

Relationships between Aspect and Plant Distribution on Calcareous Soils near Missoula, Montana

Abstract

Aspect and depth to the CaCO₃ horizon explain most of the variation in the plant communities on calcareous soils near Missoula, Montana. Linear regression and the Mann Whitney U test were used to evaluate trends in soil properties and plant communities. The CaCO₃ horizon (a proxy for leaching) ranges from 2 to 48 cm deep on the south aspect and ridge top and 46 to 125 cm deep on the north aspect. The forb-grass community dominates the south-facing slopes and the ridge top, providing more than 90% coverage, whereas on the forested north-facing slope, tree coverage ranges from 9 to 56% and forbs/grasses from 23 to 69%. Considerable difference in species composition occurs on each aspect. Differences in leaching are exemplified by higher [H⁺] on the north aspect (pH 6.6-7.0) than on the south aspect and ridge top (pH 7.1-8.3), partly as a result of twice the moisture content on the north slope (17 to 24% versus 10 to 12%).

Introduction

Through its effects on net solar radiation and microclimate, aspect can have an important influence on the formation of soils (Jenny 1941, Buol et al. 1989, Carter and Ciolkosz 1991) and plant community structure (Cantlon 1953, Gilbert and Wolfe 1959, Whittaker 1975, Yeaton and Cody 1979, Hicks and Frank 1984). This influence occurs in areas as diverse as interior Alaska (Krause et al. 1959), Alberta (Liefers and Larkin-Liefers 1987), Israel (Boyko 1947), Spain (Dariage 1987), Montana (Goldin and Nimlos 1976), and the eastern United States (Franzmeier et al. 1969, Losche et al. 1970, Hutchins et al. 1976, Boerner 1984). Higher levels of solar radiation on sun-facing slopes result in higher soil temperatures than on slopes facing away from the sun (Franzmeier et al. 1969, Hutchins et al. 1976, Macyk et al. 1978), lower soil moisture levels (Gilbert and Wolfe 1959, Stoeckler and Curtis 1960), and decreased solum development (Cooper 1959, Gilbert and Wolfe 1959, Green 1987, Carter and Ciolkosz 1991). Due to its effects on plant cover and soil depth, aspect influences runoff and soil erosion (Branson et al. 1981, Green 1987, Agassi et al. 1990, Marques and Mora 1992) and resulting levels of soil P (Klemmedson and Wienhold 1992).

Marked aspect-related differences have been reported for a range of ecosystem properties: soil physical and chemical characteristics (Finney et al. 1962, Franzmeier et al. 1969, Macyk et al. 1978, Hicks and Frank 1984); soil genesis (Green 1987, Carter and Ciolkosz 1991); stream water chemistry (Sallese et al. 1982); plant species diversity (Boyko 1947, Pook and Moore 1966, Whitney 1991, Kutiel 1992); and forest site properties (Trimble and Weitzman 1956, Hutchins et al. 1976, Hicks et al. 1982, Verbyla and Fisher 1989, Bale and Charley 1993, Mudrick et al. 1994). While the reported magnitudes of the impacts of aspect vary considerably, and may be complicated by variations in other environmental factors, there is sufficient evidence to show that at some steep mid-latitude sites, aspect may exercise a primary control in maintaining ecosystem disjunctions (Bale and Charley 1993).

Most studies acknowledge a relationship between soil moisture, as influenced by aspect, and plant distribution or soil development, including Goldin and Nimlos (1976), in the northern Rocky Mountains on calcareous parent materials. Green (1987) has shown a close correlation between aspect, leaching, and soil development in north-western Nebraska.

The purpose of this study was to examine the relationship between aspect and its effects on leaching (as measured by depth to carbonates) and consequent plant distribution.

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Description of the Area

The study area is located on a steep, rocky hill approximately 6.5 km NNE of Missoula, Montana (46°55'N, 114°00'W). The annual precipitation is approximately 450 mm, which occurs mostly as snow between November and April. The parent material is Helena limestone, a gray, laminated, sandy, and argillaceous limestone with minor amounts of impure argillite and impure quartz-

ite. The soils are principally of the Repp soil series (loamy-skeletal, mixed, superactive, frigid Typic Haplustepts) (Anderson et al. 1995). Repp soils are mapped on more than 20,000 ha in 6 soil survey areas in Montana (Wade Bott, Natural Resources Conservation Service, Bozeman, Montana, personal communication). The south exposure is oriented at 225° and the north slope at 10°. Slope steepness is 50 to 60 percent and elevation ranges from 1100 to 1275 m (Figure 1).

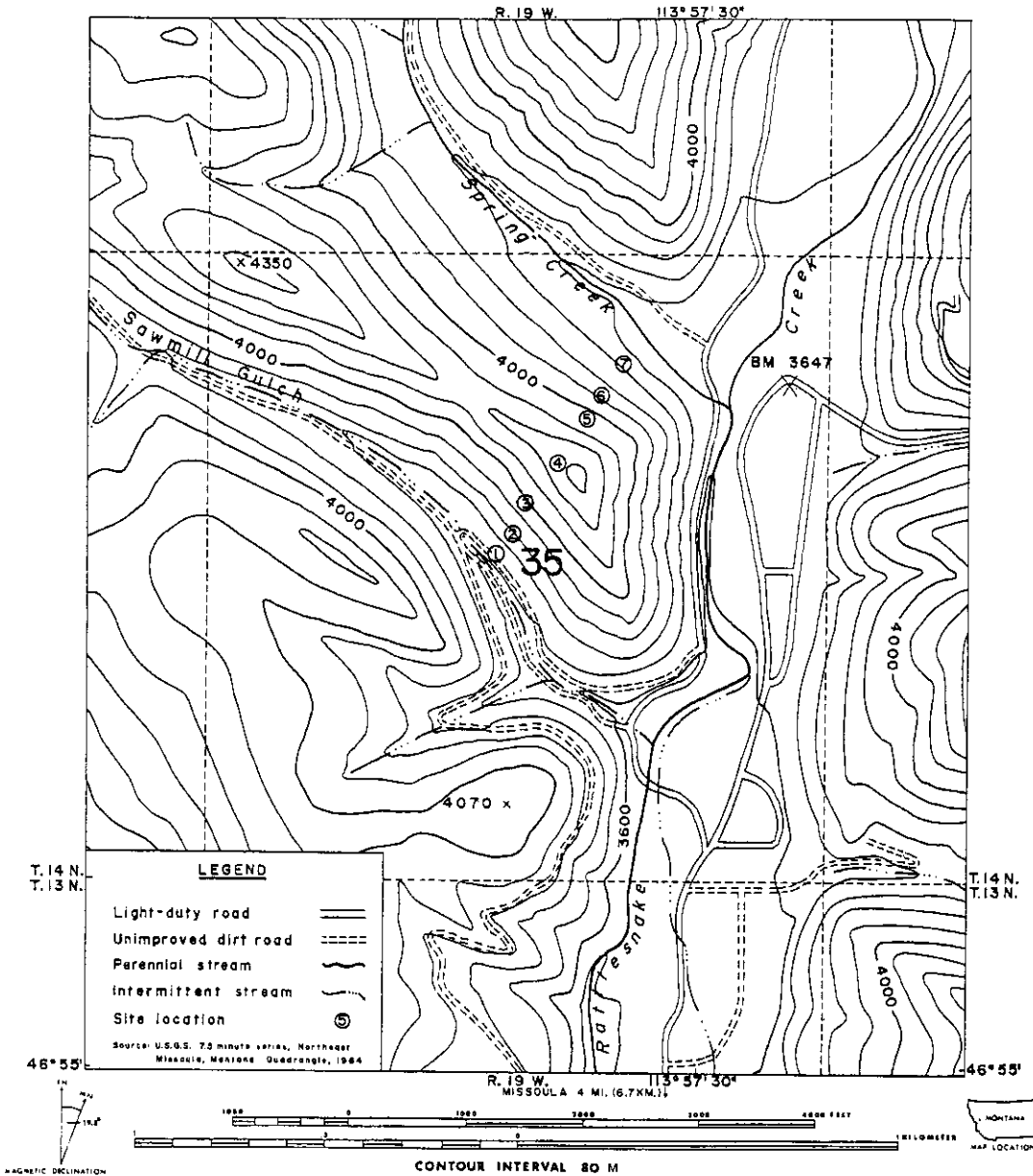


Figure 1. Map of the study area showing plot locations. Elevations are in meters.

Much of the vegetation, particularly on the south slope, has been subject to grazing as well as to fire and logging, as indicated by charred stumps and trees. Although forest fires have a long history in Montana (Arno 1980), which could have affected the plant communities on this site, the effects of fire were not studied. Although there has been disturbance due to fire, grazing, and logging, these probably had less effect on life form as compared to individual species.

Materials and Methods

Stations were located on the lower, middle, and upper parts of the north and south slopes and on the ridge top. From the plot center at each station, a ten meter line transect was established perpendicular to the slope for species identification, cover, and frequency. Cover was measured as the length in cm a species crossed the line transect and percent cover as relative to the total length (10 m).

Soil pH, spring moisture content, and depth to carbonates were measured from at least three locations within 30 meters of the plot center. Samples to determine pH (1:1 water), soil mois-

ture, and soil texture were taken from the upper 15 cm. Soil pH was analyzed on an Orion pH meter and soil texture using the hydrometer method of Day (1965).

Depth to carbonates was determined by applying dilute HCl from the land surface downward until an effervescence of CO₂ was elicited.

The Spearman Rank test was used to examine correlation of various soil and vegetative properties with depth to carbonates. The Mann-Whitney U test was used to test differences between north and south slope properties (Zar 1998).

Results

Twenty-eight vascular species were identified in the plots: two trees, seven shrubs, and 19 herbaceous plants (Figure 2 and Table 1). Fifteen species occurred on the south slope and 15 on the north slope, of which only three (Milk-vetch (*Astragalus* spp.), Strawberry (*Fragaria* spp.) and Oregon grape (*Berberis repens*)) also occurred on the south slope. The ridge site had 12 species, seven of which it shared with the south slope, three with the north slope and two were unique to the ridge (Sandberg's bluegrass (*Poa secunda*)).

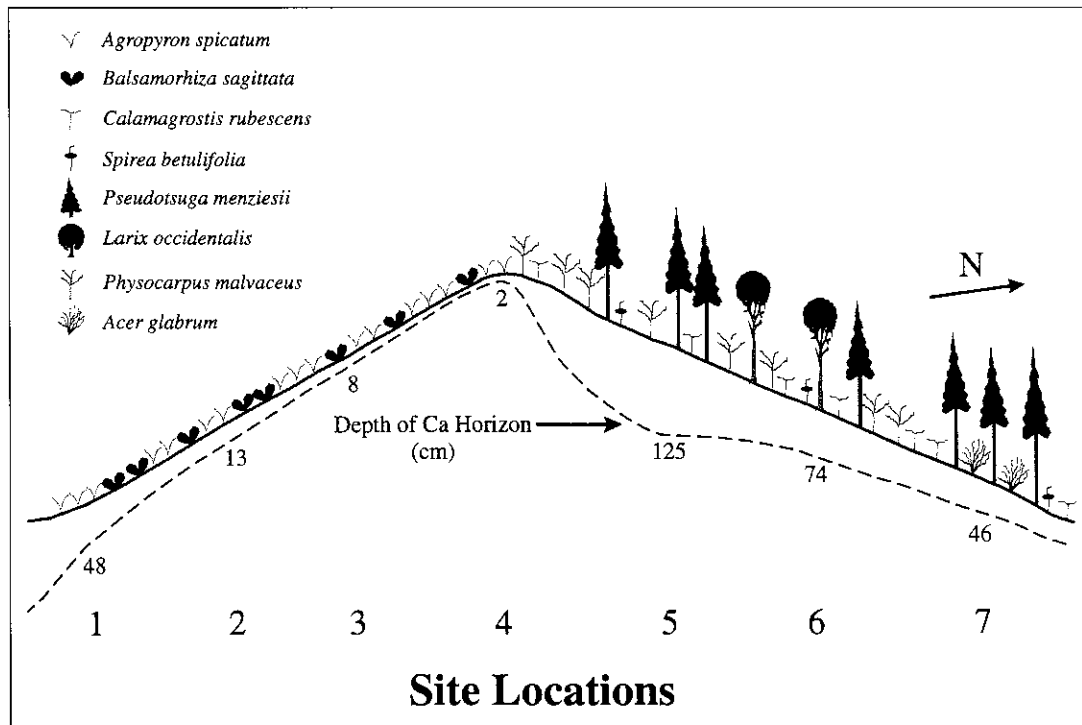


Figure 2. Relationship between depth to carbonates and plant distribution.

TABLE 1. Percent cover of species occupying at least 3% of the study area

Species	Site Number							Average cover
	1	2	3	4	5	6	7	
<i>Acer glabrum</i>							16	5
<i>Agropyron spicatum</i>	50	70	54	49				20
<i>Arnica cordifolia</i>				3	9	3	3	3
<i>Balsamorhiza sagitata</i>	33	13	17	3				6
<i>Calamagrostis rubescens</i>				6	10	5	18	8
<i>Larix occidentalis</i>						31		7
<i>Physocarpus malvaceus</i>				3	47	7	16	12
<i>Pseudotsuga menziesii</i>					21	46	42	26

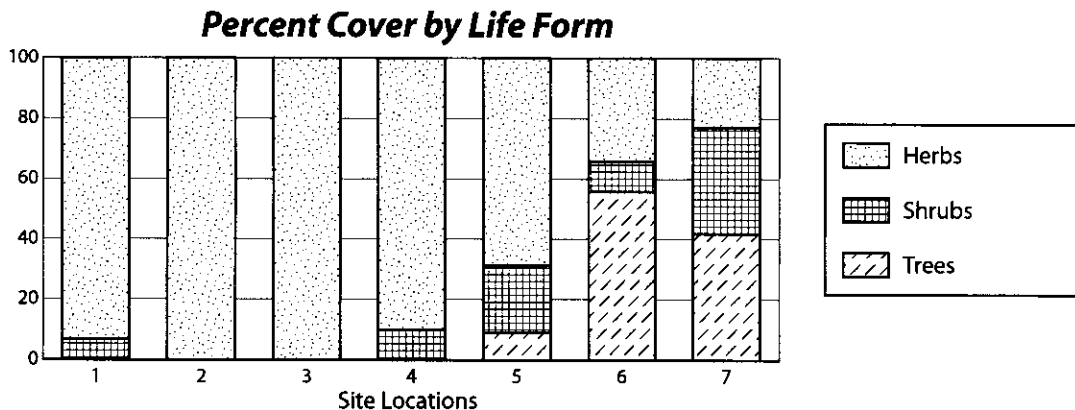


Figure 3. Relative cover by life form at site locations.

and kinnikinnick (*Arctostaphylos uva-ursi*). The three north slope sites and the three south slope sites differ significantly in soil moisture and total cover (Mann-Whitney U test, $P=0.05$).

The ridge and south slope were similar in species composition, being dominated by the herbaceous layer, especially graminoids, whereas the north slope had a mixture of trees, shrubs, and herbs. Herbs were dominant on the upper north slope, trees on the mid-slope, and trees and shrubs on the lower north slope (Figure 3).

Average spring moisture content ranged from 17 to 24% on the north slope as compared to 10 to 12% on the south slope and ridge. Each position on the north-facing slope showed a lower pH (6.2 to 6.8 on the north slope compared to 7.1 to 8.3 on the south slope and ridge) (Figure 4), higher total cover (Figure 5), and deeper carbonates (Fig-

ure 2) than the similar slope position on the south slope except at the toe slope.

The depth to carbonates was greatest at the top of the north slope (125 cm) and decreased down the north slope (74 cm mid-slope and 46 cm toe slope) with increasing plant cover. On the south slope the depth to carbonates was highest at the bottom (48 cm) and decreased upslope to 13 cm at mid-slope and 8 cm at the upper slope. The depth to carbonates on the ridge was the shallowest at 2 cm.

The following plant and soils data showed definite relationships with the depth to carbonates: a) pH was negatively correlated ($P=0.01$) and b) total cover and herbaceous plant cover positively correlated ($P=0.05$). Based on these statistical analyses, the variation in plant distribution on this hill was largely explained by the interaction of aspect and depth to carbonates.

pH in the top 15 centimeters

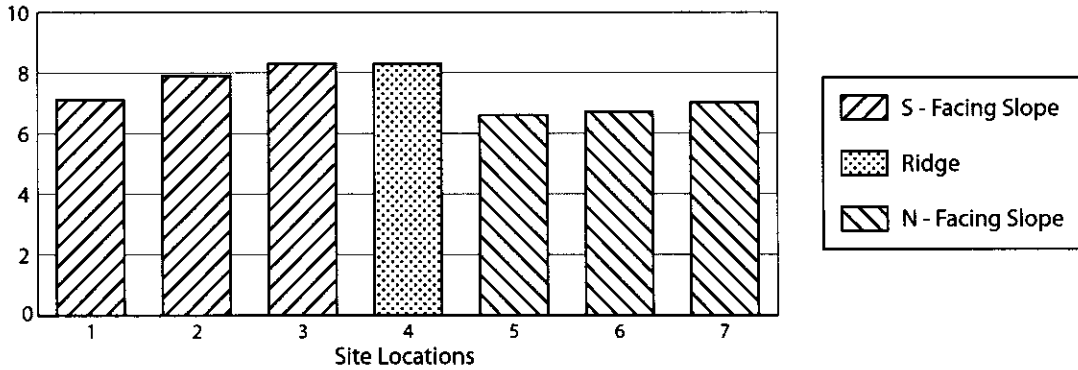


Figure 4. Soil pH in the upper 15 cm at site locations.

Total Cover (cm)

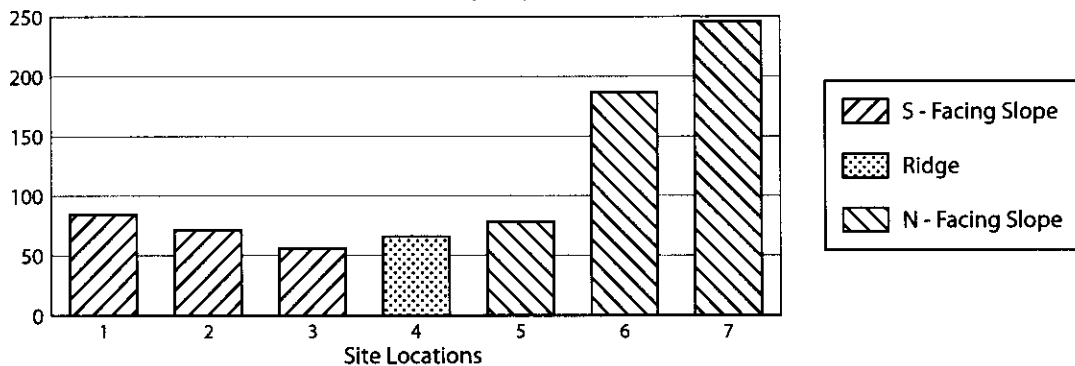


Figure 5. Total plant cover at site locations.

Discussion

The study indicates greater diversity on the north slope, where there is nearly an even mixture of trees, shrubs, and herbs, whereas the south slope and ridge are dominantly graminoids (Figure 3). Hutchins et al. (1976) also found greater diversity on northerly slopes and less developed vegetation on south-facing slopes, but Kutiel (1992) found the reverse in Israel due to the abundance of annuals in the rainy season.

In the study area moisture loss was probably accelerated on south-facing slopes since the sun angle at 47° N latitude is nearly perpendicular on 40-60% south-facing slopes during late spring to early fall. This trend is similar to the findings of Macyk et al. (1978), Hutchins et al. (1976), and Cooper (1960). As pointed out by Cooper (1960) and Loesche et al. (1970), greater soil development can occur on warmer south slopes if ad-

equately soil moisture is available. Such was not the case in this semi-arid region. The higher moisture conditions on the north slope have probably increased weathering, thereby producing a finer-textured soil on the north slope, which had 20% more silt (59.5% as compared to 39.9%) than the south slope with similar clay contents (about 8.5%). This finer texture promotes a higher water holding capacity. Some silt could have resulted from loess deposition.

The shallowest carbonates occur at the ridge site and are also shallow on the south-facing slope (Figure 2). The depth to carbonates was greatest at the top of the north slope (125 cm) probably due to accumulation of the most snow (compounded by increased snow from the ridge site) and less total cover and basal area than other north slope sites which reduces evapotranspiration and, therefore, increases leaching. The depth to

carbonates decreased down the north slope (74 cm mid-slope and 46 cm toe slope) with increasing vegetative cover. Similarly, Carter and Ciolkosz (1991) found evaporative differences due to aspect produced thicker soils on north slopes.

On the south slope the depth to carbonates was greatest at the bottom (48 cm) since this site is protected somewhat from solar insolation in the winter and early in the growing season from mountains across the narrow valley and, in addition, probably had increased runoff from upslope. The mid-slope site experienced these phenomena to a lesser extent (depth to carbonates 13 cm), the upper slope even less (8 cm), and the ridge the shallowest (2 cm). The shallower depths on the south slopes and ridge result from evaporative effects as well as to snow losses due to wind.

The increased depth to carbonates and the higher moisture content from the top of the south slope to the base can probably be attributed to the increasing influence of shading and the runoff of moisture to the base of the slope. The greater amount of cover, and consequently higher evapotranspiration, on the toe of the north slope kept the depth to carbonates shallower than other parts of the north slope.

The comparative trend of pH on north versus south slopes (lower or north slopes) is similar to the pattern observed by Kutiel (1991) in Israel but the reverse of pH trends in studies in the humid eastern United States: Franzmeier et al. (1968) in the Cumberland Plateau, Losche et al. (1970) in the southern Appalachians, Hutchins et al. (1976) in Kentucky, and Boemer (1984) in southern Ohio. Each of these humid study areas has plentiful summer moisture relative to western Montana. The deeper soils found in this study on the north slopes follow a similar pattern found in Cooper (1960), Marques and Mora (1992), and Carter and Ciolkosz (1991). Greater leaching on north slopes

in Montana will also result from a longer lasting snowpack than on south slopes.

Conclusions

The influence of aspect on soil moisture content and leaching of carbonates has been shown in this study to have significant relationships with plant distribution. In semiarid western Montana, these influences are particularly reflected in the nature of the vegetation with typical grassland being limited to the middle and upper south slopes and the ridge top, where the depth to carbonates is less than fifteen centimeters from the surface and grading to the more mesic conditions and greater tree cover on the lower south slope. The overstory is open and scattered on the lower south slope and the total cover of both overstory and undergrowth vegetation decreases upslope as depth to carbonates becomes shallower up the south slope. Shallowness and rockiness of the soil and the high solar insolation levels and probably wind on the steep south-facing slope cause moisture stress as well as osmotic stress due to the high calcium carbonate content and contribute to the xeric conditions on these slopes.

Plant distribution is not completely dependent on the depth to carbonates but probably on the interaction of this factor with aspect and available moisture. If the depth to carbonates were the sole criterion, the site 1 vegetation over 48 cm to carbonates would look very similar to the site 7 vegetation on the north slope with a 46 cm depth to carbonates.

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