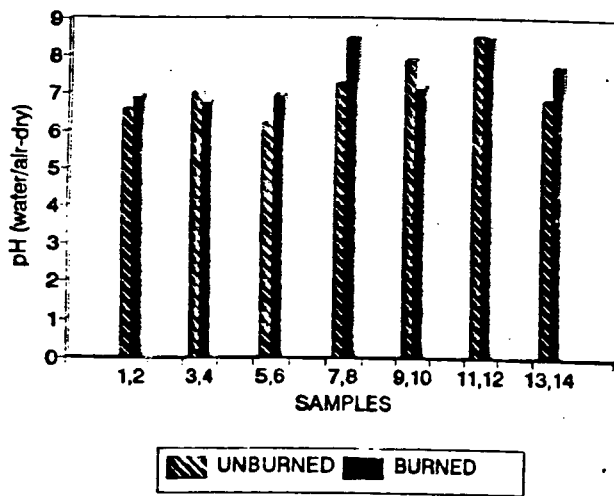


Fig. 16. PH variation along the topographic gradient.

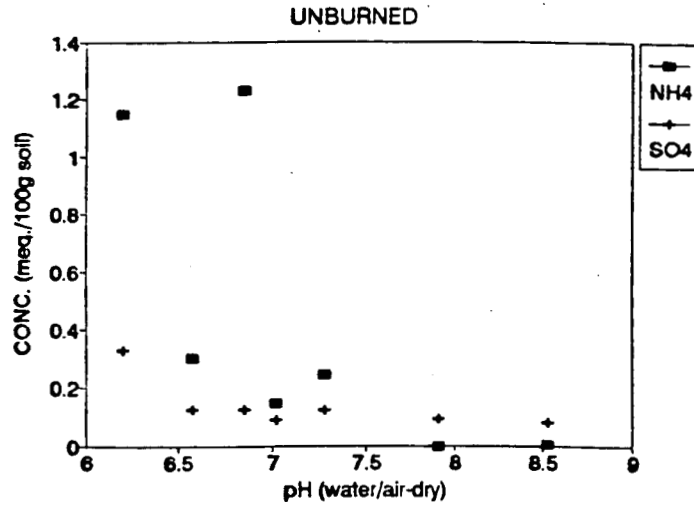


Fig. 17. Nutrient concentration variation along a pH gradient.

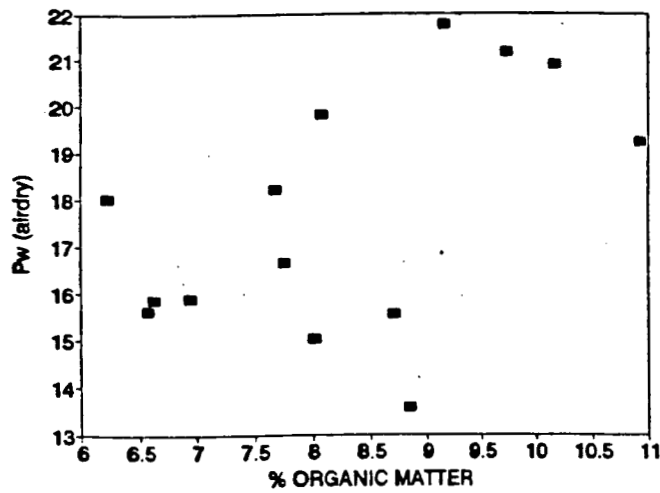


Fig. 18. Relationship between organic matter content and water content of the soil (gravimetric method).

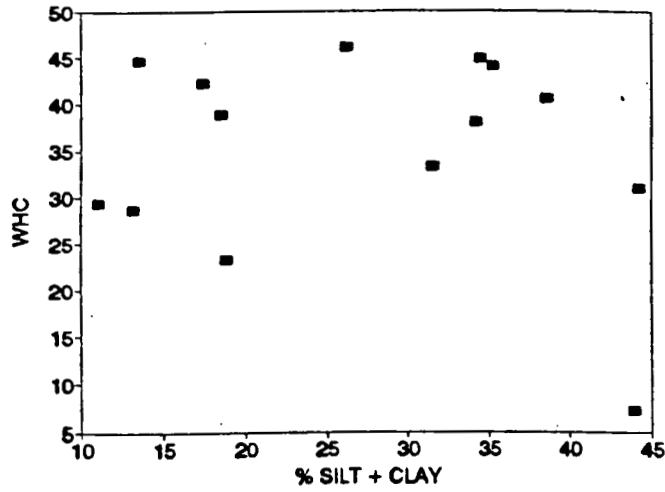


Fig. 19. Water holding capacity as a function of silt and clay content. Note the lack of relationship.

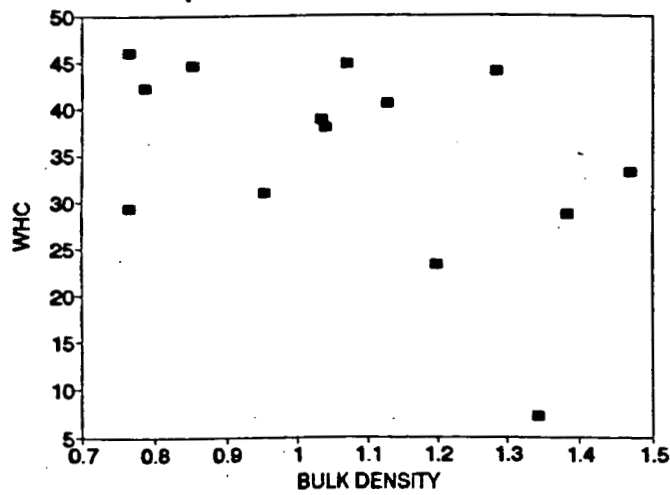


Fig. 20. Water holding capacity as a function of bulk density. Note the lack of relationship.

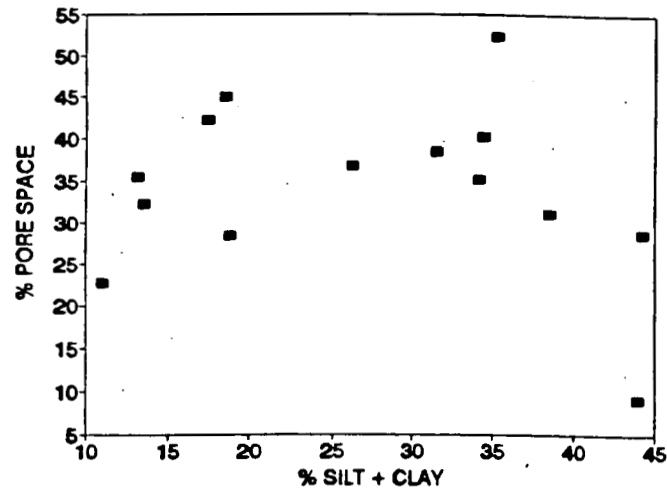


Fig. 21. % pore space as a function of silt and clay content. Note the lack of relationship.

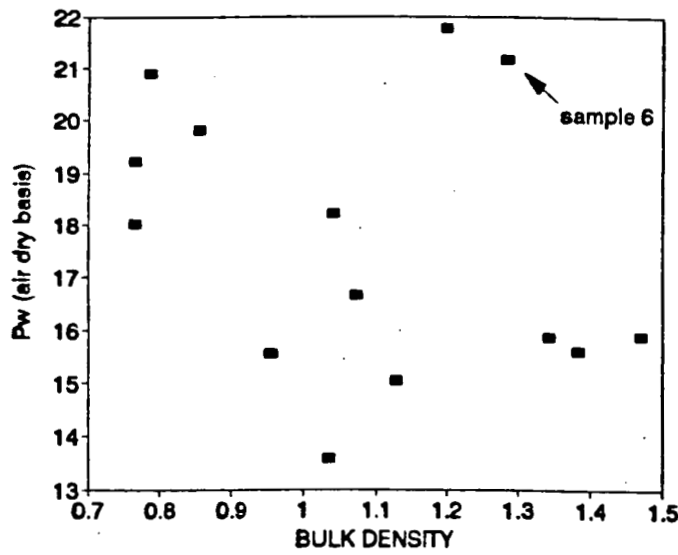


Fig. 22. Water content as a function of bulk density. Note the outlier position of sample 6 (see text for explanation).

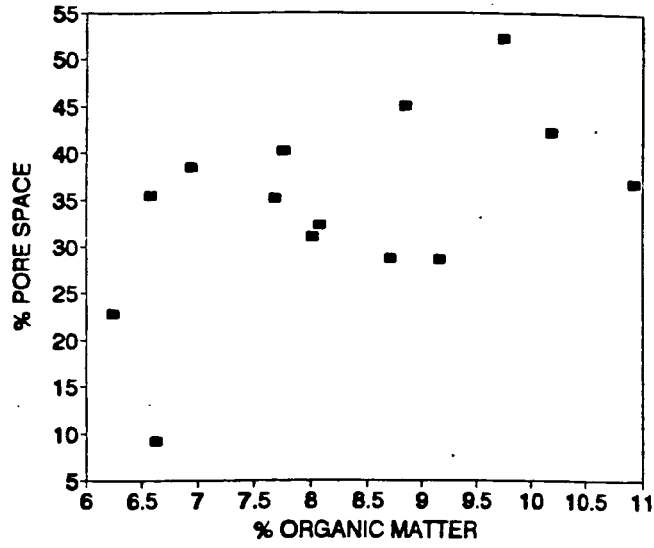


Fig. 23. Relationship between % pore space and the amount of organic matter in the soil.

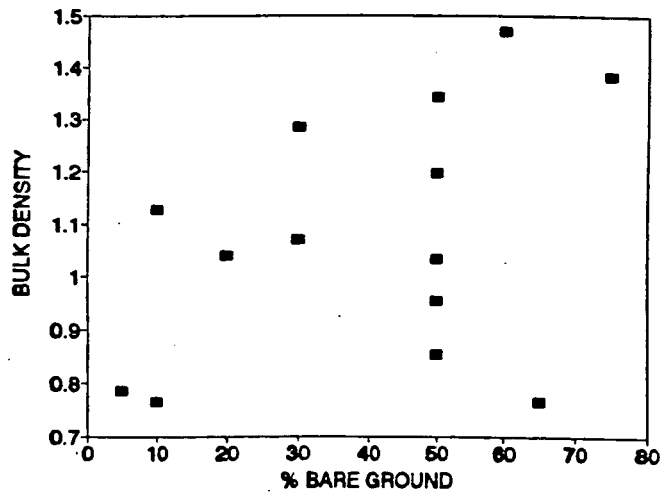


Fig. 24. Relationship between bulk density and the percent bare ground cover. Note the concentration of 50% values of % bare ground.

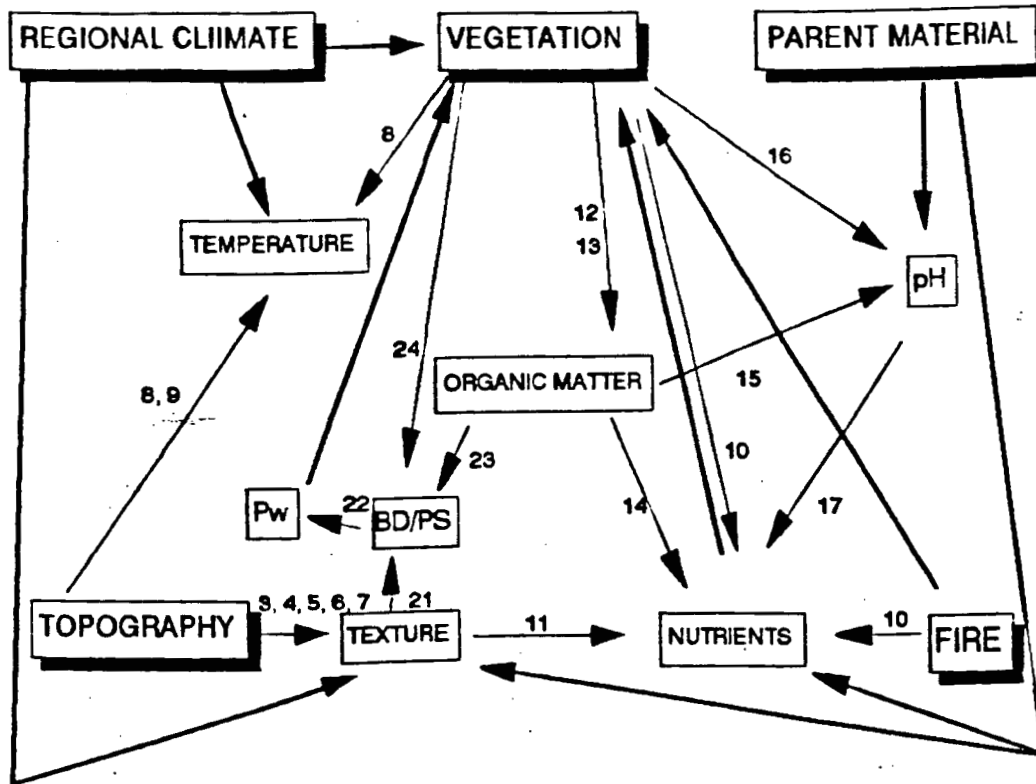


Fig. 25. Relationships among controlling factors (large boxes) and soil properties (small boxes). Thick arrows indicate assumed relationships. Thin arrows show found relationships and numbers refer to the figures depicting the relationship.

RECEIVED JAN 16 1992

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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 W. Beatty  
Associate Professor

encl. 2 reports, data sheets



City  
of  
Boulder

Real Estate/Open Space Department  
Post Office Box 791 Boulder, CO 80306  
(303) 441-3440

August 26, 1991

*- Boettcher*  
Dr. Susan Beatty  
University of Colorado  
CB 260  
Boulder, CO 80309-0260

*tel # 492-6343*

Dear Dr. Beatty:

Your proposal to study the physical properties of soils on Open Space near the Foothills Trail has been reviewed by this office. Based upon the information provided during our conversation, the Open Space Department approves of the project. This approval is valid for a period of one year.

Please fill out and return the enclosed Research Volunteer Register. (The waiver of liability is a requirement of the City.) The Open Space department values the participation of the University in research projects on open space. This form helps us record the services rendered by students and faculty from the University.

Although your project is authorized by the Open Space Department, this does not eliminate the requirement that you obey applicable Federal, State and local regulations. Find enclosed a sheet listing some of the regulations enforced by the Open Space Department.

Should at any time during the study it become evident that there is a significant safety hazard or natural resource concern, the Open Space Department must be notified immediately.

Good luck with your study. I hope to have the opportunity to meet with your class. I look forward to reading the report.

Sincerely,

*Mark*  
Mark Gershman  
Wetlands/Wildlife Coordinator

*End of semester*

encl. Volunteer Register  
Open Space Regulation Sheet  
Research Guidelines

cc: w/o enclosures Operations Supervisor  
Volunteer Coordinator