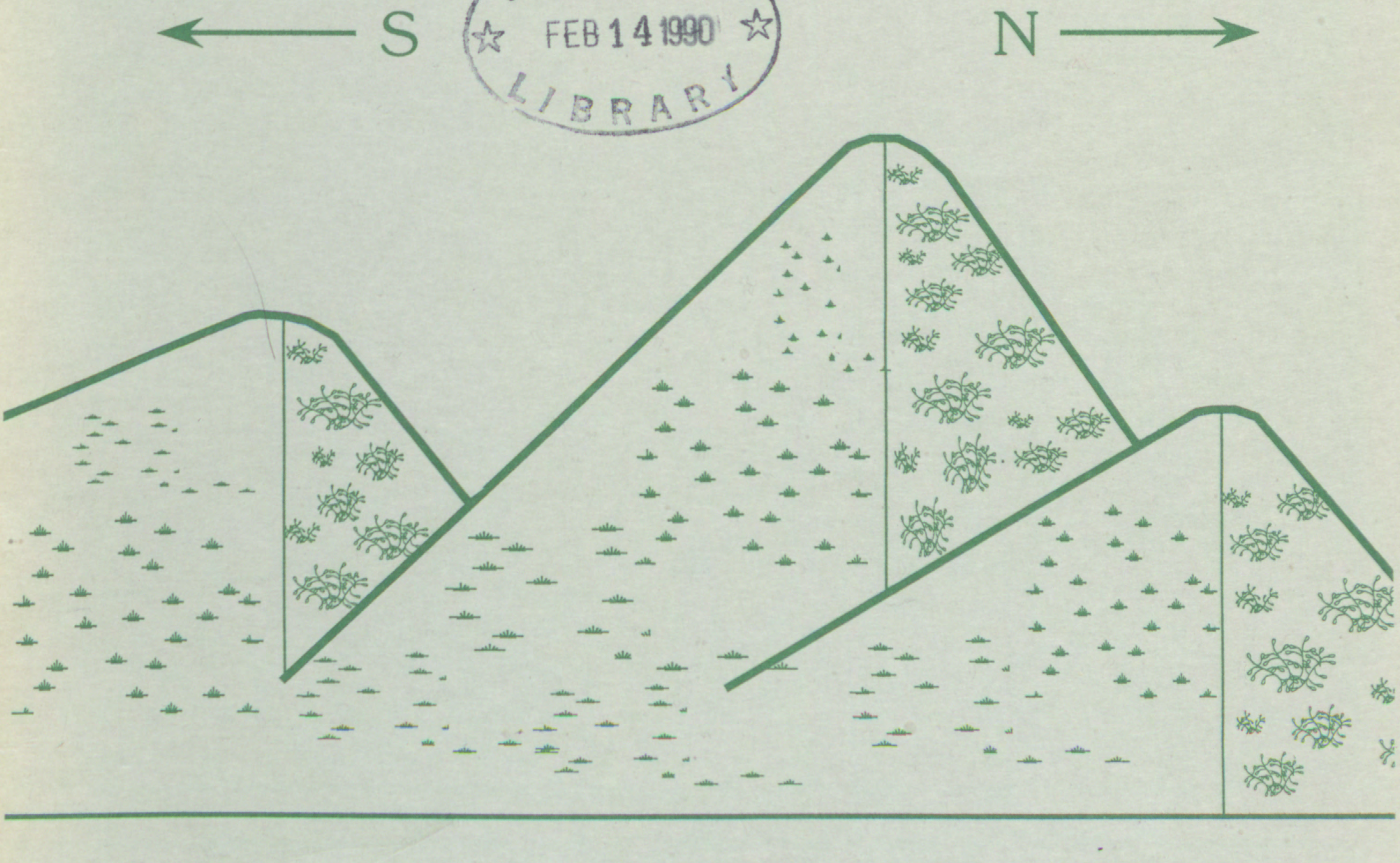
CONTRASTS OF VEGETATION, SOILS, MICROCLIMATES, AND GEOMORPHIC PROCESSES BETWEEN NORTH- AND SOUTH-FACING SLOPES ON GREEN MOUNTAIN NEAR DENVER, COLORADO

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 89-4094



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By Farrel A. Branson and Lynn M. Shown

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CONTENTS

FIGURES

TABLE

CONVERSION FACTORS

Metric (International System) units in this report may be converted to inch–pound units by using the following conversion factors:

Multiply metric unit	*By*	*To obtain inch–pound unit*
centimeter (cm)	2.54	inch
kilometer (km)	0.6214	mile
megapascal	10.0	bar
meter (m)	3.281	foot
square kilometer (km^2)	2.590	square mile

Temperature, in degrees Celsius (°C), can be converted to degrees Fahrenheit (°F) by using the following equation: °F = 9/5 (°C) + 32.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)––a geodetic datum derived from a general adjustment of the first–order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Although marked contrasts in types of vegetation on hillside with varying slopes and different exposures are common features of most landscapes with moderate to large topographic relief, few studies have been conducted to determine causes of these contrasts. Vegetation species on north-facing slopes near Denver were predominately shrubs, whereas vegetation species on south-facing slopes were nearly all herbaceous. The principal cause for these vegetation contrasts is greater solar radiation on south-facing slopes. Associated with the greater solar radiation on south slopes were higher soil temperatures, greater evaporation, and decreased soil moisture available for plant growth. More periods of freezing and thawing, and larger areas of bare soil resulted in more runoff and erosion on south slopes. These processes are probable causes for south-facing slopes being less steep than the north-facing slopes.

INTRODUCTION

Marked contrasts in types of vegetation on hillsides with varying slopes and different exposures are a familiar feature of most landscapes with moderate to large topographic relief. The magnitude of contrast increases northward from the equator because isolation-intensity differences become greater on north-facing and south-facing slopes with increases in latitude. These statements oversimplify problems with attempts to explain the biotic responses on hillsides with varying slopes and different exposures. The kinds of plants present on contrasting slopes are affected by time, in the evolutionary sense, as well as by ecologic amplitude (the range of tolerance of a species to different environments) of the species.

Because contrasts in vegetation on north-facing and south-facing slopes are such obvious features of many landscapes, it is surprising that few studies have been conducted to evaluate the cause-and-effect relations responsible for these contracts. Notable exceptions to this statement are the excellent, early papers by Shreve (1924) for areas in Arizona, and by Cottle (1932) for mountains in southwestern Texas. On the basis of detailed measurements of soil temperatures, Shreve (1924) concluded that differences in maximum temperatures were more important than those in minimum temperatures in determining differences in plant distribution, and that soil-moisture differences were even more important than temperature differences, although the two are related. Differences in temperature, soil moisture, and evaporation measured by Cottle (1932) in southwestern Texas were similar to those measured by Shreve (1924) in Arizona. In addition to determining that higher temperatures and greater evaporation were causes of lesser soil moisture on south-facing slopes, Cottle (1932) also determined that runoff was greater on these slopes, probably because vegetation was sparse in many areas. In Wisconsin, Stoeckler and Curtiss (1960) determined that soil moisture on a north-facing slope was about double that on an adjacent south-facing slope. In Kansas, Glover and others (1958) determined that soil moisture and soil thickness were greatest on north-facing slopes, and that these characteristics decreased on slopes with different exposures as follows: east facing, west facing, and south facing.

Near Fairbanks, Alaska, south-facing slopes were covered with mature white spruce 24 to 27 m in height, but north-facing slopes were covered by low growing, scraggly black spruce (Krause and others, 1959). Soils on south-facing slopes were well-drained, mature, silt loams, but on north-facing slopes, soils were poorly drained and boggy soils with permafrost at about 25.5 cm below the land surface.

Ayyad and Dix (1964) concluded that distribution of species on contrasting slopes in the prairie of Saskatchewan, Canada, was controlled by moisture and heat regimes of soil layers in contact with vegetation. Potential solar-beam irradiation was determined to be the most effective factor in integrating slope and exposure effects on gallery forests in North Dakota (Wikum and Wali, 1974). In assessing relative success of reclamation attempts on strip-mined lands in Wyoming and Montana, Toy (1979) calculated potential evapotranspiration rates and presented a method for adjusting these rates for northerly- and southerly-facing slopes.

During geomorphologic studies, researchers (Emery, 1947; Melton, 1960; Hadley, 1961; Beaty, 1962; and Hadley and Branson, 1965) have attempted to determine why north-facing slopes are usually steeper than sough-facing slopes, and why drainage basins usually are asymmetrical in shape. Opposing views are presented as explanations for greater north-slope steepness. Beaty (1962) stated that greater erosion occurs on north-facing slopes; Melton (1960) proposed that north-facing slopes "become steeper as the streams are moved against their toes by filling of debris from the south-facing slopes." Hadley (1961) was in general agreement with Melton (1960), but proposed that vegetation differences are responsible for differing slope- erosion rates. In the drainage basins studied by Hadley (1961), an average cover of only 28 percent of that on north-facing slopes resulted in both sheet

In an attempt to quantify some cause-and effect relations on contrasting slope exposures, a small drainage basin on Green Mountain, an isolated foothill near Denver, Colo., was studied. This report presents the results of that study. Micro-climatic differences are emphasized because they are probably causative.

Description of Study Area

A small drainage basin, (0.65 km), about 11.3 km^2 southwest of Denver (fig. 1)

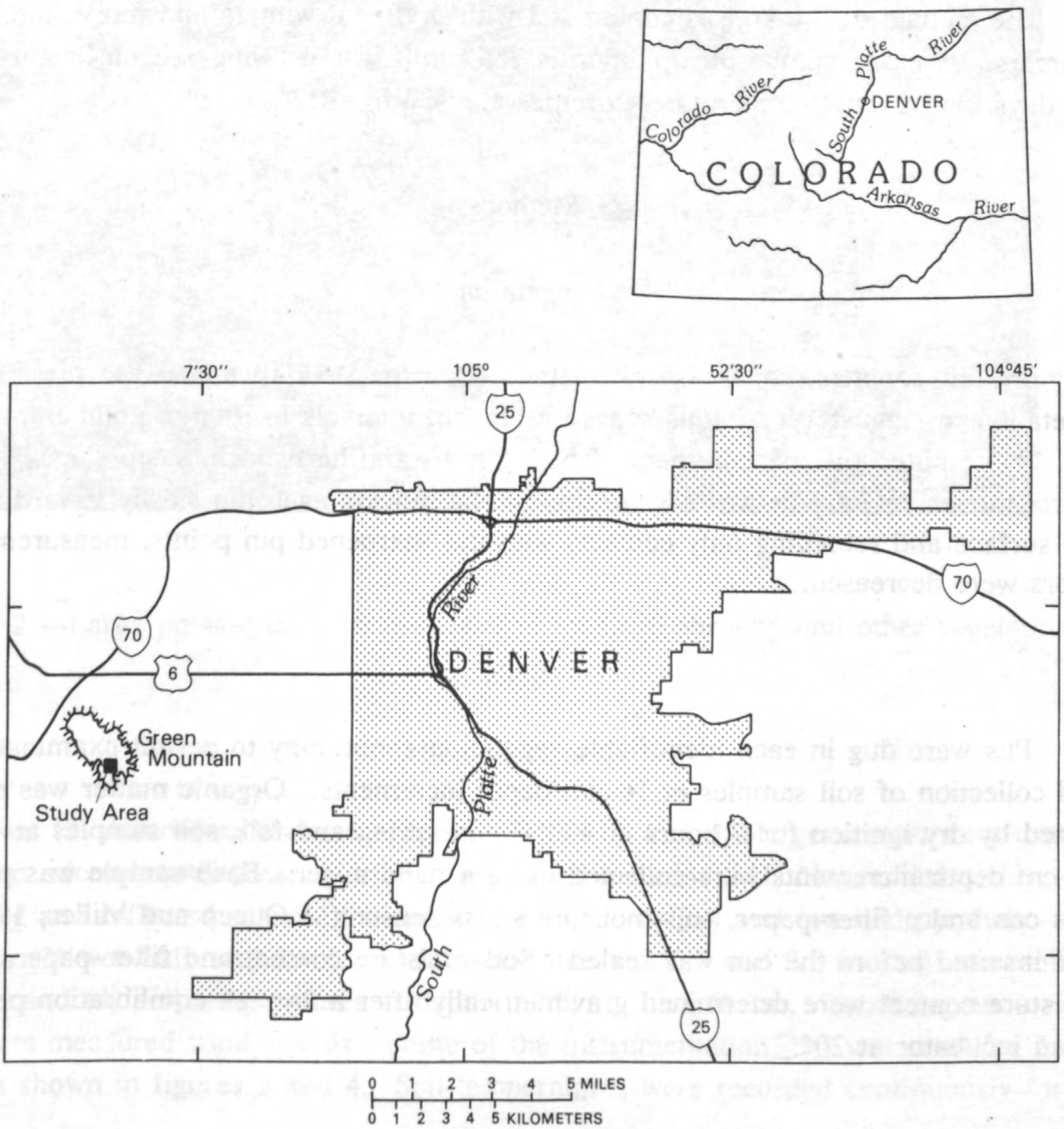


Figure 1.--Index map showing location of study area.

provided an excellent site for the study of slope and exposure effects on vegetation, soils, and geomorphology. The basin is on the south side of Green Mountain, an isolated foothill with 260 m of relief. The altitudinal range for the mountain is from 1,829 to 2,090 m. The study basin is underlain by the Denver Formation of Late Cretaceous and Paleocene age (Van Horn, 1957). The soil mantle grades from gravelly to sandy loam at the surface to a gravelly, clayey subsoil on the north-facing and south-facing slopes. The two slopes on opposite sides of the main valley face N. 28° W. and S. 15° W.

The climate of the area is continental with dry, cold winters and moist, hot summers. Average annual precipitation is 355 mm. The growing-season length is 171 days, and annual temperature extremes are -34 to +41°C.

Methods

Vegetation

The all-contacts, point-quadrat method (Branson, 1962) was used to measure vegetation in August 1962. Pins spaced at 15-cm intervals in a large point frame (fig. 2) permitted the measurement of both shrubs and herbs. On steep slopes, lateral movement of pins was a problem, but by moving each pin slowly toward the soil surface and recording only contacts with the sharpened pin points, measurement errors were decreased.

Soils

Pits were dug in each identifiable vegetation community to permit examination and collection of soil samples at 10-cm depth increments. Organic matter was determined by dry ignition for 7 hours at 400°C. In spring and fall, soil samples at 10-cm depth increments were collected using a hand auger. Each sample was placed in a can and a filter-paper, soil-moisture stress sensor (McQueen and Miller, 1968) was inserted before the can was sealed. Soil-moisture content and filter-paper-moisture content were determined gravimetrically after a 2-week equilibration period in an incubator at 20°C.

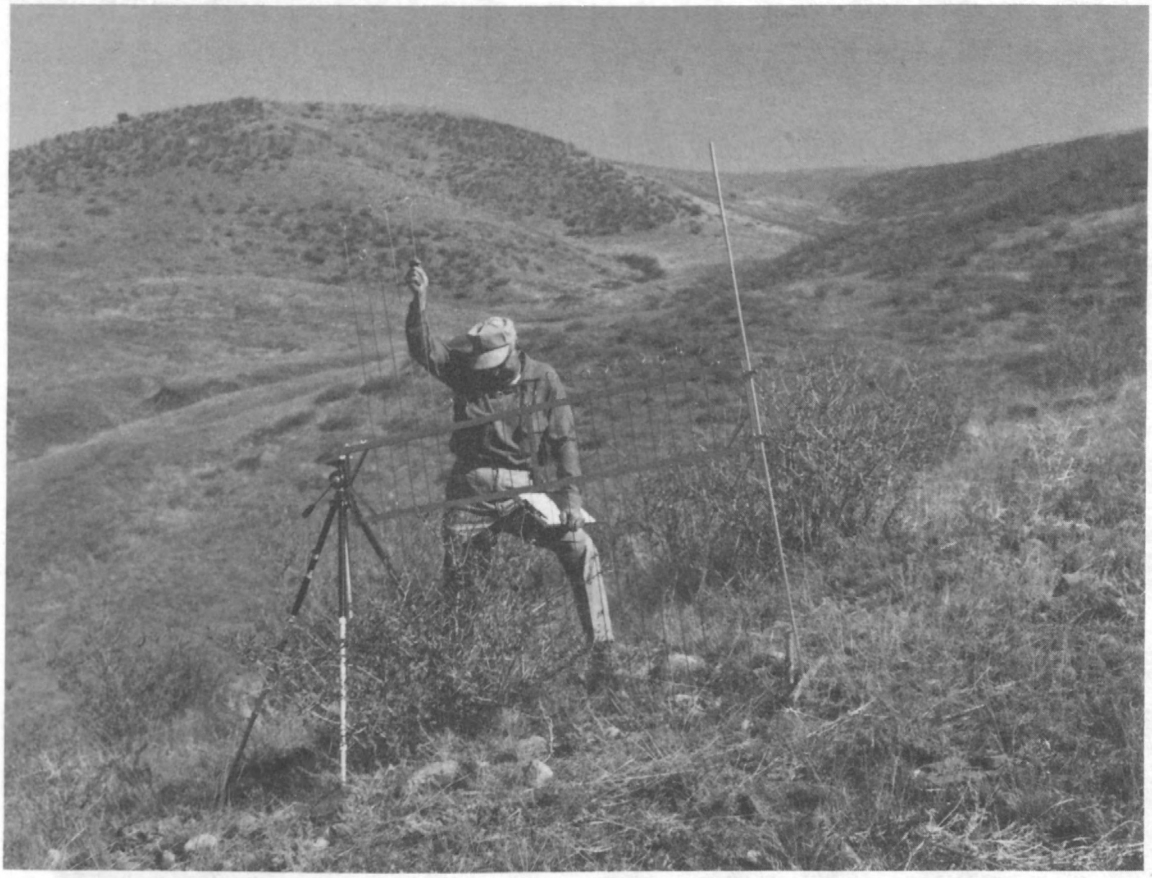


Figure 2.--Large point-quadrat frame used to measure shrubby and other vegetation.

Microclimates

Two 12-channel millivolt recorders, powered by a portable generator, were used to record microclimatic data. Variables measured included: (1) Net radiation; (2) incoming and reflected solar radiation (by means of vertical and inverted pyroheliometers); (3) wet-bulb and dry-bulb air temperatures at 0.5 and 2.0 m above the soil surface; and (4) soil temperatures at depths of 1, 30, and 60 cm. Totalizing anemometers measured wind speeds. Some of the instrumentation that was used for 2 years is shown in figures 3 and 4. Soil temperatures were recorded continuously for

3 years at depths of 3 and 30 cm by means of battery-powered recorders. Net radiometers used were a modification of the type described by Suomi and Kuhn (1957). These were constructed and calibrated in U.S. Geological Survey laboratories.

Figure 3.--Shrub-covered, north-facing slope with micro climatic instruments. Instruments visible from left to right are: anemometer; central mast with wet- and dry-bulb temperature sensors; and upright plus inverted pyroheliometers on top of the mast; and a net radiometer.

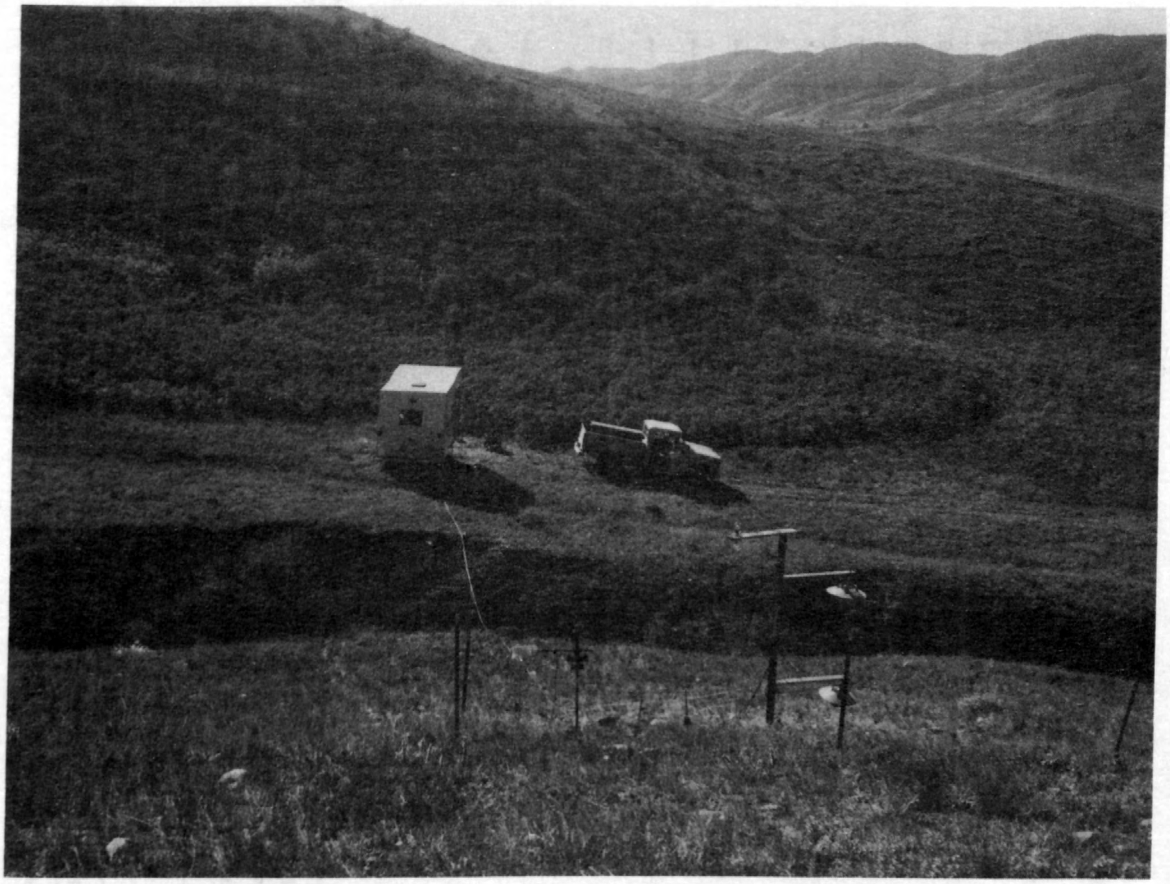


Figure 4.--South-facing slope in the foreground, with microclimatic instruments; north slope in the background. Cables from the instruments transmit data to recorders in the centrally located trailer.

CONTRASTS BETWEEN NORTH- AND SOUTH-FACING SLOPES

Vegetation

Different shrub species occupy overlapping zones from the upper to lower north-facing slope, which is a marked contrast to the grass-covered, south-facing slope (fig. 5). This distribution of plants is similar to that in southeastern Michigan (Cooper, 1961), where more phanerophytes (plants with buds 25 cm or more above the soil surface) grow on north-facing slopes, and more hemicryptophytes (plants with buds near or within the soil surface) grow on south-facing slopes.

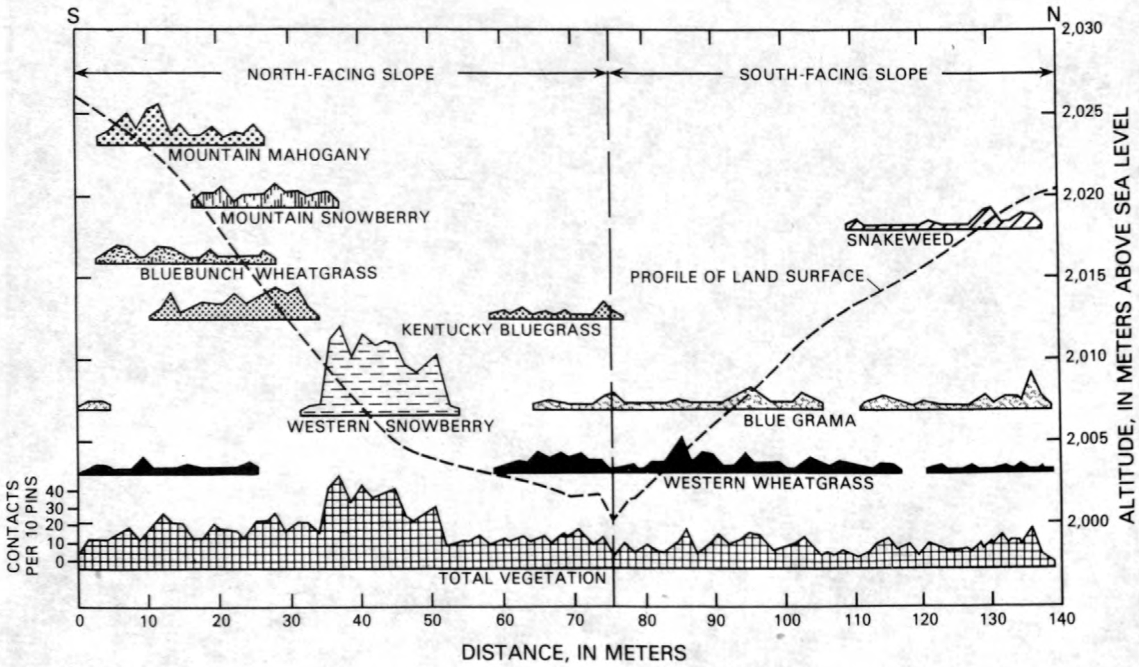


Figure 5.--Distribution of selected plant species on north- and south-facing slopes. Distribution of plant species on the slopes is shown as contacts per 10 pins per 1.5 meters from the south side to the north side of the valley as measured in 1962.

Although distributions of shrub species overlap on the north-facing slopes, each species grows within a slightly different environment. Mountain mahogany (*Cercocarpos montanus* Raf.) forms the upper north-slope zone; associated with it is bluebunch wheatgrass (*Agropyron spicatum* Scribn. and Smith). Although bluebunch wheatgrass grows locally and is infrequently found as far south as New Mexico, it probably approaches its thermal limit (lower altitudinal limit combined with southern latitude) on this north slope. The general lower altitudinal limit in Colorado is 1,524 m (Harrington, 1954), but the altitudinal limit is lower in northern Colorado than in southern Colorado. Thus, probable factors limiting its southern distribution are tolerance to maximum temperature and competition for soil moisture.

A more detailed assessment of plant-species distribution on the contrasting slopes is presented in table 1. Plant communities are separated on the basis of the most abundant and most conspicuous species present. As shown in figure 5, there is some overlap in species distribution, and the continuum concept (Curtis, 1955) could be applied to the data. As their common names indicate, mountain mahogany and

Table 1.—*Vegetation and surface materials in different plant communities on north- and south-facing slopes as measured in 1961*
[The transect begins near the top of the north-facing slope; the toe of the north-facing slope is at a horizontal distance of about 76 meters; mulch consists of fallen and standing dead-plant material; m, meters; dashes indicate no contacts]

Genus and species	Common name	Vegetation types (Contacts per 100 pin projections for indicated horizontal distance, in meters)							
		Mountain-mahogany (0–17 m)	Mountain snowberry (17–32 m)	Western snowberry (32–47 m)	Western wheatgrass (47–70 m)	Kentucky bluegrass (70–73 m)	Western wheatgrass (73–110 m)	Western wheatgrass–Blue grama (110–123 m)	Blue grama–snakeweed (123–145 m)
SHRUBS									
Artemisia frigida	Fringed sagewort	0.9	--	--	--	--	--	--	--
Cercocarpus montanus	True mountain-mahogany	74.5	15.0	--	--	--	--	--	--
Gutierrezia sarothrae	Broom snakeweed	--	--	--	--	--	--	1.6	48.3
Oppuntia polyacantha	Plains prickleypear	2.7	--	--	0.9	--	--	--	--
Ribes cernua	Currant	--	--	9.2	--	--	--	--	--
Rosa arkansana	Rose	--	--	2.3	--	--	--	--	--
Symphoricarpus occidentalus	Western snowberry	--	--	290.0	0.9	--	--	--	--
Symphoricarpus oreophylus	Mountain snowberry	--	56.0	10.0	--	--	--	--	--
GRASSES									
Agropyron smithii	Western wheatgrass	10.0	2.0	--	52.7	15.0	65.0	18.4	5.9
Agropyron spicatum	Bearded bluebunch wheatgrass	30.0	9.0	--	--	--	--	--	--
Bouteloua curtipendula	Sideoats grama	--	--	--	--	--	--	4.0	5.9
Bouteloua gracilis	Blue grama	0.9	--	--	10.9	--	7.5	21.2	50.0
Bromus tectorum	Cheatgrass brome	4.5	--	--	19.1	--	--	5.2	3.3
Koeleria cristrata	Prairie junegrass	1.8	--	--	0.9	--	--	0.4	--
Poa pratensis	Kentucky bluegrass	26.4	--	1.5	8.2	45.0	--	--	--
Stipa viridula	Green needlegrass	10.9	100.0	--	0.9	10.0	--	7.2	1.7

FORBS									
Artemisia ludoviciana	Louisiana sagebrush	3.6	2.0	--	--	--	--	4.8	--
Aster multiflorus	Prairie aster	--	--	--	--	--	--	1.6	--
Astragalus drummondii	Drummond milkvetch	2.7	--	--	--	--	10.0	2.4	1.7
Carex heleophila	Sun sedge	11.8	4.0	--	--	--	--	2.4	11.7
Gaura coccinea	Scarlet gaura	--	--	--	--	--	--	2.0	3.3
Helianthus annus	Common sunflower	--	--	--	--	--	--	0.4	--
Khunia glutinosa	False boneset	--	--	--	--	--	--	0.8	--
Lactuca sp.	Wild lettuce	--	--	--	--	--	--	0.4	--
Liatris punctata	Dotted gayfeather	--	--	--	--	--	--	1.2	--
Psoralia tenuifolia	Wild alfalfa	--	--	--	--	--	7.5	8.0	5.9
Solidago glaberrima	Smooth goldfenrod	--	1.0	3.1	--	--	--	--	--
	Unidentified forbs	--	--	--	--	--	--	0.4	--
MULCH		88.2	105.0	125.4	90.9	65.0	68.8	85.0	66.7
BARE SOIL		8.2	3.0		9.1	20.0	21.2	8.0	6.4
ROCK		6.4	7.0	1.5	0.9	10.0	3.4	7.6	13.3

mountain snowberry (*Symphoercarpos oreophilus*, Gray) are characteristic of a cool climate and occupy the north–facing slope at the altitude of this study area (table 1). Grasses, which are considered to be typical of a cool climate, that grow on this slope are: bluebunch wheatgrass, green needlegrass (*Stipa viridula*), junegrass (*Koleria cristata*), Kentucky bluegrass (*Poa pratensis*), and western wheatgrass (*Agropyron smithii*). Plants, which are considered to be typical of a warm climate, that grow on the south–facing slope include: annual sunflower (*Helianthus anus*), blazing star (*Liatris punctata*), blue grama (*Bouteloua gracilis*), side–oats grama (*B. Curtipendula*), snakeweed (*Gutierrezia sarothrae*), and wild alfalfa (*Psoralea tenuifolia*).

Soils and Microclimates

Soil temperatures were not measured in all plant communities, but some of the differences on the contrasting slopes are shown in figure 6. Soil temperatures were consistently lower on the north–facing slope during the four seasons in which measurements were made. On October 26, 1963, temperatures were almost constant at depths of 30 and 60 cm, but were quite variable near the land surface. During the day, the surface soil temperature was 30°C lower on the north–facing slope; at depth, temperatures were 9 to 10°C lower on the north–facing slope. Throughout the year, the soil temperatures on the north–facing slope at depths of 1 and 30 cm were much lower than temperatures at the same depths on the south–facing slope.

Freezing and thawing tend to loosen soils because water expands as it freezes and contracts as it thaws. The loosened soil then is more readily available for transport over soil surfaces. In 1963, the number of freeze–thaw cycles on the south–facing slope was 57; on the north–facing slope, the number was 24. In addition to more freeze–thaw cycles on south–facing slopes, Cooper (1959) also considered the larger number of wetting–and–drying cycles to be of importance in soil genesis as was shown by greater clay content and lesser organic matter in soils of south–facing slopes. Franzmeier and others (1969) attributed the lesser organic matter in soils of south–facing slopes to greater oxidation rates caused by higher temperatures. Trends in organic matter on the slopes of Green Mountain are not entirely consistent; the soil of the western–snowberry community near the base of the north–facing slope contained the greatest proportion of organic matter, about 7 percent more than that for any other area.

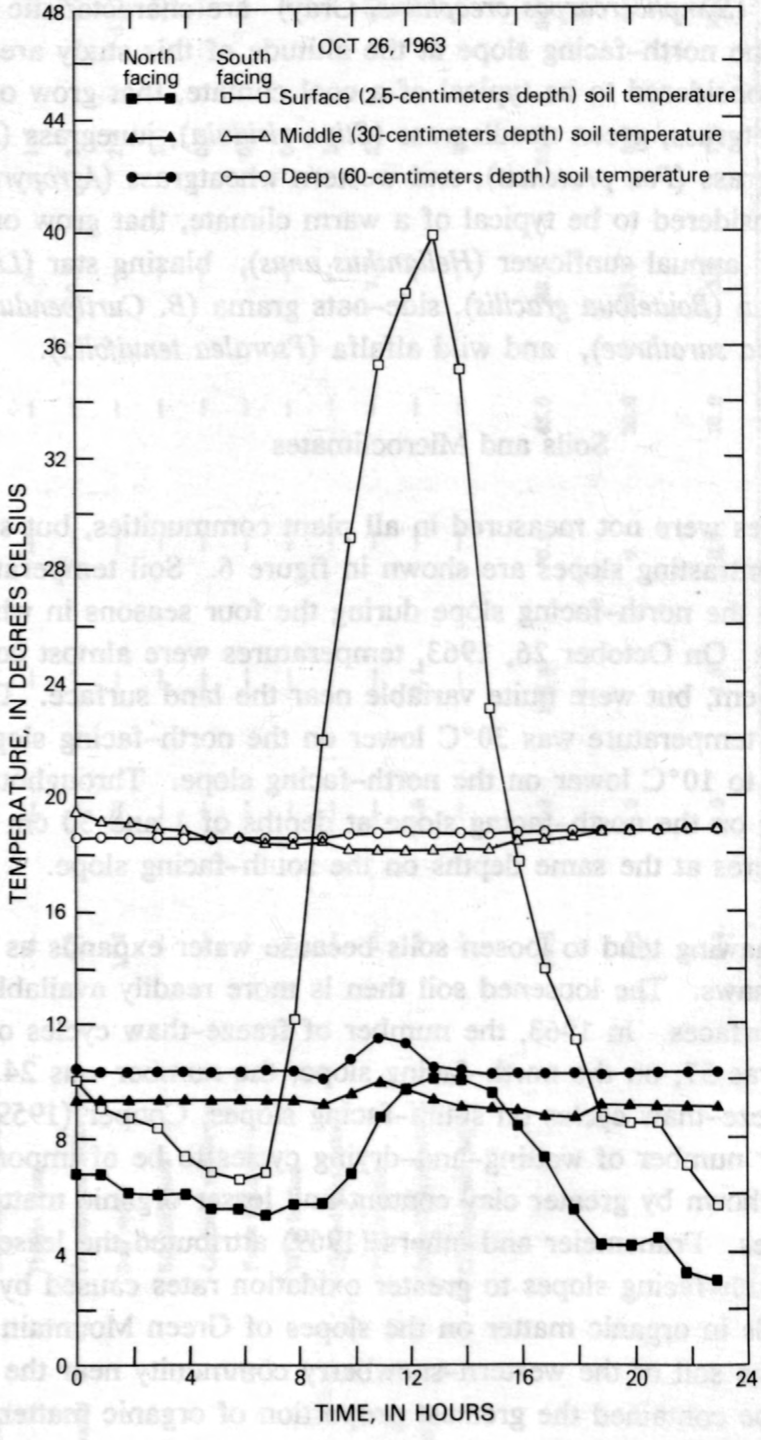


Figure 6.--Contrasting soil temperatures on north- and south-facing slopes.

Soil-moisture sampling in the spring of 1964 (fig. 7) indicated that mountain mahogany occupied the driest areas of the north-facing slope. This condition is not explained by incoming radiation (fig. 8) and may be attributable to greater wind velocities, less infiltration of moisture, and possibly greater runoff and snow transport by wind from the area. Soil pH was neutral (7.0), and soil depths (A and B) were shallow horizons (30 cm). The organic-matter content of the soil was one of the smallest measured (3.9 percent).

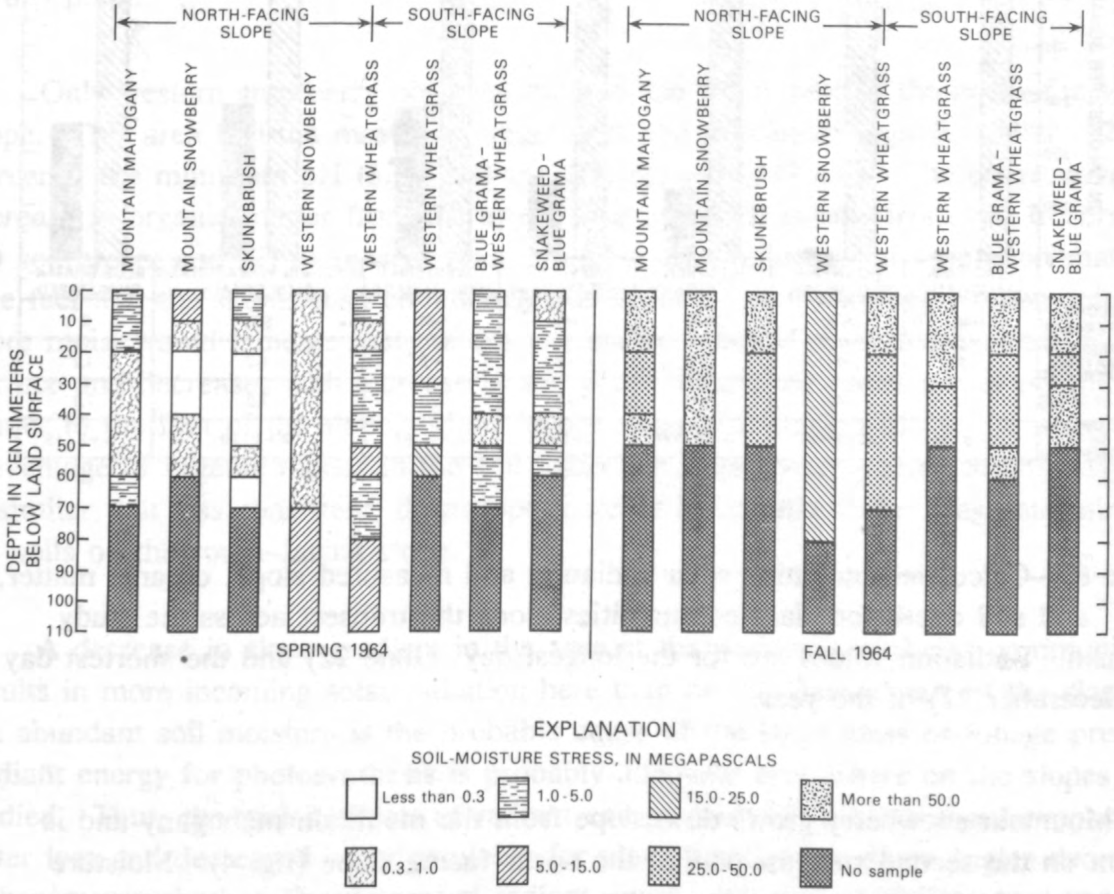
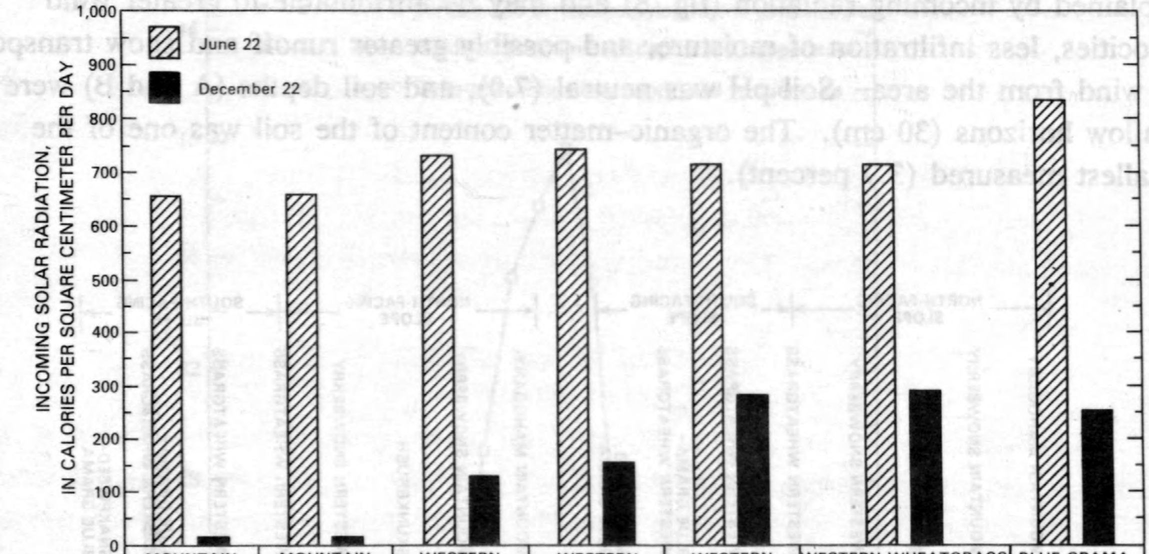


Figure 7.--Soil-moisture stress (or potential, if a negative sign is added to all values) measured in spring and fall for the eight vegetation communities on contrasting slopes.



	MOUNTAIN MAHOGANY	MOUNTAIN SNOWBERRY	WESTERN SNOWBERRY	WESTERN WHEATGRASS	WESTERN WHEATGRASS	WESTERN WHEATGRASS-BLUE GRAMA	BLUE GRAMA-SNAKEWEED
SLOPE, IN PERCENT	N 48	N 40	N 12	N 5	S 33	S 35	0
ORGANIC MATTER, IN PERCENT	3.9	4.1	12.2	4.9	4.9	5.2	3.2
pH, IN UNITS	7.0	7.0	5.0	5.5	5.0	7.0	7.0
SOIL DEPTH, IN CENTIMETERS	A + B = 30	A + B = 15	A + B = 137	A + B = 76	A + B = 67	A + B = 49	A + B = 43

Figure 8.--Calculated incoming solar radiation and measured slope, organic matter, pH, and soil depth for plant communities along the transect across the study basin. Radiation values are for the longest day (June 22) and the shortest day (December 22) of the year.

Mountain snowberry grows downslope from the mountain mahogany and is present on the second steepest part of the north-facing slope (fig. 4). Moisture availability (fig 8) increased in the mountain-snowberry community, but soil depth decreased and pH remained the same as in the mountain-mahogany community. Also indicative of increased soil moisture (fig. 7), was the presence of Kentucky bluegrass (*Poa pratensis* L) instead of bluebunch wheatgrass on the lower one-half of the north-facing slope (fig. 4).

Skunkbrush (*Rhus trilobata* Nutt. ex T. and G.), not shown in figure 5 but represented in figure 6, grows in a narrow strip between the mountain-snowberry and western-snowberry (*Symphoricarpos occidentalis* Hook.) communities. Soil moisture was more readily available in the skunkbrush community than in any other community sampled. In addition to longer flow durations and associated larger quantities of water entering the soil on lower slopes after precipitation, there may be lateral diffusion through the soil mantle into the area of the skunkbrush community. A slight break in topography, a ridge, coincided with the presence of skunkbrush, and the soil contained more stones of cobble size. These stones may have increased infiltration, decreased evapotranspiration, and decreased erosion caused by raindrop splash. The ridge may indicate that soil creep is most active to this point on the slope and, associated with the creep process, water moves downslope through the soil to this point.

Only western snowberry occupied most of the lower part of the north-facing slope. This area had the most total vegetation, the maximum organic matter (12.2 percent), the minimum pH (5.0), and the deepest soil (137 cm). The progressive increase in organic matter from the upper to lower slope results from two factors: (1) soil creep; and (2) increased water available for production of vegetation material. The fact that the skunkbrush community above the western-snowberry community is more moist would indicate that the creep process, which is most active at the soil surface and decreases with increase in soil depth, causes displacement of organic matter to the foot of the slope. More foliage mass also contributed to the larger percentage of organic matter in the soil under the western-snowberry community. A similar, but less consistent, downslope increase in organic matter was determined for soils on the south-facing slope.

A decrease in slope gradient in the area at the western-snowberry community results in more incoming solar radiation here than on the steeper part of the slope, but abundant soil moisture is the probable cause of the large mass of foliage present. Radiant energy for photosynthesis is probably adequate everywhere on the slopes studied. Thus, the major effects of radiant energy probably are increased evaporative water loss and decreased water available for plant functions as slope angles decrease or become southerly. The decreased radiant-energy effect is partially compensated for by increased overland flow reaching the lower slopes. Duration of flow over an area may be far more important than infiltration rates in determining water available for plant functions (Branson and others, 1970).

Western wheatgrass (*Agropyron smithii* Rydb.) was widely distributed in the basin, but was dominant only in the valley bottom and on lower south-facing slope (fig. 5). On the drier and warmer, upper, south-facing slope, blue gramsa (*Bouteloua gracilis* [H.B.K.] Lag.) is one of the dominants. Other drought- and hightemperature-tolerant species on the south-facing slope included yucca (*Yucca glauca* Nutt.) and pricklypear cactus (*Opuntia polyacantha* Raf.). Snakeweed (*Gutierrezia sarothraen* [Pursh] Britt. and Rusby), also a warm-climate plant, becomes a dominant on the upper part of the south-facing slope where the slope angle becomes slightly less steep.

Geomorphic Processes

The south-facing slope has considerably more bare soil and exposed rock than the north-facing slope. Studies in Colorado have determined that runoff increases as the area of bare soil increases (Branson and Owen, 1970); studies in New Mexico have determined that sediment yields increase as vegetation plus mulch decrease (Shown, 1971). One would expect similar results on this south-facing slope. A greater surface-erosion rate is a probable cause for the less steep gradients on the south-facing slope shown in figure 5.

SUMMARY

A small drainage basin on Green Mountain, an isolated foothill near Denver, Colorado, was studied to determine causes for differences in vegetation and contrasting slope angles on north- and south-facing slopes. Vegetation species on north-facing slopes were predominantly shrubs, whereas herbaceous vegetation dominated south-facing slopes. The principal cause for these vegetation contrasts is greater solar radiation on south-facing slopes. Associated with the greater solar radiation on south-facing slopes were higher soil temperatures, greater evaporation, decreased soil moisture available for plant growth, and generally less organic matter in soil profiles. More periods of freezing and thawing, and more area of bare soil resulted in more runoff and erosion on south-facing slopes. These processes are probable causes for south-facing slopes being less steep than north-facing slopes.

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