THESIS

SOIL-VEGETATION RELATIONSHIPS OF A BITTERBRUSH-SAGEBRUSH ASSOCIATION IN NORTHWESTERN COLORADO

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY HUGH CUNNINGHAM ENTITLED SOIL-VEGETATION RELATIONSHIPS OF A BITTERBRUSH-SAGEBRUSH ASSOCIATION IN NORTHWESTERN COLORADO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

SOIL-VEGETATION RELATIONSHIPS OF A BITTERBRUSH-SAGEBRUSH ASSOCIATION IN NORTHWESTERN COLORADO

Site evaluation is becoming increasingly important as management of forest and rangelands intensifies. Soil-vegetation studies may help to provide a basis for site prediction on disturbed areas, or areas considered for type conversion. In this study soil properties were compared with native vegetation responses in a bitterbrush (*Purshia tridentata*), sagebrush (*Artemisia spp.*) association on a single parent material. The effort was directed toward isolating those soil characteristics which are most valuable as indicators of potential vegetation production.

Detailed soil and vegetation data were collected from 22 stands, all occurring on a sandy parent material, within the same climatic region, and on similar topography. Stands were selected along gradients of vegetation growth responses, i.e., changes in species composition, shrub height, shrub density, vigor, etc. Soil profiles at each location were described, and samples were collected for laboratory analysis of physical and chemical characteristics.

Analysis of data by simple correlation and stepwise multiple regression revealed that the amount of gravel and rock occurring as

a layer in the soil profile is the most important factor for predicting bitterbrush production on the area studied. The negative effect of the coarse fragments layer on production of the deep-rooted shrub is thought to indicate less moisture penetration. Other negative factors found important to the prediction equation were: available P, available K, and percent sand, all in the top six inches. The only positive factor appearing in the prediction equation was available P at a depth of 6-12 inches.

Silver sagebrush production was apparently influenced by more favorable moisture conditions near the surface than by restriction of deep penetration of water. Thickness of the A horizon, percent organic matter in the 6-12 inch zone, and extractable Mg in the 12-24 inch strata were positive factors, while depth of abundant rooting and extractable Mg in the surface six inches were negative factors included in the prediction equation.

Measurements must be taken of chemical and physical properties at several depths in order to predict total forage production. Surface soil measurements found important were: available K and percent sand in the top six inches. Their effects were negative. The amount of gravel and rock, and the thickness of the B2 horizon were also negatively correlated with production, while available K and percent coarse sand in the 12-24 inch layer had a positive influence on production.

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INTRODUCTION

Successful land management results when a careful balance is maintained between the desire for a particular level of productivity and the inherent suitability of the land to meet that desire. Greater demand from land resources in recent years has narrowed the latitude in decision making which was enjoyed under extensive management systems of the past.

Fundamental to any decision regarding use or manipulation of vegetation is a knowledge of the relationships between the native plants and other factors of the natural environment. Soil, because it is relatively stable, and because it reflects other environmental factors through interactions, can often provide a reliable evaluation of site productivity potential.

Previous studies at Colorado State University have investigated soil and site characteristics associated with production and palatability of sagebrush (Smith, 1966; and Powell, 1968). This investigation continues to examine the relationships between vegetation composition and production and soil properties on sagebrush ranges in Northwestern Colorado.

Antelope bitterbrush (*Purshia tridentata*) occurs as an associate of sagebrush on many sites, and is a highly favored browse species. Because of this the revegetation of deer winter ranges with bitterbrush has been suggested. In most cases scientific estimates of the potential success from such ventures are unavailable. This study was conducted to establish a basis for providing such information to land managers.

Specifically, the objectives were: (1) to describe and quantify as many soil properties and phytosociological characters as possible on each of several stands selected from the full range of bitterbrush soils within a "controlled" natural environment; (2) to screen data by simple correlation and regression techniques to determine the most effective bitterbrush production indicators; and (3) to devise a multiple regression equation which includes the fewest number of factors that can effectively predict vegetation production.

Although it would be advantageous in many ways to understand the nature of how and why soil factors affect vegetation, this information is not always necessary in order to make predictions which are useful. For that reason this study will leave to future research many unanswered questions regarding such physical and biological phenomena.

FIGURE 1: GENERAL VIEW OF STUDY AREA

FIGURE 2: BROWN'S PARK GEOLOGIC FORMATION AT ROAD-CUT ALONG U.S. 40 IN STUDY AREA

REVIEW OF LITERATURE

Antelope bitterbrush and sagebrush (*Artemisia spp.*) occupy hundreds of thousands of square miles of land throughout western United States (Beetle, 1960; Nord, 1965; Stanton, 1959). Individually and in combination they represent the most widely distributed and economically important western range shrubs.

Sagebrush, because of its relatively low forage value is often treated as an unwanted member of the range ecosystem. All species of sage however, have some importance as domestic stock winter feed, and may be important to the diet of mule deer, elk, and sage-grouse (Beetle, 1960; Powell, 1968). Management practices on sage-brush lands have been mostly directed to elimination of the species. In contrast, bitterbrush ranks high in forage value for both domestic and game animals; and, is considered one of the most important browse species (U.S. For. Ser., 1937). It is high in crude protein, and provides green forage four to six weeks longer in the Fall than most bunchgrasses and herbs. Extensive reseeding of antelope bitter-brush has been attempted in recent years to improve winter range cover (Hubbard, 1964).

Both species can occur in stands where each is very nearly the only shrub present; or, they may appear in combination with each other or other shrubs or trees. In Colorado, Harrington (1964) describes transition zones between sagebrush and saltbush (*Atriplex spp.*) and greasewood (*Sarcobatus vermiculatus*) at lower elevations, and piñon-juniper, ponderosa pine, mountain shrub or oak at higher elevations or under different soil conditions. Bitterbrush has been found to be associated with these same vegetation types except that no reports of a transition with salt or alkali tolerant species were found. Rabbitbrush (*Chrysothamnus spp.*) is a common associate with both sagebrush and bitterbrush.

A bitterbrush-sagebrush vegetation type has been described by a number of authors (Nord, 1965; Standton, 1959; Daubenmire, 1942; Hyder *et al.*, 1962; Chadwick and Dolke, 1965). In most cases, big sagebrush (*Artemisia tridentata*) was reported as the most common sagebrush species associated with bitterbrush, although Blaisdell and Mueggler (1956) described a community in Idaho in which threetip sagebrush (*A. tripartita*) was a third member.

In California, the sagebrush-bitterbrush type is characterized by a dominance of shrubs, usually more than 90 percent of the vegetation cover; whereas forbs constitute less than one percent of the cover, and perennial grasses form only small to negligible proportions of the vegetation (Nord, 1965). Common grasses associated with the type in eastern Washington and adjacent Idaho are Indian ricegrass (*Oryzopsis hymenoides*) and needle and thread (*Stipa comata*) (Daubenmire, 1942). In California, bottlebrush squirreltail

(Sitanion hystrix), sedges (Carex spp.), and cheatgrass (Bromus tectorum) were the more dominant grass species.

Bitterbrush is known to play an important role in primary succession of vegetation. Nord (1965) found bitterbrush as a dominant shrub on thirty year old road cuts in California. It has been described by Eggler (1940) to be a pioneer shrub on recent volcanic deposits, and is a codominant with ponderosa pine on 27 year old mud flows near Mount Shasta (Dickson and Crocker, 1953). Daubenmire (1942) however, classifies the Artemisia-Purshia association in Washington as "edaphic climax." He defines an edaphic climax type as an apparently permanent association in which substratal peculiarities exerts a strong limiting influence upon the community in addition to those imposed by climate and flora. Beetle (1960) too suggests that accumulating evidence indicates edaphic climax status for all species of sagebrush.

An examination of plant succession on sand dunes in Idaho by Chadwick and Dolke (1965) revealed some interesting relationships concerning the development of a bitterbrush-sagebrush type. The area studied was in a 30+ inch precipitation zone. Four general stages of succession were observed on sand dunes. Elymus flavascens and scurfpea (Psoralea lancelata) comprised the pioneer stage which lasted about 30 years. Rubber rabbitbrush (Chrysothamnus nauseosus) appeared at 10 years and remained for about 50-60 more, to be replaced by bitterbrush, big sagebrush, and on some sites, common chokecherry (*Prunus virginiana*). This association remained relatively unchanged for 700 to 900 years, at which time the big sagebrush disappeared, leaving bitterbrush as the dominant species.

The authors concluded that the establishment of a species on sand depends on relative site stability rather than on soil nutrient build-up caused by previous vegetation. Deep sand holds moisture available to plants throughout the dry part of the growing season. On the area they studied, greater shrub density and higher vigor was noted on sandier soils than on heavier textures.

It is apparent from the literature reviewed that soil characteristics play a most important role in distribution and development of the bitterbrush-sagebrush type. It is on this assumption that this study has been conducted.

Site Factors And Vegetation Response

Jenny (1941) proposed that soil is a function of five independent soil forming factors. Jenny's equation for development of soil is: $S=f(cl, r, p, o, t)$; where S=soil properties, cl=the overall climate, r=topographic effects, p=initial state of soil system (i.e., parent material), o=organisms or the biotic factor, and t=time. Chemical and physical properties of soil which ultimately effect plant behavior, are therefore reflections of gradients of these factors and interactions between them. Following is a brief discussion of these five factors as related to bitterbrush and sagebrush sites.

Climate--Because of the widespread geographical distribution of both bitterbrush and sagebrush, climate effects can only be described in general terms. Average annual precipitation may vary from six to over 20 inches, although the majority of sites occur near the median of that range. Generally more than half of the precipitation falls during the dormant season. Winters are cold and summers cool to hot, varying mainly with elevation. Changes in climate accompanying changes in elevation are often associated with changes in forage production and species composition. Smith (1966) found that both total production and shrub production were significantly correlated with elevation. The effect of elevation was interpreted to be related to the amount of moisture received by the site and the effective use of the moisture. He observed that at high elevations where ample moisture is available in summer and winter, big sagebrush is tall and productive. There it is associated with a dense understory of grasses and forbs. As elevation and total precipitation decrease, soil characteristics favorable to sagebrush decrease, and also forbs begin to disappear. On very dry sites sagebrush size and density become very reduced and associated species composition changes to early maturing grasses and low mat-like forbs. If snow accumulates on these dry areas, sagebrush grows well, but the understory remains sparce.

Blaisdell (1953) found no great difference in production of big sagebrush, thick spike wheatgrass (Agropyron dasystachyum), or Idaho fescue (Festuca idahoensis) when comparing similar soils on two sites with 11 and 16 inches of rainfall at the same elevation. The moist site did show an increase in total production over the drier site, mainly due to an increase in bitterbrush.

Thatcher (1959) in Wyoming discovered changes in sagebrush species associated with precipitation amounts. Black sage (Artemisia nova) along with silver sage (Artemisia cana) and big sagebrush were found predominantly on a 10-14 inch precipitation belt, whereas threetip sage (Artemisia tripartita) favored higher precipitation--15 to 19 inches, and higher elevation.

Microclimate is largely determined by topography, however vegetation can influence effective precipitation. Ground level temperature, relative humidity and snow accumulation are altered by type and density of cover present. Hutchison (1965) indicated that snow accumulation on sagebrush areas was significantly greater than on open grass because of the effect of crowns in inducing snow drift. Big sagebrush can also hasten snowmelt because of the effect of dark body radiation and increased surface area of snow (Robertson, 1947).

Topographic Effects--Local topography can have profound effects on species composition, production, and soil characteristics. Position, steepness, direction and length of slope affect microclimate, infiltration, and soil movement. A slope of 10 degrees or more can cause some soils to creep downslope so as to mask any effect of weathering due to percolating water (Russell, 1961). Anderson (1956) reported that as percent slope increased, soil depth decreased and vegetative composition changed. Position and direction of slope were found by Klemmedson (1964) to have significant effects on species composition and production, soil nitrogen, organic matter, moisture retention and gravel content.

Both bitterbrush and big sagebrush grow in a variety of topographic positions and at great extremes of elevation. Stanton (1959) said that throughout its range, bitterbrush occurs on upland sites and almost never found on typically wet sites. Along the Columbia River in Oregon, bitterbrush was found to occupy lowland sites that are well drained (Nord, 1965). Silver sagebrush grows most often and best on lowland sites (Thatcher, 1959).

Generally north exposures create a microclimate where temperatures are cooler and effective precipitation is greater, resulting in more favorable conditions for plant growth. The ability of bitterbrush to sprout following fire is increased on northerly slopes (Driscoll, 1963).

Parent Material--Neither bitterbrush nor sagebrush is limited in occurrence because of parent materials. Nord (1965) found bitterbrush on soils developed in granitic, basaltic, rhyolitic, pumiceous sandstone and shale. He also noted that plants growing on alluvial soils were much taller and massive than those on residual soils. In Oregon, Stanton (1959) described a bitterbrush community on Sierozem Soils formed from alluvial terrace deposits over basaltic bedrock. A big sagebrush-bitterbrush association was found on Brown Soils from pumice origin. In these cases Stipa spp. was the common grass association on sandy alluvium, whereas Idaho fescue and bluebunch wheatgrass (Agropyron spicatum) occurred more often on the pumice soils.

Nearly all soil characteristics are affected by parent material in some way. The direct influence of parent material is often obscured by interactions with other site factors which cause weathering. However, plant growth may be affected by special characteristics inherited from the parent material, such as phosphorous content or type of clay minerals (Smith, 1966).

Organisms--The complexity of this factor is such that no treatment here could include all of the effects on soil and vegetation formation. The influence of plant competition and animal influence on the bitterbrush-sagebrush type will briefly be discussed.

Rooting habits and phenology are closely related to competition between plant species. Sagebrush has a branching taproot with a highly developed system of lateral roots that tend to concentrate in a zone above 15 inches (Robertson, 1943; Weaver and Clements, 1938;

Fautin, 1946). Root systems of bitterbrush can extend downward 18 feet or more. Roots are meandering but the system is rather simple and fibrous with strong vertical growth, moderate lateral spread, and a concentration of adventitious roots near the surface is characteristic (McConnell, 1961). Serious competition for soil moisture between either shrub and grasses can occur. Booth (1947) found sagebrush reproduction substantially reduced by grass competition. Blaisdell (1949) reported that if both sagebrush and grass are established at the same time, grass has the initial advantage but sagebrush will be less affected as its root system develops. Either one is difficult to establish if the other is present. This same observation has been reported for bitterbrush. Hormay (1943) observed that cheatgrass retarded natural establishment of bitterbrush. Cheatgrass is an equal threat to planted bitterbrush seedlings. Broad-leaved summer annual weeds offer far less competition (Holmgren, 1956). Hubbard (1956) found that under favorable site and moisture conditions, seedling mortality was 57-60% under heavy competition, and 21% under light competition. Seedling growth was reduced about six fold in heavy grass and about three to four fold under light grass competition. Growth and survival was reduced on poorer sites. Bitterbrush reproduction may be high in the shade of sagebrush, but growth is severely retarded until bitterbrush overtops the sage (Stanton, 1959).

Grazing animals, rodents and insects play an important role in distribution and growth of bitterbrush and sagebrush. Their effects are too complex to include in a soil-vegetation study, but several good references are available (Nord, 1959; Stanton, 1959; Hubbard, 1956; Nord, 1965; Beetle, 1960).

A recent report by McConnell and Smith (1970) indicates that bitterbrush density may be reduced by heavy grazing. Moderate use was found not to affect density. Large increases in mean area per plant were observed under heavy grazing also.

Time--This soil forming factor can only be adequately described by studying its effects on areas where all other factors are constant (Jenny, 1941). Because of the limited occurrence of such areas, little research has been reported on the time factor. No references were found in which time data were related to vegetation production estimates. Time as a factor in plant succession on sand dunes has already been discussed.

Soil Properties Affecting Sagebrush And Bitterbrush

Gradients and interactions of soil forming factors produce soil conditions which in turn influence plant growth. Some of these conditions may be discussed in terms of soil properties.

Physical Properties

Soil Depth--Some common measurements used in correlation studies of vegetation production are: depth to C horizon, thickness of the A horizon, depth to hardpan, depth of moisture penetration, and depth to lime accumulation (Driscoll, 1964; Smith, 1966; Geist, 1965). Thatcher (1959) found that big sagebrush required free root penetration of at least 15 inches, and that soil depths greater than 24 inches are required for healthy vigorous growth. Silver sage was also found to require moderately deep soils.

Bitterbrush makes its best development on soils five feet deep or more (Hubbard, 1964; Stanton, 1959; Nord, 1965). Hardpans or claypans have been found detrimental to bitterbrush growth. Nord (1965) states that bitterbrush is rarely found on soils with a restrictive layer within two feet of the surface. Hubbard (1964) rules out any area for planting bitterbrush where a hardpan exists within three feet of the surface.

Depth of rooting, depth to lime accumulation, and thickness of the A horizon were among the factors found by Smith (1966) to increase significantly with annual production of all vegetation, and of shrubs, grasses and forbs taken separately. Total production and shrub production showed a closer relationship to depth measurements than did grass or forb production.

Texture--The effect of texture on plant responses is mainly indirect, through its influence on moisture holding capacity, nitrogen supply and structural development (Black, 1968; Russell, 1961). Finer textured soils usually carry higher moisture and nitrogen supplies. Of the species of sagebrush, big sage is the most tolerant of texture differences. However it usually reaches best development on medium textures. Anderson (1962) found big sagebrush on loam to silt loam in Oregon. In Wyoming, Thatcher (1959) reported that big sagebrush growth can be retarded on heavy clay soils. On rocky knolls and hillsides, where soil is shallow and coarser in texture, big sage may be replaced by black sage (Fautin, 1946). Thatcher (1959) reported silver sage occurring on uplands, only when surface soils were sandy and subsoils were at least moderately permeable. Smith (1966) did not find silver sage to be thus restricted in North Park, Colorado. However, it occurred only on sites with very favorable moisture conditions.

Smith (1966) reported that percentage of clay in the top six inches of sagebrush soils was positively correlated with total plant production in North Park. This same measurement showed a positive correlation with volatile oil content in sagebrush leaves, while percent clay in the effective rooting zone showed a negative correlation to oil content (Powell, 1968).

Throughout its range, bitterbrush occurs most often and makes its best growth on deep coarse textured soils (Stanton, 1959; Hubbard, 1964; Giunta, 1968). Nord (1965) noted that the size and percent composition of bitterbrush decreased as soil texture became heavier. Average size, number and density of bitterbrush plants were at least

30 percent greater on deep, coarse-textured soils than on adjoining finer textures. The decrease in abundance of bitterbrush was most pronounced on clay soils. Big sagebrush and perennial grasses were more predominant on heavier textured soils. Sagebrush was not found with bitterbrush on very coarse soils. In the bitterbrush-ponderosa pine type, Giunta (1968) found little difference in the percent sand between A and B horizons. Average sand content was about 65-75 percent throughout the solum.

Bitterbrush reproduction has been correlated with texture by a number of authors. Stem layering is more common on finer textured soils (Nord, 1965). Sprouting frequency following burns in Oregon was found to be higher as soil texture became coarser (Driscoll, 1963). Sandy loam was found by Stanton (1959) to be most favorable for seedling establishment in Oregon.

Structure--Soil structure or particle arrangement affects plants through interactions with other factors such as aeration and soil moisture supply. As in the case with soil depth, the influence which structure has on plants is related to rooting habits and phenology. Quantitative expression of structural effects on plants has not been developed with any great success. Bulk density is often lower in undisturbed sagebrush areas than in adjacent vegetative types. Sagebrush areas that have been burned have higher bulk densities than unburned areas (Cook, 1961). Tabler (1964) saw big sagebrush roots following the pattern of coarse prismatic structure in the B horizon.

As previously mentioned under "soil depth," several writers have reported variations in species composition related to presence of hardpans or compacted layers. Goodwin (1956) found that big sagebrush roots could penetrate indurated layers by slow vertical extensions.

Rockiness--Amount and distribution of rocks and gravel in the soil profile may affect soil moisture and temperature. Downward movement of water may be increased by rock presence, except in the case where a layer of coarse material is overlain by finer textured soil. In this case, when the upper soil layer moisture is not saturated, drainage into the coarse layer is restricted (Gardner, 1962).

Stoniness in the form of cinders was found to hinder sprouting of bitterbrush following fire (Driscoll, 1963). This observation was explained by deeper transfer of heat during the burn.

Soil Moisture--The most important single factor in determining the kind and number of plants which occupy a given site is soil moisture (Dix, 1958). Physical properties of the soil have strong influences on soil moisture supply. Soil moisture storage is important in sagebrush regions since more than half of the annual precipitation falls during the dormant season. Smith (1966) found that sagebrush production was primarily related to the amount of Winter and Spring moisture stored in the soil. Although big sagebrush requires more soil moisture than does bitterbrush, neither species can exist on poorly drained sites (Thatcher, 1959; Nord, 1965). Silver sage however can tolerate high water tables (Thatcher, 1959). The occurrence of bitterbrush on some of the most arid sites in desert regions of California is possible because of its ability to tap the water table at very great depths (Nord, 1965).

Chemical Properties

Chemical factors such as nutrient levels and rate of supply, and salt content have been found to strongly influence the composition of vegetation which occupies a site. Effects on plant production are generally less significant than those exerted by physical properties (Beadle, 1953; Dix, 1958; Smith, 1966). However, reliable predictions of plant production cannot be made without inclusion of soil chemical data into the model (Baker, 1968).

Organic Matter--Organic matter may directly effect plant growth by providing small amounts of plant nutrients and growth promoting substances. In direct effects through interactions with other soil properties are more influential to plant behavior. Soil color, consistency, water holding capacity, cation exchange capacity, structure, and fertility are to a large extent related to amount and distribution of organic matter (Buckman and Brady, 1960). Smith (1966) found that organic matter content in the top 12 inches of soil was significantly correlated with amounts of N, P, K and percent clay. Negative correlations were found with organic matter and percent sand in the surface soil. Although the average percentage of organic matter found by Smith was only 2.02 percent, a significant correlation with big sagebrush production was established.

On ponderosa pine sites in Northern Colorado, a significant correlation exists between organic matter and cation exchange capacity, indicating that organic matter may be a principle source of exchangeable nutrients (Geist, 1965).

Low organic matter content generally follows the coarse texture character of bitterbrush soils. Stanton (1959) described bitterbrush soils in Oregon as being low in organic matter throughout all layers of the profile. In contrast, relatively high amounts of organic matter were found in soils on bitterbrush-pine sites studied by Giunta (1968). These soils contained 3.2 to 8.5 percent organic matter in the shallow A horizons and 2.2 to 5 percent in the relatively deep B horizons.

Nitrogen--Nitrogen content is highly correlated with amounts of organic matter, P, K, and clay in the surface soils of sagebrush sites studied by Powell (1968) and Smith (1966). Deficiency of nitrogen is not generally a problem on native sagebrush rangelands, however, increased forage production generally follows higher soil nitrogen content. Bitterbrush has been recognized as a nonleguminous nitrogen fixing plant (Youngberg, 1970; Bartholomew and Clark, 1965). This may partly explain how bitterbrush can often be successful as a pioneer invader.

Phosphorus--Box (1961) in South Texas noted a larger proportion of climax grasses on soils where P content was higher. Available P is apparently one limiting factor in shrub production on sagebrush sites in North Park, Colorado (Smith, 1966). However, Geist (1965) reported no significant relationship between phosphorus and ponderosa pine or herbaceous vegetation production. Neither could Medin (1960) relate phosphorous with production in mountain mahogany (*Cercocarpus montanus*) communities. Volatile oil content in sagebrush leaves is significantly and positively correlated with phosphorus on sites in North Central Colorado (Powell, 1968). In controlled fertilizer tests in Oregon, Stanton (1959) found that when equal amounts of different nutrients were present, phosphorus produced the largest response in bitterbrush seedling emergence.

Potassium--Sagebrush growth was not found by Smith (1966) to be significantly affected by variations in available potassium. However, oil content in sagebrush leaves is negatively correlated with amount of available K (Powell, 1968). Percentage of brush cover on Texas range was found to decrease as amounts of potassium increased (Box, 1961).

Sodium--The undesirable effects of exchangeable sodium on soil reaction and physical properties apparently are not often critical in sagebrush or bitterbrush areas. Neither species occurs where exchangeable sodium percentage is high enough to cause high pH and colloid dispersion (Stanton, 1959; Nord, 1965; Smith, 1966).

Calcium and Magnesium--Extractable calcium was not found by Smith (1966) or Powell (1968) to be related to vegetation production on sagebrush sites in Colorado. Extractable magnesium in the A horizon was highly and negatively correlated with percent oil in sagebrush leaves, but no correlation was found with growth or size of sagebrush (Powell, 1968). No relationships of Mg to vegetation production was found by Smith, however Geist (1965) indicated an association between herbaceous plant production under ponderosa pine and magnesium in the soil.

Lime--Depth to calcium and magnesium carbonate accumulation was positively related to production in Smith's (1966) study. This depth to lime zone relationship was interpreted to reflect moisture penetration. No studies were found that indicate any such relationship on bitterbrush sites. Because of the coarse texture of bitterbrush soils, lime accumulation is apparently not common at depths which affect plants. Both Nord (1965) and Stanton (1959) indicated that bitterbrush occurs only rarely on calcareous soils. Baker (1968) stated that high vegetation production did not exist if percent lime in surface soil exceeded 10 percent on Powell's study area.

Soluble Salts--Soluble salts in the soil solution raise the osmotic pressure and may lower the rate of solution uptake by plants (Meyer and Anderson, 1952). Specific toxicity of certain ions to plants and physiological disturbances within the plant can be caused by salts in the soil also (Black, 1957).

Sagebrush and bitterbrush generally make their best growth on soils low in salts (Thatcher, 1959; Nord, 1965). Although Smith (1966) did not attempt to correlate salt content with sagebrush production, he did note that soluble salts were higher in subsoils developed from Pierre and Coalmont Shales than other adjacent parent materials. These soils were also the least productive in dry areas, but were very productive in higher precipitation zones. Removal of salts by leaching was apparently one factor of increased productivity.

A maximum of 719 ppm. of soluble sodium was reported by Gates (1956) as the limit of salt tolerance of big sagebrush in Utah.

Soil Reaction--Species distribution is generally more affected by pH than is plant growth, although Baker (1968) indicates that pH in the surface soil may be useful in prediction equations for grass and brush models. Stanton (1959) suggests that a relationship between high pH and low availability of phosphorous exists on some Oregon rangeland.

Big sagebrush has been observed on strongly alkaline and non-alkaline soils by Beetle (1960). Thatcher (1959) reported quite a wide range of pH (6.6-8.5) for big sagebrush in Wyoming.

Bitterbrush comprised 25 percent of the vegetation on one site in Oregon where pH was 6.5-7.0 in the upper five feet, but with pH of 8.0 below five feet in depth (Nord, 1965). On sites where pH was basic above four foot depth, bitterbrush disappeared. Hubbard (1964) recommends bitterbrush planting on soils with pH of 6.0-7.0. Plummer, Christensen, and Monsen (1968) indicate that seed from sources growing on granitic and basaltic soils having an acid reaction have not produced healthy bitterbrush plants on soils in basic sedimentary rock in Utah. They do acknowledge that native bitterbrush may grow well on either acid or basic soils.

DESCRIPTION OF THE STUDY AREA

Location

The study area is situated in the western portion of the Axial Basin in Moffat County, Colorado, approximately 35 miles west of the town of Craig. The site is roughly bounded on the north by the Yampa River and State Highway 318, on the east by Deception Creek, on the south by the Dansforth Hills, and on the west by Cedar Springs Draw. Portions of five townships are included. Highway U.S. 40 passes through the center of the area. Figure 3 shows locations of macro-plots.

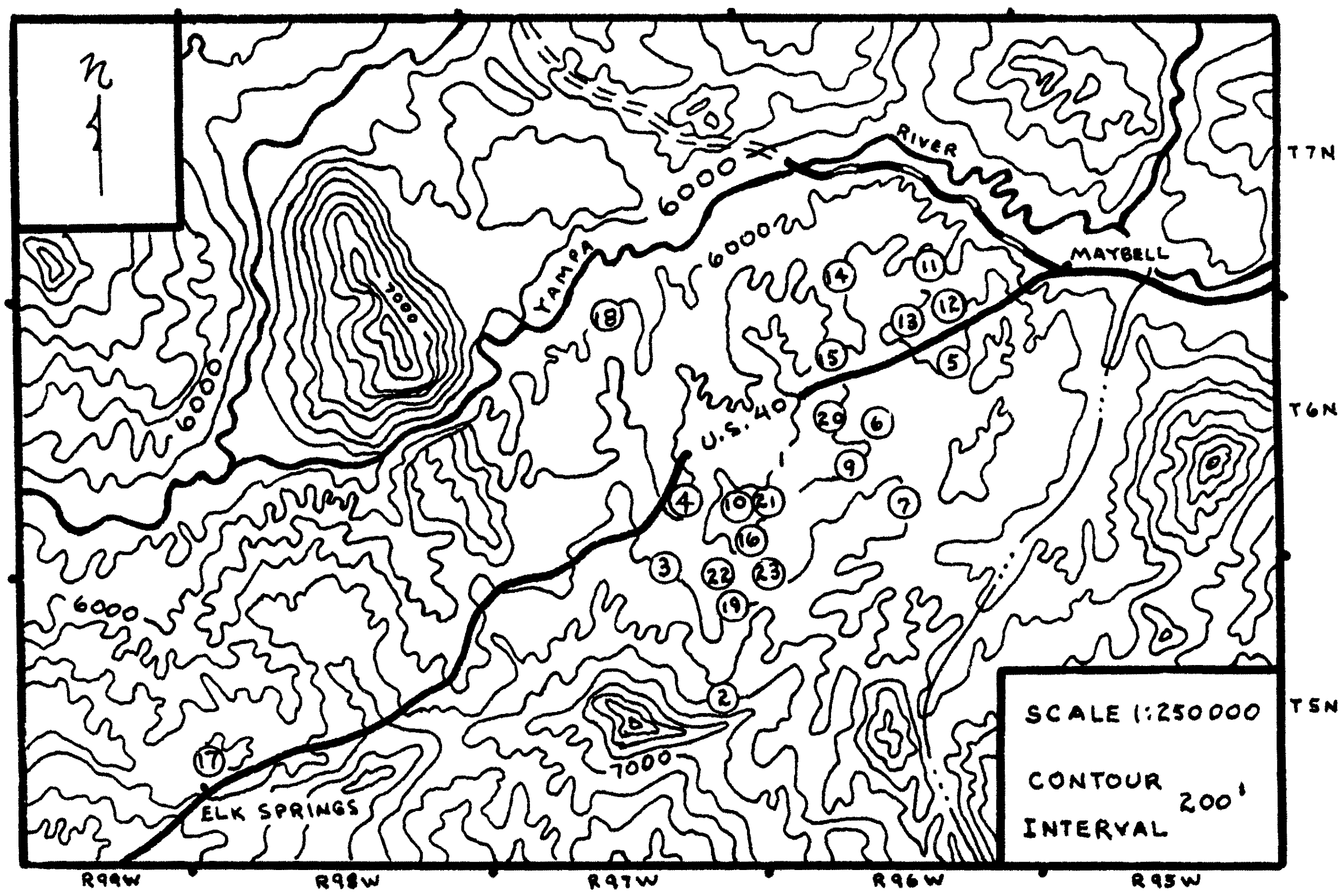
Topography

Elevation ranges from 6000 to 6700 feet over the area sampled. Relief varies from long gentle slopes of more than a mile in length to short steep slopes of 100 feet or less. Relief is characterized by gently rolling hills with an occasional occurrence of steeper active dune and blow-out areas. The general drainage pattern of the land-scape is northward to the Yampa River.

Geology

The Uinta Formation was described by F. W. Hayden (1876) as having two layers; the Bridger Group and the Uinta Group. The Uinta Group, later named The Brown's Park Formation by J. W. Powell,

FIGURE 3: TOPOGRAPHIC MAP OF STUDY AREA SHOWING LOCATIONS OF MACROPLOTS



rests directly but by unconformity of sequence upon all the tertiary and cretaceous groups in the region.

The Browns' Park Formation of Tertiary miocene age filled an ancient basin of considerable relief to a depth of 2000 feet in places, and its thickness is very irregular (USGS, 1964). It is composed of fine and coarse-grained friable sandstones with intermixed gravel in some places forming a conglomerate. The materials are more or less stratified, crossbedded, and in places nearly or quite incoherent (Figure 2). Color varies from brownish red to gray or white.

Large low-grade deposits of uranium salts which occur in the upper more tuffaceous layers east of Maybell have led to a uranium rush in recent years (Bergin, 1957). Since the ore has no vanadium, and as the metalurgical problems of extraction are great, development of the deposit has been greatly retarded (Donnell & Clement, 1960).

Most hills in the area are capped with gravel and rock layers of quartzite, jasper, and other rocks highly resistant to weathering. Continuous erosive action of wind and water have created the present rolling terrain. Wind has been a significant factor in recent times as local dune activity is strongly in evidence.

Soils

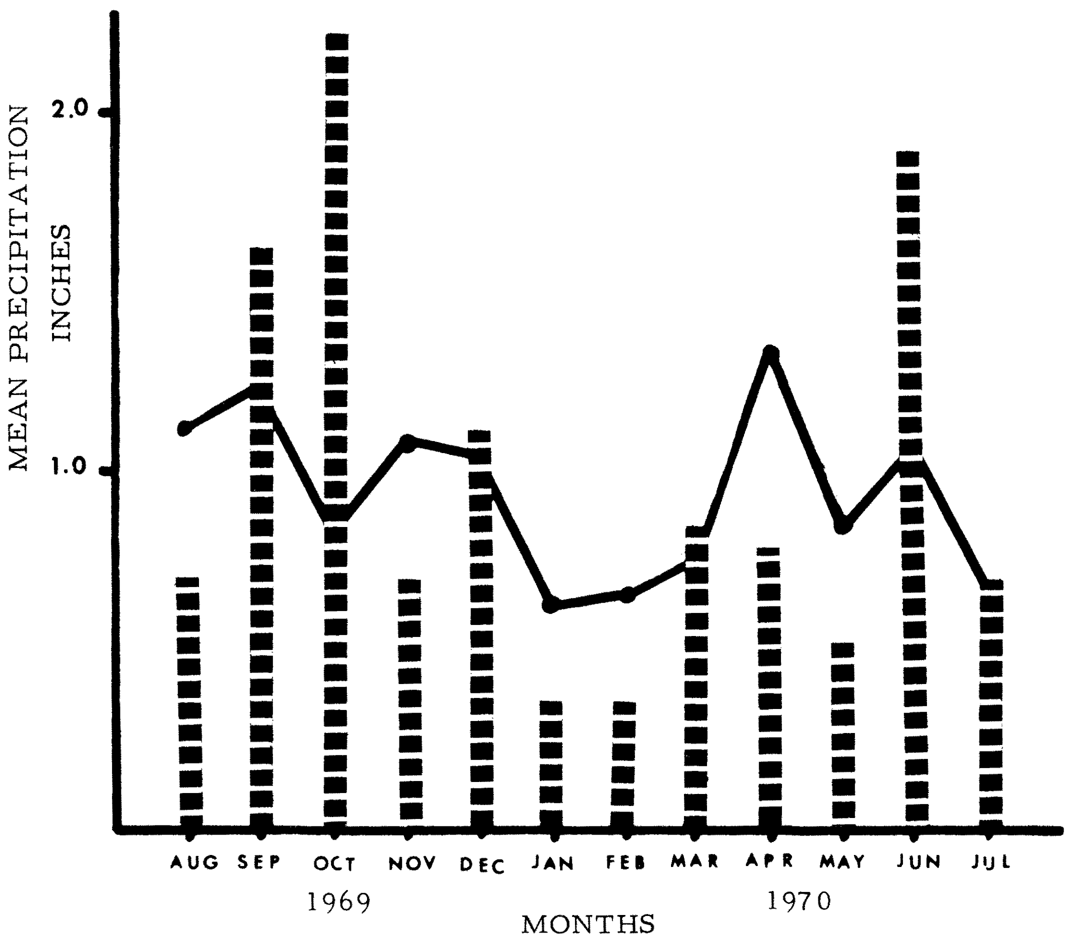
Soils throughout the study area are very light textured, structureless, low in organic matter, relatively high in mineral nutrition and without distinct profile development. Color is generally brown to dark brown grading into shades of yellowish brown or gray with depth. Parent material, in the form of loose light colored sand occurs at a depth of four or five feet. Surface soil is loose and subject to movement. The B horizon becomes very hard upon drying and thus restricts moisture penetration. Although no measurements of infiltration or percolation were taken, observations indicated that the rate of movement through dry surface soil may be five to ten times faster than through dry subsoil.

It is believed that the presence of this hard layer may have ecological significance since light rainfall may not penetrate it, whereas heavier precipitation, after once loosening the layer, may penetrate to much greater depths. Since soils were examined under various moisture conditions, this layer was not always in evidence.

Climate

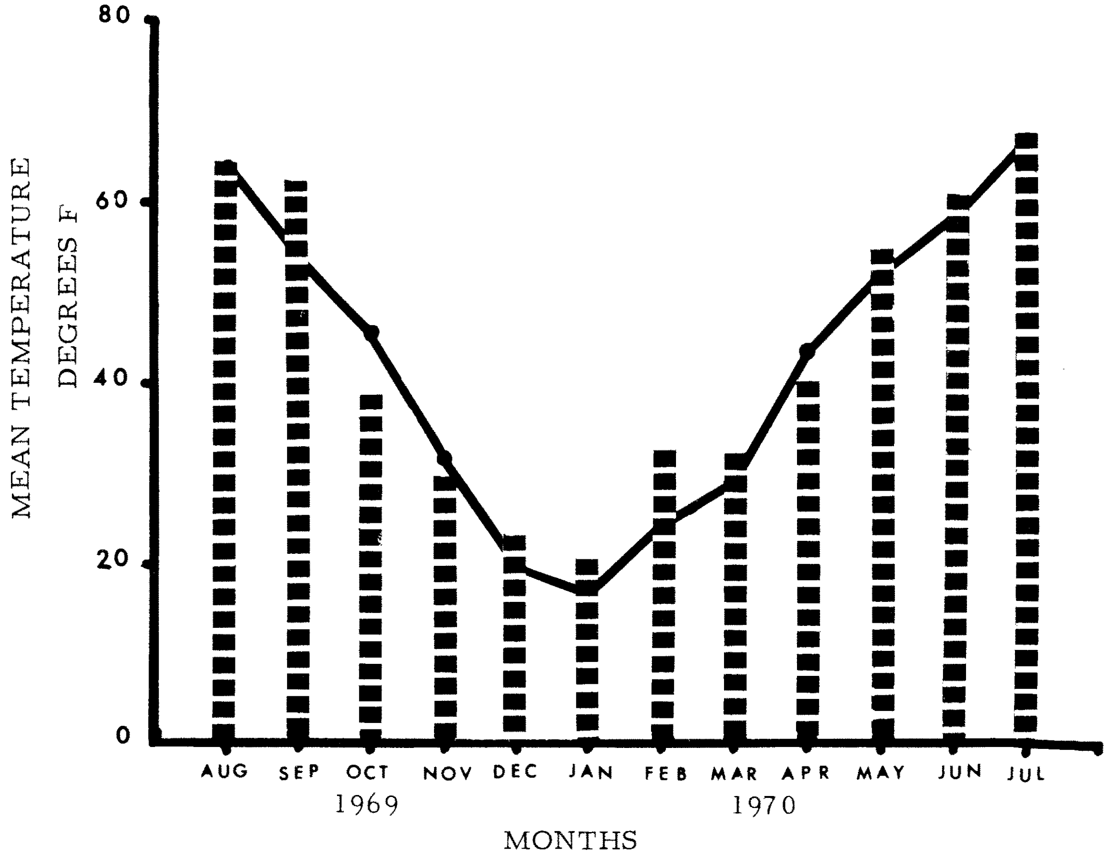
Since the plots were located in a limited geographic area, and elevation differences are not great, macroclimate is considered to be uniform on all stands sampled. Annual precipitation averaged over the past 10 years at Maybell, Colorado is 11.6 inches (Figure 4). Distribution of precipitation is equally as important to plant growth as is total amount. Rainfall during the growing season is usually rather evenly distributed with the exception of July which is exceptionally dry. Individual storms are generally light. Prevailing winds are

FIGURE 4: MEAN MONTHLY PRECIPITATION MEASURED AT MAYBELL, COLORADO



Line indicates ten year average; bar indicates 12 months preceding vegetation sampling.

FIGURE 5: MEAN MONTHLY TEMPERATURE MEASURED AT MAYBELL, COLORADO



Line indicates ten year average; bar indicates 12 months preceding vegetation sampling.

from the west. The average frost free period is about 92 days. Mean monthly temperatures (Figure 5) range from 16.8 degrees F in January to 67.1 degrees in July, with extreme recordings of -50 and +95. The 1970 growing season began very dry, and then June followed as an exceptionally wet month. July precipitation was near normal.

Vegetation

Plant cover is composed primarily of shrubs. Antelope bitterbrush dominates most of the upland terrain with big sagebrush (*Artemisia tridentata tridentata*) occupying the lowland draws. *A. tridentata wyomingensis* inhabits scattered upland patches. Silver sagebrush occurs with bitterbrush over most of the area, however vegetation pattern is irregular and abrupt as one or another species of shrub dominates a particular patch. These patches, which vary in size from little more than an acre or so to 100 acres or more, do not seem to be associated with relief except as mentioned in the draws near the fringes of the study area.

Other shrubs which are present on the area, usually in fewer numbers, are: horsebrush (*Tetradymia canescens*), snakeweed (*Gutierrezia sarothrae*), rubber rabbitbrush (*Chrysothamnus nauseosus*), and low rabbitbrush (*C. viscidiflorus*). Prickly pear cactus (*Opuntia spp.*) is present as a ground cover between shrubs, and often fills the open spaces completely. Grasses and forbs tend to grow more or less near or under the shrubs. This condition may have been brought about by grazing.

Needle and thread is the principle grass species. Although it is present on nearly all sites, it is most abundant in depressions and washes. Indian rice grass and sand dropseed (Sporobolus cryptandrus) predominate on sandier more actively blowing areas. Blowout grass (Redfeldia flexuosa) and prairie sandreed (Calamovilfa longifolia) occur in a few small isolated colonies. Cheatgrass has invaded the area and is common on many sites.

Annual and perennial forbs comprise a very small percentage of the vegetation. Early maturing herbaceous plants such as sego lily (Calochortus nuttallii), larkspur (Delphinium nelsonii), and death camas (Zygodenus paniculatus) are sparsely distributed throughout the landscape. Golden aster (Chrysopsis villosa), evening primrose (Oenothera trichocalyx), Lappula spp., and Cryptantha flavoculata are the most common forbs which are present through most of the growing season. The more abundant late blooming plants are most represented by Aster leucanthemifolius and Eriogonum campanulatum.

Native Animals

Wildlife which affect soil development on the area do so mainly through their influence on vegetation. Browsing and grazing animals include a sizeable herd of 200-300 pronghorn antelope (Antilocapra americana) which remain in the vicinity throughout the summer. The area also serves as a winter range for mule deer (*Odocoileus hemionus*) from nearby mountains. Jackrabbits (*Lepus townsendii*) are common but do not appear to be overly abundant. The large herbivores generally prefer bitterbrush over sagebrush, whereas for rabbits the reverse is true. Sagegrouse (*Centrocercus urophasianus*) are present in rather small numbers and appear to have little effect on the vegetation.

Insects were not present in excessive amounts except for a very dense population of ants which inhabit much of the area. They were observed most often eating silver sagebrush and various forbs, while almost never being found on bitterbrush. Although no data were collected concerning numbers of native herbivores, their effect may be locally significant when combined with domestic grazing pressure.

Burrowing animals are rather scarce on the area. The sandy nature of the soil is not conducive to stable tunnels.

Land Use

Most of the land is under control of the U.S. Government and managed by the Bureau of Land Management. Multiple use concept of management here as elsewhere allows for various uses of the land. Domestic livestock grazing, watershed protection and recreation are the principle uses. Except for big game hunting, recreational use is limited.

Originally forage use was restricted to bison, antelope, mule-deer and elk. Between 1880 and 1900 immense herds of cattle were driven into the region from Texas. Adding to the heavy pressure caused by cattle were countless numbers of sheep which later were herded onto much of the rangeland of the region. Following the Taylor Grazing Act of 1934, control of forage use has been accomplished by the BLM. The study area is grazed by sheep during April and May, again in October and November, and occasionally during the summer months. The current range use probably approximates that prior to 1880 when wild animal herds were much larger than today.

METHODS

The design of this study and the methods employed are based on the concept that different combinations of soil forming factors have produced unique soil characteristics and vegetation responses. By measuring soil properties at points where vegetation responses appear different, then relating the two by regression analysis, some evidence may be found for predicting plant behavior from measurable soil properties. Procedures and techniques used by Smith (1966) and to some extent Powell (1968) were followed as closely as possible in order to provide for useful comparison of data.

The Sample

During the summer of 1969, soils data were collected from 22 plot locations. Vegetation data were collected during the following summer in July following peak annual vegetative growth.

Topographic and vegetation data were taken on plots measuring 100 feet on a side. One side, running with the aspect, was designated as the baseline. Transects used to collect vegetation data were run perpendicular to the baseline and thus roughly followed the contour. Percent slope and direction of slope were measured with an abney level and staff compass. Soils data were collected from a pit located near one edge of the square plot. The square plot and soil pit combined was termed a macroplot.

Macroplot locations were marked on a U.S.G.S. topographic map. Legal description down to the quarter section was noted along with access by way of local landmarks.

The Study Area

The study area was selected because it offered a unique opportunity to research soil-vegetation relationships of bitterbrush and sagebrush, while holding constant many other site factors. All macroplots were located on the Brown's Park Sandstone geologic formation. Climate is essentially constant throughout the entire study area. Elevation does not vary much on the area. Slope and aspect were held essentially constant by locating plots on relatively level uplands. In most cases slope did not exceed 5.0%. The biotic factor was maintained as uniform as possible by avoiding areas with recognizable disturbances. Plots were not located in or immediately adjacent to areas where fire, chemical spraying, excessive animal concentration, fences, roads or other such disturbances would influence vegetation composition or growth.

Collection of Soils Data

Field Procedures--Soil pits were dug to the depth of parent material. This depth usually did not include the entire rooting zone of bitterbrush. In some cases a soil auger was used to investigate the nature of parent material below pit depth.

Standard Soil Survey procedures were used to describe profiles (Soil Survey Staff, 1951). Roots were classified as very abundant, abundant, common, few, rare or none for each horizon. An estimate of the percentage of gravel and rocks in each horizon was also made. Additional notes were made concerning character of ground surface, moisture conditions, and other pertinent information. Samples of each horizon were gathered for laboratory analysis. Color slides and black and white photographs were taken of each profile.

Laboratory Analysis--Mechanical analysis was begun by seiving samples through a 2 m.m. screen. Sand, silt and clay percentages were determined by the sedimentation method of Boyoucous (1939), with slight modification. Four grams of Calgon per liter of soil solution were used as a dispersing agent. Mechanical shakers were used in place of stirrers for dispersion. Percentage of coarse sand was determined by wet seiving through a .351 mm. screen.

Chemical analysis were performed by the Colorado State University Soil Testing Laboratory. The characteristics determined and methods of analysis used are as follows: (1) $CaCO_3$ equivalent (%) was determined by the acid titration method; (2) pH was measured with a pH meter on a 1:5 soil suspension; (3) organic matter percentage was determined from colorimetric reading on a potassium dichromate sulfuric acid solution; (4) total soluble salts were determined by the electrical conductivity of a saturation extract expressed as mmhos/cm; (5) available phosphorus was based on colorimetric determination of phosphorus in a $NaHCO_3$ extract and expressed as ppm; (6) available potassium was determined by extraction with 1 N ammonium acetate and K determination with a flame photometer; (7) extractable (exchangeable plus water soluble) cations were calculated by flame photometer determination of sodium and potassium, and atomic absorption spectrophotometer of calcium and magnesium following three washings with 1 N NH_4AC. Each was expressed as milliequivalents per 100 grams; (8) total nitrogen percent was determined by the Kjehldahl Method (Hergert, 1970).

Collection of Vegetation Data

Selection of macroplots was initially based on differences in vegetation characteristics. Variations were sought in species composition, shrub density and shrub size. Bitterbrush was present on all plots in varying proportions with big sagebrush and silver sage. Macroplots were located so as to have as much uniformity within the plot as possible.

Black and white pictures and color slides were taken of the vegetation on each macroplot from a distance of about ten feet. In addition, the entire macroplot along with surrounding terrain was photographed.

All species of higher plants were identified in the field when possible. A pressed collection was made of uncertain specimens for later identification.

Composition, Cover and Production Data--Six 9.6 square foot plots, systematically located within each macroplot, were used to obtain composition, cover and production data. These plots measured 2 x 4.8 feet, and were located by pacing at distances of 25 and 75 feet, at right angles to the 20, 50, and 80 foot marks on the baseline. Estimates were made of species composition by percent of total weight of current year's growth. Ground cover was determined by estimate of percentage of bare soil, litter, rocks over one inch diameter, and vertical projection of current living crown of grasses, forbs, shrubs and half shrubs including prickly pear. Current year's production of grasses and forbs was clipped, air dried and weighed to the nearest gram. Weight of current years growth of shrubs was estimated. Periodic checks were made on these estimates by clipping, air drying and weighing an estimated amount.

Frequency and Density--Twenty-five 12 x 12 inch quadrats were evenly spaced along five transects in each macroplot. Each transect was located at random within a 20 foot section of the baseline, and ran the full 100 foot length of the plot. Plants were counted if any portion was rooted within the quadrat, i.e., any basal stem at point of contact with the ground. Prickly pear cactus was recorded if more than $\frac{1}{2}$ of one lobe was within the quadrat. Total count for each transect was recorded.

Bitterbrush and sagebrush density was determined by counting each plant which rooted within six inches of the transect line. Each plant counted was classified by age as seedling, young, mature, decadent or dead. Bitterbrush grows in essentially two growth forms in the area--single individuals and clumps of many layered daughters surrounding a mother plant. An attempt was made to count daughters as individuals.

Line Intercept and Shrub Height--Each woody shrub intercepted on the above transects was measured along the line to the nearest one-half inch. Corrections were made for holes in the crown exceeding three inches of intercept.

Total height of vegetative growth of live sagebrush (seed stalks not included) and bitterbrush plants was measured to the nearest one-half inch. The heights of the five tallest plants of each of these species was averaged for each transect to give a less variable height index.

Expression of Variables

Physical and chemical soil properties were expressed as concentration or percentages in layers of fixed depths 0-6, 6-12, 12-24, 24-36 inches; or as the amount of a factor in the genetic horizon. The gradual transitions between major horizons in the soil profiles allowed considerable variability in selection of boundaries. For this reason it was thought that soil factors expressed by strata of definite thicknesses would have more meaning. Smith (1966) and Powell (1968) found similar systems to be satisfactory.

Since soil samples were collected in the field by horizons, the fixed layer values had to be calculated, and were often averages of more than one horizon sample. When factors were expressed as concentration in a fixed portion of the profile, the volume of soil is a constant so that concentration and amount are equivalent. To obtain the amount of a factor in a genetic horizon, concentration was multiplied by thickness of the horizon in inches. Allowances were made for rocks and gravel in the profile. Tables VIII and IX present a list of the soil and vegetation factors, their units, means, standard deviations and range of values.

Statistical Analysis

Qualitative description of field observations gives expression to characters that cannot be fully appreciated in terms of numerical value. Soil color, structure and consistence, aspect of the site or topographic position are examples of variables which are not easily expressed quantitatively in a meaningful way. Soil descriptions, species lists and other qualitative data are presented in the Appendix to this paper and will not be discussed here. Measured characteristics which can be expressed quantitatively are best evaluated by statistical techniques. Correlation and regression methods were used to help in the evaluation of data. These techniques, although subject to definite limitations are valuable when used to construct prediction equations.

Simple Linear Correlation and Regression--Initially simple linear correlation coefficients were computed between all possible pairs of vegetation and soil characteristics which seemed important. This step revealed the simple relationships between all variables. By examining the matrix of (r) values it was determined which soil factors were highly correlated with vegetation factors, and therefore might be used as indicators of vegetation responses. Furthermore, if two soil factors were found to be highly correlated with a measure of vegetation and also with each other, one of the soil factors was eliminated from consideration on some biological or economical basis. In this way a large number of variables was reduced to a manageable number. Forty five soil factor measurements were entered into this analysis along with 43 vegetation factor measurements. Twenty-one soil factors were chosen for further analysis using stepwise multiple regression with each of eight measurements of vegetation production.

Simple correlation coefficients were tested for significance under the null hypothesis that $r = 0$, i.e., there is no relationship between the two variables which can be accounted for by linear regression. In this study both the 1% (*) and 5% (**) levels of probability were tested.

Multiple Linear Regression--Following the initial step of reducing the number of variables by simple correlation, there still remained the task of building a suitable prediction equation with the least possible number of variables. The general multiple linear regression model can be written:

$$Y = BoXo + B1X1 + B2X2 + \ldots + BpXp + e. \quad \text{(Draper \& Smith, 1968)}$$

Y = a measured characteristic of vegetation

Bo = value of Y when all X's are zero

Xo = 1 = a dummy variable

Bp = linear partial regression coefficient for the p^{th} soil factor

Xp = value of the p^{th} soil factor

e = error term (portion of Y not accounted for by X's)

In order for an equation to be useful for prediction purposes, the model should include as many variables as necessary to obtain reliable values of predicted Y, but not more than is necessary because of costs involved in collection and evaluation of data. Several statistical procedures are available for doing this. The stepwise regression procedure is considered the best method by Draper and Smith, and it has proven successful in many environmental relations studies.

As with other multiple regression techniques, stepwise procedure has the advantage of isolating the effects of one factor while holding the others constant. Unique to this procedure is the method of selection and inclusion of variables. X variables are entered into the regression equation according to their partial correlation coefficient values with Y. As X variables are entered they are re-examined as to their worth to the equation had they been included before all previous variables. Variables which show a high degree of correlation with Y initially may be excluded from the equation at a later stage because of their relationship with other variables included at that time.

At each step in the analysis a coefficient of determination (R^2) is calculated. R^2 measures the proportion of total variation about the mean $\overline{Y}$ explained by the regression, and may be defined as:

$$R^2 = \frac{\text{Sum of Squares of Deviations From Mean Due to Regression}}{\text{Total Sum of Squares of Deviations From the Mean}}$$

If the prediction is perfect, $R^2 = 1$. If $Y = Bo + e$, then $R^2 = 0$.

Although regression analysis has been widely used in site evaluation work, the method is subject to certain limitations and preconditions which were considered during evaluation of the results. It was assumed that the effects of the independent factors on the dependent factor are additive. It was understood that only those factors which display a wide range of values are included in the final prediction equation, and that no cause and effect relationships were implied by the statistical analysis results.

Prediction equations were computed for annual dry matter vegetation production in pounds per acre for eight "dependent" variables: grasses, forbs, shrubs, bitterbrush, silver sagebrush, all sagebrush, total forage (excluding prickly pear), and total vegetation. The screening process described earlier using (r) values was used to select the 21 "independent" variables. The computer program used was BMDO2R-Stepwise Regression Version of July 1, 1970, Colorado State University Statistical Laboratory. This program is similar to the one described by Draper and Smith (1966).

Selection of the step for prediction was based on a comparison of the R^2 values and the F ratios for testing the significance of each variable in the equation at the step selected for prediction. A most important consideration was the significance of the individual variables to the equation, since R^2 values alone may not reflect the true accuracy of the prediction. If variables which are non-significant at the confidence level selected are accepted as part of the equation merely to show an account for more of the variability, it should be realized that there is a greater risk that the R^2 values may result from chance alone. A compromise was usually met between these two considerations in selecting the step for prediction.

Since no cause and effect relationships are implied by the correlation and regression analysis, extreme care was used in attempting to interpret the results. However, it is necessary only to know which factors to measure, and the values of the regression coefficients in order to use the prediction equations.

RESULTS AND DISCUSSION

Simple correlation coefficients between individual soil factors and various measures of vegetation production were in general rather weak. Few values were found to be statistically significant at the 1% or 5% level of probability. More variables were found to be significantly correlated with grass and forb production than with any dependent variable involving shrubs.

In most cases those factors which showed the highest simple correlations with production were also the most important factors in multiple regression prediction equations.

The pages which follow present a brief summary of the most important relationships between soil and vegetation factors for bitterbrush, silver sagebrush, and all forage on the study area.

Simple Correlations Between Soil Factors

Table III gives an indication of the magnitude of some correlation coefficients between soil factor measurements. The entire matrix of soil factor measurements was not included here in the interest of simplicity. Interpretation of these relationships is difficult since interactions are not considered by the simple correlation analysis. The important point is that relationships which exist between factors may aid in the process of selection of variables suitable for determination of site productivity. The factors which were entered into stepwise regression as independent variables are generally not highly correlated with each other, since that was one basis for selecting variables for the multiple regression analysis.

In addition to the coefficients illustrated there were some others worthy of mention. The amount of gravel and rock in the profile was significantly correlated with only one other soil factor measurement, extractable magnesium in the 12-24 inch zone (r=.48*). Thickness of the gravel and rock layer was found to be positively associated with depth of abundant rooting **, percent sand in the 12-24 inch zone *, and amount of phosphorus in the top six inches *. The amount of gravel and rock was chosen for inclusion in multiple regression analysis rather than thickness of the layer because amount was highly correlated with production and relatively independent in its effects.

Table I shows that there is a high degree of correlation between available and extractable potassium in the soil profile. Extractable potassium in the subsoil was also found to be highly related to the level of available phosphorus in the subsoil, (r=.86**). Amounts of calcium and magnesium were highly correlated with each other as well as with potassium. Particle size distribution of the mineral fraction also was significantly correlated with extractable potassium. The relationship was negative with sand percentage and positive with percent clay. Depth of abundant rooting and amount of organic

TABLE I: SIMPLE CORRELATION COEFFICIENTS BETWEEN SELECTED SOIL FACTOR MEASUREMENTS

	1	2	3	4	5	6	7	8
1 Amt. Gravel (% x inches)	1.00							
2 Avail K 0-6" (ppm)	-.19	1.00						
3 Extr. K 0-6" (meq/100 g.)	-.23	** .88	1.00					
4 Avail P 0-6" (ppm)	-.09	.16	.24	1.00				
5 Thickness "A" (inches)	-.19	.25	.33	.01	1.00			
6 Thickness "B2" (inches)	-.14	.10	.20	.20	.39	1.00		
7 Sand 0-6" (%)	-.23	.52	* -.42	.17	-.13	.11	1.00	
8 Extr. Mg 0-6" (meq/100 g.)	-.05	.37	** .57	.01	.31	.17	.29	1.00

matter in the 6-12 inch strata were both highly related to potassium in the lower horizons.

Phosphorus was not highly correlated with other soil factors, except as mentioned concerning potassium and gravel. A strong correlation exists between organic matter and total nitrogen in the soil. Nitrogen was not found to be highly correlated with any other soil measurement.

Analysis of Bitterbrush Production

Simple Correlations--Table II shows some of the simple correlation coefficients between measures of bitterbrush and other vegetation characteristics. Bitterbrush production significantly increases as its percent intercept, height, density and percent composition by weight increases, and as total vegetation production and cover increase. Percent intercept would appear to be the best plant measurement indicator of bitterbrush production since it showed the highest correlation of any measurement of the species. However differences between significant correlations were not great. A significant negative relationship exists between bitterbrush production and percent composition of forbs. There is a rather weak positive relationship between presence of bitterbrush and prickly pear on a site. The association of bitterbrush with percent composition of needle and thread grass was even weaker and negative.

TABLE II: SIMPLE CORRELATION COEFFICIENTS BETWEEN MEASURES OF BITTERBRUSH AND OTHER VEGETATION CHARACTERISTICS

	Production lbs./A.	Density no./100sq.ft.	Height inches	Intercept %
Production	1.00			
Density	.49*	1.00		
Height	.44*	.32	1.00	
Intercept	.51**	.79**	.67**	1.00
% Comp. By Wt.	.81**	.52*	.62**	.70**
Prod. Shrubs lbs./A.	.48*	-.01	-.02	-.13
Vege. Cover % area	.53*	.46*	.31	.52*
% Comp. By Wt. Grasses	.03	.43*	-.09	.17
Forbs	-.44*	-.10	-.10	-.13
Shrubs	.24	-.29	.00	-.16
Opuntia sp.	.17	.30	.28	.35
S. comata	-.03	-.05	-.26	-.23
A. cana	-.23	-.42	-.21	-.25

As Table III illustrates significant negative correlations were found between all measurements of bitterbrush and the amount of rock and gravel in the soil profile. Thickness of the coarse fragments layer was negatively correlated with relative production of bitterbrush. The major effect of coarse fragments in sandy soils at or below field capacity was shown by Meiman (1962) to be a decrease in downward vapor movement into lower layers. Bitterbrush is a deep rooted shrub, and its success is to some degree a function of how well the soil can supply needed moisture at depths below the solum. Since rainfall usually occurs as light showers during the growing season, the soil is unsaturated most of the time. Gardner (1962) has shown that unsaturated flow through stratified soils or soils containing gravel layers may be impeded. This disruption to the optimum moisture regime of bitterbrush may also affect other soil properties, which may be detrimental to development species.

No soil factors other than the amount of rock and gravel were found by the simple correlation analysis to be significantly related to bitterbrush production. Chemical factor relationships were generally weak and were probably reflections of interactions with physical properties affecting moisture. For example, phosphorus is negatively correlated with bitterbrush production in the top six inches but positively correlated below that depth. This unexpected result may indicate a downward movement of this nutrient. Phosphorus usually

TABLE III: SIMPLE CORRELATION COEFFICIENTS BETWEEN YEARLY VEGETATION PRODUCTION AND SELECTED SOIL FACTORS

Soil Factor	Bitterbrush (lbs./A.)	Silver Sage (lbs./A.)	Total Forage (lbs./A.)
Amount of Gravel (% x inches)	-.50*	.25	-.32
Avail. P 0-6" (ppm)	-.26	.02	-.38
Avail. P 6-12" (ppm)	.27	.13	.15
% Coarse Sand 12-24"	-.28	.15	.24
% Sand 0-6"	-.15	-.17	-.36
Extr. Mg 0-6" (meq/100 g.)	-.13	-.31	.25
Extr. Mg 12-24" (meq/100 g.)	-.18	.47*	.33
Thickness A Horiz. (inches)	.03	.20	.22
Thickness B2 Horiz.	-.17	.24	-.35
Depth Abund. Roots (inches)	.00	.02	.13
Avail. K 0-6" (ppm)	-.12	.07	.16
Avail. K 12-24" (ppm)	.21	.15	.49*
% Org. Mat. 6-12"	.12	.01	.17

does not move in the soil except in very coarse textured soils such as those sampled. Medin (1959) also reported a negative correlation of vegetation production with phosphorus. His explanation that phosphorus is negatively correlated with other factors which affect vegetation in a positive direction could not be confirmed by this data.

Stepwise Multiple Regression--Table IV shows the soil factors which were found most important to bitterbrush production by multiple regression analysis. The amount of gravel and rock in the profile was most important to the equation, accounting for 25 percent of the variation in bitterbrush production. The effect of the coarse fragment layer on production was negative as previously shown by simple analysis. Available P in the 6-12 inch layer was the only soil factor to have a positive relationship with bitterbrush production in the step selected for a prediction equation. Four soil factor measurements taken alone were found to be significantly correlated with production of bitterbrush when the effects of all other variables were held constant. All measurements in the 24-36 inch soil strata appeared low on the list of variables entered into regression. This indicates that their importance may have been reduced by the overwhelming effect of the gravel layer.

Sand in the surface six inches was included in the equation since it was close to being significant and accounted for about six percent of the variability. Below the fifth step in the analysis the number of significant variables declined.

TABLE IV: STEPWISE MULTIPLE REGRESSION SUMMARY ANNUAL PRODUCTION OF BITTERBRUSH AS THE DEPENDENT VARIABLE

Order Variables Entered	R^2	F Ratio For Variables In Step Selected For Prediction
Amt. of Gravel (-)[1] (% x inches)	.250	14.22**
Avail. P 0-6" (-) (ppm)	.348	4.50
Avail. P 6-12" (ppm)	.543	5.52*
Avail. K 0-6" (-) (ppm)	.592	4.70*
% Sand 0-6" (-)	.652	2.78

Prediction Equation:

Production of Bitterbrush (lbs./A./yr.) = 3749 - 229.1x(Amt. of Gravel) - 48.9x(Avail. P 0-6") + 65.0x(Avail. P 6-12") - 1905x(Avail. K 0-6") - 30.1x(% Sand 0-6").

[1] Indicates negative correlation with production.

Analysis of Silver Sagebrush Production

Simple Correlations--As with bitterbrush, the vegetation measurement most associated with production of silver sage is percent line intercept. Table V shows this and other simple correlations between silver sagebrush and measures of vegetation. A strong negative correlation was shown between height of silver sagebrush and percentage grass composition. In general, silver sagebrush success was negatively associated with all measures of other vegetation except forbs. There was essentially no correlation at all with percentage of forbs.

Table III reveals that silver sagebrush production was strongly related by simple correlations with extractable magnesium in the 12-24 inch layer. Percent sand in the same layer was negatively related to production. The root system of silver sagebrush is shallower than that of bitterbrush. Silver sage has been found to occur on soils with imperfect drainage (Smith, 1966; Thatcher, 1959). Thus if the role of the gravel layer is in fact to restrict the movement of water, a positive correlation between gravel content and some measure of silver sage would be expected. This was found to be the case. The relative production and percent intercept of silver sage were significantly and positively correlated at the 5% and 1% levels respectively with amount of rock and gravel in the soil profile. Percent line intercept was also positively correlated with thickness of the gravel layer.

TABLE V: SIMPLE CORRELATION COEFFICIENTS BETWEEN MEASURES OF SILVER SAGEBRUSH AND OTHER VEGETATION CHARACTERISTICS

	Production lbs./A.	Density no./100sq.ft.	Height inches	Intercept %
Production	1.00			
Density	.32	1.00		
Height	.52*	.60**	1.00	
Intercept	.70**	.47*	.54**	1.00
% Comp. By Wt.	.89**	.42*	.55**	.83**
Prod. Shrubs lbs./A.	.24	.73**	.17	.01
Vege. Cover % of area	-.32	-.14	-.14	-.34
% Comp. By Wt. Grasses	-.28	-.23	-.52*	-.40
Forbs	-.13	.37	-.07	.05
Shrubs	.34	-.02	.34	.28
Opuntia sp.	-.18	-.40	-.16	-.24
S. comata	.01	-.22	-.29	-.11
P. tridentata	-.38	-.27	.18	-.28

When only those plots which contained gravel and rock were examined separately, very strong negative correlations existed between depth to the gravel layer and relative density and height of silver sagebrush. This indicates that as the depth increases, the importance of the gravel to the moisture regime of this species decreases.

Stepwise Multiple Regression--Table VI shows five variables in the step chosen for prediction of annual dry weight of silver sagebrush. Extractable magnesium in two separate layers, thickness of the A horizon, and depth of abundant rooting were the soil measurements found significant. Extr. Mg. was most important to the equation. The change in sign of the coefficient from minus in the top six inches to plus in the 12-24 inch zone may be a reflection of movement of magnesium by water, as suggested for phosphorus in the bitterbrush prediction equation.

Amount of gravel was not included in the equation, however the inclusion of percent organic matter and thickness of the A horizon may indicate that increased moisture near the surface was favored by silver sage. Field observations did indicate that silver sagebrush occurred in somewhat purer stands where gravel and rock was near to the surface. This condition may have been more the result of exclusion of other shrubs than a benefit for silver sagebrush.

TABLE VI: STEPWISE MULTIPLE REGRESSION SUMMARY ANNUAL PRODUCTION OF SILVER SAGEBRUSH AS THE DEPENDENT VARIABLE

Order Variables Entered	R^2	F Ratio For Variables In Step Selected For Prediction
Extr. Mg 12-24" (meq/100 g.)	.221	22.17**
Extr. Mg 0-6" (-) (meq/100 g.)	.416	19.21**
Thickness A Horiz. (inches)	.506	6.50*
Depth Abund. Roots (-) (inches)	.603	7.00*
Org. Mat. 6-12" (%)	.672	3.34

Prediction Equation:

Production of Silver Sage (lbs./A./yr.) = -55.9 + 521.3x(Extr. Mg 12-24") - 772.0x(Extr. Mg 0-6") + 23.5x(Thickness A Horiz.) - 12.1 x (Depth Abund. Roots) + 279.7x(Org. Mat. 6-12").

Analysis of Forage Production

Total annual forage production was defined earlier to be annual dry matter production of all vegetation excluding prickly pear cactus. Since this measurement includes such a variety of species and life forms of vegetation, the interpretation of statistical results is difficult.

Four of the 21 soil property measurements which were entered into regression, appeared significant at the sixth step of the analysis. Three of the six variables in the prediction equation shown in Table VII, also appeared in the bitterbrush equation. The amount of coarse fragments in the soil profile again appeared as the most important factor. The forage production equation included three factors at depths below the A horizon or surface foot of soil. These factors appeared significant in multiple regression with production of grass and all shrubs.

Prickly Pear Soil-Vegetation Relationships

Prickly pear cactus occurs throughout the area, sometimes in profuse amounts. Its presence can hardly be ignored as it occupies space on the site which presumably could be filled by some more favorable ground cover. Since it is nearly impossible to determine the annual dry matter production of this species, its above-ground living biomass was estimated for inclusion in a total vegetation production figure. Prickly pear production was not analyzed by simple or

TABLE VII: STEPWISE MULTIPLE REGRESSION SUMMARY YEARLY FORAGE PRODUCTION AS THE DEPENDENT VARIABLE

Order Variables Entered	R^2	F Ratio For Variables In Step Selected For Prediction
Avail. K 12-24" (ppm)	.239	6.74*
Thickness B2 Horiz. (-) (inches)	.383	4.06
Amt. of Gravel (-) (% x inches)	.474	9.85**
Coarse Sand 12-24" (%)	.546	5.04*
Avail. K 0-6" (-) (ppm)	.614	4.61*
Sand 0-6" (-) (%)	.682	3.23

Prediction Equation:

Production of Forage (lbs./A./yr.) = 4241 + 2067x(Avail. K 12-24") - 12.8x(Thickness of B2 Horiz.) - 196.8x(Amt. of Gravel) + 10.04x(Coarse Sand 12-24") - 2252x(Avail. K 0-6") - 32.5x(Sand 0-6").

multiple regression, but total vegetation was examined, and percent composition of cactus was included in the analysis of simple correlations. Since the only difference between total vegetation and total forage was the dry matter estimate of the cactus, the differences in the effects of various independent factors should be due to prickly pear. The best equations for both forms of production shared the independent factors of available K in the 12-24 inch zone, and thickness of the B_2 horizon. This would seem to indicate that presence of prickly pear on the site was not affected by these factors. This is no doubt a reflection of the plant's shallow root system.

The percentage composition of prickly pear was not highly correlated with any soil factors in the simple regression analysis. A significant positive relationship was found between relative production of prickly pear and relative production of bitterbrush. The two species did not share high correlations with the same soil factors however.

If any conclusion can be drawn from the above observations it would be that prickly pear cactus and bitterbrush are positively associated on the area, but common factors which favor the two species are probably not soil related.

SUMMARY AND CONCLUSIONS

The purpose of this study was to examine the relationships between soil properties and native vegetation responses in a bitterbrush-sagebrush association. Specific objectives were to: (1) Describe and quantify various soil properties and vegetation responses. (2) Establish which soil properties are correlated most with selected measurements of vegetation. (3) Determine the best equation that can be used to predict annual vegetation production from soil properties.

The study area, which was located in Northwestern Colorado, reflected differences in vegetation production and composition along observable gradients. In order to isolate the soil factor influence and minimize the possible overwhelming effects of other environmental factors, the study was limited to an area where climate, elevation, and geology were uniform. Topographic influences were minimized by locating sample plots on relatively level uplands.

Climate of the region is dry (12 inches of precipitation annually), warm in summer, and cold in winter. Summer rains are light and infrequent. Vegetation is composed of northern desert shrub-grass species. Sheep grazing and game management are the principle land uses. Soils are young, coarse-textured, structureless, low in organic matter, and relatively high in mineral nutrition. Active dunes are present in the vicinity, and geologic wind erosion is in evidence throughout the area. Accelerated erosion is not a characteristic of the landscape.

Twenty-two study plots were selected to represent the range of characteristics for the two principle shrub species, *Purshia tridentata* and *Artemisia cana*. Recently disturbed areas were avoided. Data was collected on shrub density, frequency of all species, shrub line intercept, shrub height, species composition by weight, ground cover percent of grasses, forbs, and shrubs, and dry weight of annual production of grasses, forbs, shrubs, bitterbrush, and sagebrush.

Standard soil survey procedures were followed in describing soils at each plot. Relative abundance of roots was estimated for each horizon. Textural analysis followed the method of Boyoucous (1939). Chemical analysis was performed by the Colorado State University Soil Testing Laboratory. The following properties were measured: pH, lime, organic matter content, total soluble salts, available phosphorus, available potassium, total nitrogen, extractable calcium, magnesium, sodium, and potassium. Values of soil properties were expressed as concentration or amounts in horizons and in layers of various thicknesses.

Soil and vegetation data were related by means of simple correlation coefficients and multiple linear regression analysis. The stepwise procedure was used to determine the best regression equation for prediction of eight categories of vegetation production:

grasses, forbs, shrubs, bitterbrush, silver sagebrush, all sagebrush, all forage, and all vegetation.

Initial screening of the data eliminated some soil factors from further consideration. Extractable sodium, pH, and total soluble salts showed rather constant values for all samples and thus would not have been suitable for regression analysis. Simple linear correlation coefficients (r) were computed between all possible combinations of 88 soil and vegetation variables. These coefficients were tested for significance at the 1% and 5% levels of probability under the null hypothesis that there was no relationship between the variables which could be accounted for by linear regression. A total of 21 independent variables were selected for stepwise multiple regression analysis with eight dependent variables. Independent variables were chosen on the basis of their simple correlations with the dependent variables.

Simple Correlations-Soil Factors--An examination was made of the (r) values between soil factors which were found to be highly correlated with one or more vegetation factors. The amount of gravel, found to be so important to prediction of bitterbrush production was significantly correlated with only one other soil factor measurement, magnesium in the 12-24 inch zone. This would indicate that the gravel factor was relatively independent from the other soil measurements in its effect on the vegetation, and therefore would be a good predictor of vegetation characteristics.

Simple correlation coefficients showing a high positive association between extractable and available potassium. Much of the available K may be leached from upper soil horizons to lower ones where it may accumulate if enough clay is present. Because available K is a less expensive laboratory determination, it was entered into multiple regression analysis in place of extractable K when feasible.

This step in the process of screening variables for further analyses was used relatively little since there were usually few factors significantly related to vegetation production by simple regression analysis.

Bitterbrush Results--Percent line intercept of living crown appeared as the best vegetative indicator of bitterbrush annual dry matter production. The layer of coarse fragments which was present in about half of the profiles was found to be very important to the prediction of bitterbrush production. The relationship between amount of gravel and rock and all measures of bitterbrush was negative and significant at the 5% level or better. Although the specific effects of the gravel and rock is not known, it is believed to be associated with a disruption in deep moisture penetration.

No other soil factors were found to be significantly correlated with bitterbrush production in the simple regression analysis. In general, physical properties gave higher correlation coefficients with bitterbrush production than did chemical factors.

The prediction equation chosen for bitterbrush production contained five independent variables and accounted for 65% of the variability in production. The order of variables in the step selected for prediction was: amount of gravel, available P in the top 6-12 inch zone, available K in the top six inches, available P in the top six inches, and percent sand in the same layer. Available P below the surface was the only positive factor included. The overwhelming effects of the gravel layer to the moisture regime of bitterbrush apparently overshadowed the high simple correlations with soil factors at depths below the coarse fragments layer, so that factors which were found important to a multiple regression equation for prediction of annual production were all located in the top six or 12 inches of soil.

Chemical soil factors which were important to bitterbrush production may be reflection of physical properties affecting movement of these elements.

Silver Sagebrush Results--The gravel layer did not appear to be important to prediction of silver sagebrush. Although the influence of gravel was manifested in relative production and percent intercept of the sagebrush species. It appeared from field observations that the presence of rock and gravel at or near the surface of a site resulted in exclusion of bitterbrush, thus indirectly improving the competitive advantage of silver sagebrush.

The relationships of magnesium to silver sage was similar to that found with P and K and bitterbrush, i.e., negative correlation near the surface and positive correlation in a deeper zone. The implication of movement by water is the same. Although no sites were poorly drained or even what is normally considered imperfectly drained, silver sagebrush success was positively associated with factors generally associated with a more moist soil near the surface; i.e., organic matter and thickness of the A horizon.

<u>All Forage-Results</u>--Measurements must be taken of chemical and physical properties at several depths in the soil profiles in order to satisfactorily predict production of all forage on an area. Three of the six soil factors found most important to prediction of total forage were also important to prediction of the dominant shrub on the area, bitterbrush. The remaining factors were also important to prediction of grass and all shrubs. More than 60% of the variability in forage production can be accounted for by five rather simple determinations. Amount of gravel and thickness of the B2 horizon can be determined in the field, and percentage sand and coarse sand can be determined by a simple seiving process. A laboratory determination of available K in two zones would complete the measurements necessary for prediction data.

<u>Prickly Pear-Results</u>--No strong correlations were found between soil factors and distribution of prickly pear cactus. There was

significant evidence to establish a positive relationship between relative production of prickly pear and bitterbrush. The relationship was not apparently connected to soil factors.

Conclusions

Perhaps the most notable conclusion to be emphasized by this study is that ecological research or land management programs which do not include examination of soil properties may easily overlook an important factor limiting vegetation development. In regions where soils are young--subjected to soil forming processes for relatively short periods of time, the influence of parent material is very important. Even on the same parent material great differences may exist in soils due to erosion patterns and stratification. The existence of the gravel layer and its apparent effect on the moisture regime of vegetation in the area studied was not recognized prior to sampling the soils.

Further research in the soil-vegetation relationships of the sagebrush-bitterbrush type should surely include studies to find the cause and effect relationships of important factors. Additional studies are needed to uncover the effects of those environmental factors which this study held constant, i.e., climate, parent material, and topography.

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APPENDIX

TABLE VIII: MEASURES OF DISPERSION AND CENTRAL TENDENCY FOR SELECTED VEGETATION FACTORS ON 22 SITES

Factor	Units	Mean	Std. Dev.	Range
Grass Production	lbs./A./yr.	171	95	35. - 483.
Forbs Production	lbs./A./yr.	74	64	8. - 238.
Shrubs Production	lbs./A./yr.	1193	350	613. -2025.
Bitterbrush Prod.	lbs./A./yr.	664	332	67. -1550.
Silver Sage Prod.	lbs./A./yr.	177	189	0 - 633.
All Sagebrush Prod.	lbs./A./yr.	298	315	0 -1167.
Forage Production	lbs./A./yr.	1445	346	828. -2187.
Total Vege. Prod.	lbs./A./yr.	1583	373	977. -2340.
Density Bitterbrush	no./100 sq. ft.	9.2	5.1	1.0- 18.0
Density Silver Sage	no./100 sq. ft.	7.9	7.2	0 - 31.4
Density Shrubs	no./100 sq. ft.	27.6	11.4	9.8- 57.6
Comp. By Wt. Bitterbrush	%	38.9	19.6	5.0- 68.4
Comp. By Wt. Silver Sage	%	9.5	9.9	0 - 29.8

TABLE VIII: (CONTINUED)

Factor	Units	Mean	Std. Dev.	Range
Comp. By Wt. S. Comata	%	9.9	6.1	0 - 21.8
Comp. By Wt. Opuntia sp.	%	8.5	8.1	0 - 31.2
Ground Cover Bare	%	26.7	12.7	7.3- 65.0
Ground Cover Litter	%	10.5	7.3	3.5- 36.7
Ground Cover Grass	%	13.2	6.1	5.3- 26.7
Ground Cover Forbs	%	3.7	3.8	.8- 14.3
Ground Cover Shrubs	%	48.3	12.7	24.5- 69.2
Ground Cover Opuntia sp.	%	6.9	5.1	0 - 19.2
Intercept Bitterbrush	%	27.5	14.5	2.2- 59.1
Intercept Silver Sage	%	4.0	3.6	0 - 12.1
Intercept Shrubs	%	39.0	11.3	18.6- 63.6
Height Bitterbrush	inches	32.7	7.4	16.9- 44.5
Height Silver Sage	inches	18.4	6.9	0 - 28.5

TABLE IX. MEASURES OF DISPERSION AND CENTRAL TENDENCY FOR SELECTED SOIL FACTORS ON 22 SITES

Factor	Units	Mean	Std. Dev.[1]	Range
Thickness A Horizon	inches	10.7	3.5	4.5-17.0
Thickness B2 Horizon	inches	15.4	8.3	6.5-35.0
Depth to B2 Horizon	inches	13.0	5.8	4.5-26.0
Clay in B2 Horizon	%	10.9	3.1	6.3-20.1
Clay in 0-6"	%	7.7	2.0	5.0-10.7
Clay in 6-12"	%	8.6	2.4	6.0-12.1
Clay in 12-24"	%	9.6	2.2	4.7-12.8
Clay in 24-36"	%	8.8	3.1	5.1-19.0
Sand in 0-6"	%	86.9	3.6	79.6-92.6
Sand in 6-12"	%	86.8	3.4	80.7-92.6
Sand in 12-24"	%	86.4	4.2	76.3-92.6
Sand in 24-36"	%	88.0	5.2	73.8-92.9
Coarse Sand in 0-6"	%	34.8	11.3	13.0-49.0
Coarse Sand in 6-12"	%	34.8	11.0	12.0-58.0
Coarse Sand in 12-24"	%	33.9	11.7	9.0-64.0
Coarse Sand in 24-36"	%	34.2	14.4	8.0-66.0
Organic Matter in 0-6"	%	0.61	0.27	0.2- 1.3
Organic Matter in 6-12"	%	0.50	0.21	0.2- 1.0
Nitrogen in 0-6"	%	0.04	0.01	0.02-0.05
Nitrogen in 6-12"	%	0.03	0.01	0.02-0.05

[1] Standard Deviation

TABLE IX: (CONTINUED)

Factor	Units	Mean	Std. Dev.	Range
Extr. Mg in 0-6"	meq/100 g.	.78	.18	.5 -1.5
Extr. Mg in 6-12"	meq/100 g.	.93	.23	.6 -1.4
Extr. Mg in 12-24"	meq/100 g.	1.16	.28	.7 -1.7
Extr. Mg in 24-36"	meq/100 g.	1.20	.31	.7 -2.1
Extr. K in 0-6"	meq/100 g.	.26	.07	.15- .41
Extr. K in 6-12"	meq/100 g.	.27	.08	.15- .41
Extr. K in 12-24"	meq/100 g.	.26	.09	.15- .39
Extr. K in 24-36"	meq/100 g.	.24	.09	.13- .46
Avail. K in 0-6"	ppm	111.3	37.4	56.-203.
Avail. K in 6-12"	ppm	120.4	41.9	58.-203.
Avail. K in 12-24"	ppm	107.2	41.6	45.-191.
Avail. K in 24-36"	ppm	77.6	45.9	31.-225.
Extr. Ca in 0-6"	meq/100 g.	3.8	1.0	2.5- 7.4
Extr. Ca in 6-12"	meq/100 g.	4.2	.9	2.7- 6.9
Extr. Ca in 12-24"	meq/100 g.	4.9	1.2	3.3- 7.8
Extr. Ca in 24-36"	meq/100 g.	5.0	1.8	3.3-10.9
Avail. P in 0-6"	ppm	7.9	2.9	3.8-14.3
Avail. P in 6-12"	ppm	7.7	2.3	4.1-11.9
Avail. P in 12-24"	ppm	7.7	2.6	4.1-13.4
Avail. P in 24-36"	ppm	7.4	4.0	2.9-21.7
Amount of Gravel	% x inches	.35	.9	0 - 4.0

TABLE IX: (CONTINUED)

Factor	Units	Mean	Std. Dev.	Range
Thickness Gravel Layer[1]	inches	6.4	6.8	0 -20.
Depth to Gravel Layer[1]	inches	30.6	24.3	0 -60.
Depth of Abund. Roots	inches	13.1	7.2	4.5-36.0
Depth to Few Roots	inches	24.1	9.4	10.0-48.0
Salts in A Horizon	mmohs/cm.	0.3	.14	.1- .7
pH in A Horizon	1:5	7.3	.16	7.0- 7.6
pH in B Horizon	1:5	7.5	.17	7.2- 7.7
Lime in A Horizon	%	.2	.15	0 - .8
Lime in B Horizon	%	.3	.25	0 - 1.0

[1]Values are for gravel-containing profiles only.

TABLE X: MAJOR SPECIES OF PLANTS

CODE	SCIENTIFIC NAME	COMMON NAME
	Shrubs	
ARCA	*Artemisia cana viscidula* (Osterhout) Beetle	silver sagebrush
ARTRTR	*A. tridentata tridentata* Nutt.	big sagebrush
ARTRWY	*A. tridentata wyomingensis*	
CHNA	*Chrysothamnus nauseosus* (Pallas) Britt.	rubber rabbitbrush
CHVS	*C. viscidiflorus* (Hook) Nutt.	low rabbitbrush
GUSA	*Gutierrezia sarothrae* (Pursh) Britt. & Rusby	snakeweed
PUTR	*Purshia tridentata* (Pursh) D.C.	bitterbrush
TECA	*Tetradymia canescens* D.C.	horsebrush
	Grasses	
AGSM	*Agropyron smithii* Rydb.	western wheatgrass
ARLO	*Aristida longiseta* Steud.	threeawn
BRTE	*Bromus tectorum* L.	cheatgrass
CALO	*Calamovilfa longifolia* (Hook) Scribn.	prairie sandreed
CAREX	*Carex* sp.	sedge
FEOC	*Festuca octaflora* Walt.	fescue
KOCR	*Koeleria cristata* (L.) Pers.	junegrass
ORHY	*Oryzopsis hymenoides* (R.&S.) Ricker	Indian ricegrass
POFE	*Poa fendleriana* (Steud.) Vasey	mutton bluegrass
POPR	*P. Pretensis*	Kentucky bluegrass
POSE	*P. secunda* Presl.	Sandberg bluegrass
SIHY	*Sitanion hystrix* (Nutt.) Smith	squirreltail
SPCR	*Sporobolus cryptandrus* (Torr.) A. Gray	sand dropseed
STCO	*Stipa comata* Trin. & Rupr.	needle and thread
	Half-Shrubs & Forbs	
ARFR	*Artemisia frigida* Willd.	fringed sage
EULA	*Eurotia lanata* (Pursh) Mog.	winterfat
OPUN	*Opuntia polycantha* Haw.	prickly pear cactus

TABLE X: (CONTINUED)

CODE	SCIENTIFIC NAME	COMMON NAME
ARLU	Artemisia ludaviciana Nutt.	cudweed sagewort
ARLI	Arabis lignifera A. Nels.	rockcress
ALCE	Allium cernum L.	onion
BASA	Balsamorhiza saggitata (Pursh) Nutt.	balsamroot
CALI	Castelleja linariaefolia Benth. in DC.	Wyoming paintbrush
CANU	Calochortus nuttallii Pursh.	sego lily
CHVI	Chrysopsis villosa (Pursh) Nutt.	hairy goldaster
COUM	Comandra umbellata (L.) Nutt.	bastard toadflax
CRFL	Cryptantha flavoculata A. Nels.	
CROC	Crepis occidentalis Nutt.	hawksbeard
DERI	Descurainia richardsonii viscosa (Rydb) Detling	tansey mustard
ERCA	Eriogonum campanulatum Nutt.	
EROV	E. ovalifolium Nutt.	cushion eriogonum
EREN	Erigeron engelmanii A. Nels.	wild daisy
GICO	Gilia congesta Hook.	
LAFR	Lappula fremontii (Torr.) Greene	stickseed
LARE	L. redowski (Hornem.) Greene	stickseed
LEDE	Lepidium densiflorum Schrad.	pepperweed
LELU	Lesquerella ludoviciana (Nutt.)	bladder pod
LEPU	Leptodactylon pungens (Torr.) Rydb.	
LUAR	Lupinus argenteus Pursh	lupine
LUGR	L. greenei A. Nels.	tailcup lupine
ONTR	Oenothera trichocalyx Nutt. ex T. & G.	evening primrose
ORLU	Orthocarpus luteus Nutt.	owlclover
PHBR	Phlox bryoides Nutt.	phlox
PLPU	Plantago purshii Roem. & Schult.	woolly indianwheat
PORA	Polygonum ramosissimum Nichx.	knotweed
PSOR	Psoralea sp. L.	scurfpea
SEFE	Senecio fendleri lanatus Osterh.	
SENE	Senecio sp. L.	groundsel
SPCO	Sphaeralcea coccinea (Pursh) Rydb.	scarlet globemallow
STEX	Stephanomeria exigua Nutt.	wirelettuce
TRDU	Tragopogon dubuis Scop.	goatsbeard
ZYPA	Zygadenus paniculatus (Nutt.) S. Wats.	deathcamas

FIGURE 6: SOIL PROFILE FOR MACROPLOT #13

A1	0-8½"	Light brownish gray (10YR 6/2, dry) to dark brown (10YR 4/3, moist) sandy loam (80-10-10); structureless; loose dry, very friable moist; $CaCO_3$ eq.=.1*; E.C.=.2; pH(1:5)=7.1; O.M.=.5%; roots very abundant; clear smooth boundary.
B2**	8½-19½"	Yellowish brown (10YR 5/4, dry) to dark yellowish brown (10YR 4/4, moist) sandy loam (81-7-12); structureless; hard dry; very friable moist; $CaCO_3$ eq.=.4%; E.C.=.3; pH(1:5)=7.3; O.M.=.6%; roots common; clear smooth boundary.
B3	19½-28"	Brown (10YR 5/3, dry) to dark brown (10YR 4/3, moist) sand (93-1-6); structureless; soft dry, loose moist; $CaCO_3$ eq.=.1%; E.C.=.3; pH(1:5)=7.4; O.M.=.3%; roots rare; clear smooth boundary.
C	28"+	Pale brown (10YR 6/3, dry) to brown (10YR 5/3, moist) sand (94-2-4); structureless; loose dry, loose moist; $CaCO_3$ eq.=.2%; E.C.=.2; pH(1:5)=7.4; O.M.=.4%; roots rare.

*A value this low may have resulted from laboratory determination procedures. Field observations indicated no reaction with HCl.

**The B horizons indicated in several profiles which follow are weakly developed. In some cases clay increases from A horizon may not justify B2 designation according to SCS criterion.

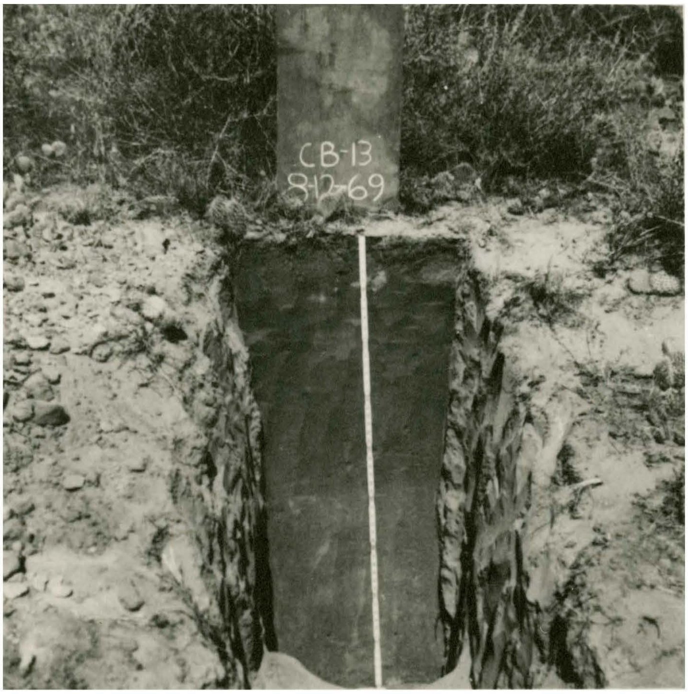
FIGURE 7: VEGETATION DESCRIPTION FOR MACROPLOT #13

This sample represents an area of high production of bitterbrush and low production of silver sagebrush.

	Total	PUTR	ARCA
Forage production-lbs./acre	2217	1500	100
Shrub density-plants/100ft.^{2}	23.6	15.2	3.2
Intercept-percent	45.7	37.5	3.5
Ave. max. height-inches		30.6	22.6

Species composition by weight-percent

Shrubs	74.0	Grasses	17.3	Forbs & Half-shrubs	8.7
PUTR	66.5	STCO	14.1	OPUN	6.5
ARCA	5.0	BRTE	1.7	ARFR	0.8
GUSA	2.5	AGSM	0.8	CRFL	0.7
		SPCR	0.5	OETR	0.5
		CAREX	0.2	OTHER	0.2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CB-13
7-23-70

FIGURE 8: SOIL PROFILE FOR MACROPLOT #15

A1	0-10"	Dark brown (10YR 4/3, dry) to very dark grayish brown (10YR 3/2, moist) loamy sand (87-5-8); structureless; loose dry, loose moist; $CaCO_3$ eq.=.1%; E.C.=.3; pH(1:5)=7.0; O.M.=.5%; roots very abundant; clear smooth boundary.
B2	10-24"	Dark brown (7.5YR 4/4, dry) to dark yellowish brown (10YR 4/4, moist) loamy sand (84-4-12); structureless; hard dry, very friable moist; $CaCO_3$ eq.=.1%; E.C.=.2; pH(1:5)=7.3; O.M.=.2%; gravel 9% and rock 1% in a 4" thick layer at a depth of 14"; roots common to few; gradual smooth boundary.
B3	24-60½"	Yellowish brown (10YR 5/4, dry) to brown (10YR 5/3, moist) sand (91-1-8); structureless; soft dry, loose moist; $CaCO_3$ eq.=.2%; E.C.=.1; pH(1:5)=7.4; O.M.=.1%; roots rare; gradual smooth boundary.
C	60½"+	Light gray (10YR 7/2, dry) to brown (10YR 5/3, moist) sand (95-1-4); structureless; loose dry, loose moist; $CaCO_3$ eq.=.2%; E.C.=.2; pH(1:5)=7.4; O.M.=.3%; roots rare.

FIGURE 9: VEGETATION DESCRIPTION FOR MACROPLOT #15

This sample represents an area of low production of bitterbrush and high production of silver sagebrush.

	Total	PUTR	ARCA
Forage production-lbs./acre	1660	158	642
Shrub density-plants/100ft.^{2}	34.8	4.0	16.0
Intercept-percent	43.1	15.9	12.0
Ave. max. height-inches		30.8	25.5

Species composition by weight-percent

Shrubs	52.5	Grasses	23.5	Forbs & Half-shrubs			24.0
ARCA	26.8	STCO	21.8	CRFL	3.2	OPUN	20.0
PUTR	7.2	BRTE	1.0	ARFR	0.3	OTHER	0.1
CHNA	13.8	AGSM	0.7	EROV	0.2		
GUSA	4.7			OETR	0.2		


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FIGURE 10: SOIL PROFILE FOR MACROPLOT #3

A1	0-9"	Brown (10YR 5/3, dry) to dark brown (10YR 4/3, moist) loamy sand (83-7-10); structureless; loose dry, loose moist; $CaCO_3$ eq.=.2%; E.C.=.5; pH (1:5)=7.2; O.M.=.5%; gravel 1%; rocks 1%; roots very abundant; gradual smooth boundary.
B2	9-16½"	Pale brown (10YR 6/3, dry) to brown (10YR 5/3, moist) sandy loam (82-4-14); structureless; loose dry, loose moist; $CaCO_3$ eq.=.7%; E.C.=.2; pH (1:5)=7.4; O.M.=.1%; gravel 1%; rock 1%; roots abundant; gradual smooth boundary.
C	16½"+	Light yellowish brown (10YR 6/4, dry) to brown to yellowish brown (10YR 5/3-5/4, moist) loamy sand (87-3-10); structureless; loose dry, loose moist; $CaCO_3$ eq.=.4%; E.C. =.2; pH(1:5)=7.6; O.M.=.1%; less than 1% gravel; roots few.

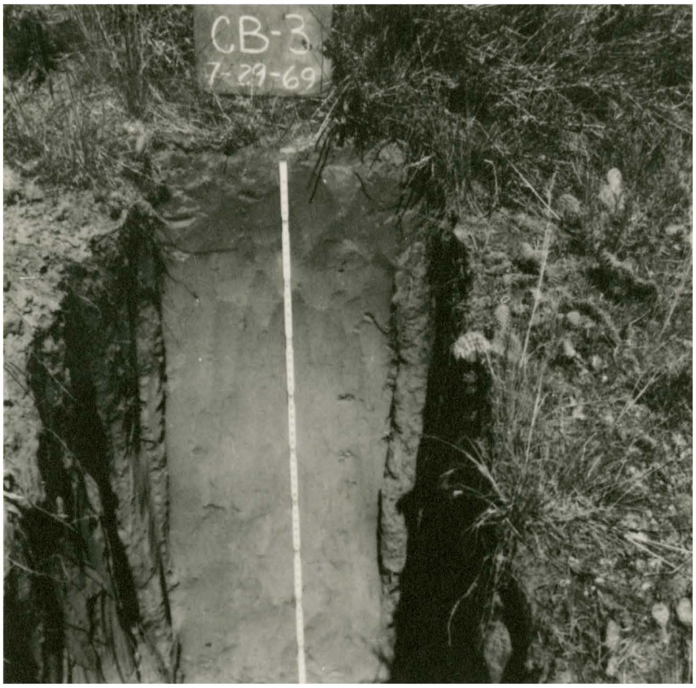
FIGURE 11: VEGETATION DESCRIPTION FOR MACROPLOT #3

This sample represents an area of high production of bitterbrush and low production of big sagebrush.

	Total	PUTR	ARTR
Forage production-lbs./acre	1693	1092	0.8
Shrub density-plants/100ft.^{2}	28.6	7.4	7.0
Intercept-percent	43.4	26.9	2.2
Ave. Max. height-inches		33.3	27.7

Species composition by weight-percent

Shrubs	79.0	Grasses	8.1	Forbs	12.9
PUTR	56.7	STCO	6.8	OPUN	7.0
CHNA	8.5	BRTE	1.0	LUP	2.0
ARCA	6.7	AGSM	0.3	SPCR	2.0
GUSA	6.3			COUM	1.0
ARTR	0.8			OTHER	0.9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CB-3
7-24-70

FIGURE 12: SOIL PROFILE FOR MACROPLOT #2

A1	0-8"	Dark grayish brown (10YR 4/2, dry) to very dark grayish brown (10YR 3/2, moist) loamy sand (85-5-10); structureless; loose dry, loose moist; $CaCO_3$ eq.=.3%; E.C.=.3; pH(1:5)=7.2; O.M.= 1.5%; roots very abundant; clear wavy boundary.
A3	8-16"	Dark gray (10YR 4/1, dry) to very dark gray (10YR 3/1, moist) loamy sand (84-5-11); structureless; loose dry, loose moist; $CaCO_3$ eq.=.3%; E.C.=.4; pH(1:5)=7.5; O.M.=.6%; roots common; clear wavy boundary.
B1	16-26"	Grayish brown (10YR 5/2, dry) to dark grayish brown (10YR 4/2, moist) sandy loam (83-4-13); structureless; soft dry, loose moist; $CaCO_3$ eq.= .4%; E.C.=.2; pH(1:5)=7.5; O.M.=1.1%; less than 1% gravel; roots few; clear irregular boundary; 7-14" thick.
B2	26-38"	Pale brown (10YR 6/3, dry) to brown (10YR 5/3, moist) sandy clay loam (73-7-20); structureless; hard dry, friable moist; $CaCO_3$ eq.=.9%; E.C.=.3; pH(1:5)=7.5; O.M.=.5%; roots few; clear wavy boundary.
C	38"+	Light brownish gray (10YR 6/2, dry) to grayish brown (10YR 5/2, moist) loamy sand (84-4-12); structureless; loose dry, loose moist; $CaCO_3$ eq.= .8%; E.C.=.3; pH(1:5)=8.4; O.M.=.2%; less than 1% gravel; roots few.

FIGURE 13: VEGETATION DESCRIPTION FOR MACROPLOT #2

This sample represents an area of low production of bitterbrush and high production of big sagebrush.

	Total	PUTR	ARTR
Forage production-lbs./acre	1813	442	1167
Shrub density-plants/100ft.^{2}	30.8	7.6	21.8
Intercept-percent	41.2	17.8	22.6
Ave. max. height-inches		32.4	32.1

Species composition by weight-percent

Shrubs	85.5	Grasses	11.7	Forbs	2.8		
ARTR	61.0	POPR	9.2	L JP	0.5	EROV	0.2
PUTR	23.7	SIHY	2.0	CALI	1.2	CHVI	0.7
CHNA	0.8	BRTE	0.5	BASA	0.2		


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FIGURE 14: SOIL PROFILE FOR MACROPLOT # 17

A1	0-10½"	Grayish brown (10YR 5/2, dry) to dark brown (10YR 5/3, moist) sand (89-2-9); structureless; loose dry, loose moist; $CaCO_3$ eq.=.1%; E.C.=.2; pH(1:5)=7.2; O.M.=.2%; roots very abundant; clear smooth boundary.
B2	10½-20"	Yellowish brown (10YR 5/4, dry) to dark yellowish brown (10YR 4/4, moist) sand (88-1-11); $CaCO_3$ eq.=.3%; E.C.=.1; pH(1:5)=7.2; O.M.=.7%; roots common to few; gradual smooth boundary.
B3	20-30½"	Light yellowish brown (10YR 6/4, dry) to dark yellowish brown (10YR 4/4, moist) sand (91-0-9); structureless; soft dry, loose moist; $CaCO_3$ eq.=.3%; E.C.=.3; pH(1:5)=7.4; O.M.=.4%; roots rare; gradual smooth boundary.
C	30"+	Pale brown to brown (10YR 5.5/3, dry and moist) sand (90-2-8); structureless; soft dry, loose moist; $CaCO_3$ eq.=.1%; E.C.=.2; pH(1:5)=7.4; O.M.=.1%; roots rare; gradual smooth boundary.

FIGURE 15: VEGETATION DESCRIPTION FOR MACROPLOT #17

This sample represents an area of high production of grasses and forbs.

	Total	PUTR	ARTR	Grasses	Forbs
Forage production-lbs./acre	1822	592	267	483	200
Shrub density-plants/100ft.^{2}	34.6	15.4	10.4		
Intercept-percent	31.8	20.1	6.0		
Ave. max. height-inches		26.7	20.5		

Species composition by weight-percent

Shrubs	52.3	Grasses	18.9	Forbs & Half-shrubs			28.8
PUTR	25.9	STCO	15.7	CHVI	4.5	BASA	3.0
ARTR	13.7	ORHY	1.3	ONTR	0.7	OPUN	18.7
GUSA	12.5	BRTE	0.9	LUP	0.5	OTHER	0.8
CHNA	0.2	AGSM	0.7	COUM	0.3		
		SPCR	0.3	ARLI	0.3		


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CB-17

FIGURE 16: SOIL PROFILE FOR MACROPLOT #7

A11	0-2"	Dark brown (10YR 4/3, dry) to very dark grayish brown (10YR 3/2, moist) sand (91-4-5) structureless loose dry, loose moist; CaCO3 eq. =. 3%; E. C. =. 2; pH(1-5)=7. 3; O. M. =. 9%; roots very abundant; abrupt smooth boundary.
A12	2-6½"	Dark brown (10YR 4/3, dry) to very dark grayish brown (10YR 3/3, moist) loamy sand (85-6-9); structureless; loose dry, loose moist; CaCO3 eq. =. 2%; E. C. =. 2; pH(1-5)=7. 3; O. M. =. 7%; roots very abundant; clear smooth boundary.
B1	6½-11"	Dark brown (10YR 4/3, dry) to dark brown (7. 5YR 3/2, moist) loamy sand (82=5=13); structureless; soft dry, very friable moist; CaCO3 eq. =. 5%; E. C. =. 3; pH(1-5)=7. 4; O. M. =. 4%; less than 1% gravel; roots abundant; clear smooth boundary.
B2	11-21"	Yellowish brown (10YR 5/4, dry) to dark yellowish brown (10YR 4/4, moist) loamy sand (85-2-13); structureless; slightly hard dry, very friable moist; CaCO3 eq. =1. 0%; E. C. =. 2; pH(1-5)=7. 5; O. M. =. 7%; gravel about 25%, rock about 25%; roots common; gradual smooth boundary.
B3	21-36"	Pale brown (10YR 6/3, dry) to yellowish brown (10YR 5/4) loamy sand (88-1-11); structureless; soft dry, very friable moist; CaCO3 eq. =1. 4%; E. C. =. 2; pH(1-5)=7. 6; O. M. =. 2%; less than 1% gravel; roots few; abrupt irregular boundary; 18-33 inches thick.
C	36½"+	Light gray (10YR 7/1, dry) to brown (2. 5YR 5/2, moist) sand (93-1-6); structureless; loose dry, loose moist; CaCO3 eq. =. 4%; E. C. =. 2; pH(1-5) =8. 4; O. M. =. 6%; roots rare.

FIGURE 17: VEGETATION DESCRIPTION FOR MACROPLOT #7

This sample represents an area of low production of shrubs.

	Total	PUTR	ARCA
Forage production-lbs./acre	962	67	283
Shrub density-plants/100ft.^{2}	33.4	9.6	17.4
Intercept-percent	21.6	2.2	12.1
Ave. max. height-inches		17.3	17.8

Species composition by weight-percent

Shrubs	67.7	Grasses	10.3	Forbs & Half Shrubs			22.0
ARCA	24.5	STCO	8.8	CHVI	15.1	ARFR	4.2
GUSA	24.5	ORHY	0.8	CRFL	0.7	OPUN	1.5
TECA	7.5	KOCR	0.3	SPCO	0.3		
CHNA	6.2	BRTE	0.2	CCUM	0.2		
PUTR	5.0	SIHY	0.2				


CB-7
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CB-7
7-27-70