SOIL DEPTH--VEGETATION RELATIONSHIPS ON NIOBRARA SHALE IN COLORADO FOOTHILLS

Sultan Maqsood Khan*

Abstract. *The study was conducted on the Niobrara Shale hog-back in the Colorado Foothills near Fort Collins, to determine the effect of soil depth on composition, total cover, shrub cover and herbaceous cover of the vegetation. The analysis of variance showed significant difference between the stands and t test gave significant difference between the shrubby and non shrubby stands. The herbaceous cover and total vegetation cover were found positively correlated and shrub cover negatively correlated with the soil depth. The shrubs and herbaceous vegetation occupied thin and deep soils respectively.*

Introduction. It is generally believed that if all habitat characteristics are constant, the kind and density of vegetation varies with the depth of soil. To verify this general idea, the present study was undertaken with the specific objectives to find out:

1. Variation in composition and cover of stands on different soil depths;

2. Variation in total vegetation cover of the shrubby and non shrubby stands;

3. Relationship between soil depth and total aerial cover, shrub cover and herbaceous cover.

This study was also aimed at proving or disproving the contention, that depth of soil by erosion, caused as a result of faulty management practices results in changing the good grass ranges to shrubby vegetation on the Colorado foothills hog-backs.

Study Area. The study area is located about 6 kilometres northwest of Colorado State University's main campus in the relict true prairie-mountain shrub and grassland communities on Niobrara Shale hog-back running south to north from Engineering Research Centre lake to an abrupt ending just north of the Beef Cattle research area of Colorado State University. It is situated at about 40½° N Latitude, 105°W Longitude and an elevation of about 1600 metres.

Located in the semi-arid climatic type described by Thornthwaite (1948), the area was cool and temperate. The 88 year (1887-1975) averages of tempera-

*The author is Range Management Officer in Pakistan Forest Institute, Peshawar.

tures and precipitation of Fort Collins Weather Station, situated about 6 kilometres east of the study area, are given in Table 1 (Wirsnoorn, 1977).

Table 1

Average of temperatures and precipitation of Fort Collins Weather Station (1887-1975)

Month	Maximum temp. (C)	Minimum temp. (C)	Rainfall (mm)	Snowfall (cm)
January	4.7	--11.0	9	13.5
February	6.2	-- 9.2	13	17.8
March	9.9	— 5.3	26	24.6
April	15.6	0.1	50	16.3
May	20.3	5.2	71	2.5
June	25.9	9.7	44	0
July	28.9	12.7	39	0
August	28.6	11.8	36	0.8
September	24.1	6.7	33	0.8
October	17.9	0.8	29	7.1
November	10.6	— 5.5	13	14.0
December	5.8	-- 9.4	12	14.5
Total for year			375	111.9

The parent material is Niobrara Shale. The soil is alpha soil closely resembling grey brown podzol. The soil mantle is generally thin. Soluble materials are leached only to limited depths and lime accumulates at depths 13-38 cm below surface. Base saturation is high and increases with depth. Clay is accumulated in B horizon (Twilliger, 1977).

The general vegetation of foothill region is described in detail by Vestal (1917). The main species occurring in the study area are listed below:

Shrubs: *Artemisia glauca, Cactus* spp., *Cercocarpus montanus, Chrysothamnus* spp., *Yucca* spp.

Grasses: *Agropyron smithii, Andropogon gerardii, Andropogon scoparius, Aristida longiseta, Bouteloua curtipendula, Bouteloua gracilis, Bromus tectorum,*

Stipa comata, Stipa robusta, Stipa viridula.

Herbs: *Salsola hali, Senesio spartioides.*

The area has been protected from grazing animals for a long time. A large population of rabbits along with rodents and insects etc., are making the only use of this vegetation.

Methods: During October 1977, twelve vegetation stands on this approximately 3 Km long hog-back were delineated for analysis. These stands were selected on the basis of their apparent homogeneity as indicated by the physiognomy, kinds and distribution of prominent shrub or herbaceous species and the uniformity of the site.

To secure data 30 one-meter^2 open rod quadrats were systematically distributed within each stand along parallel lines, several metres apart, extended along the contour of the slope. The quadrats were placed at definite intervals depending upon the area of the stand. In each quadrat the percentages of the vegetation cover, shrubs cover, herbaceous cover and bare soil were recorded separately. The soil depth for each stand was measured with the help of a hand soil auger at the mid-point of each line and the average worked out for the stand. The boring stopped automatically when the shale was hit.

The analysis of variance for the total vegetation cover of 12 stands was carried out to determine whether it differed significantly between stands. The t test was used to find out whether there was significant difference between the total vegetation cover of the non-shrubby stands and that of the shrubby stands. Least significant difference for the total vegetation cover of these 12 stands was worked out for the comparison of stand means. Indices of similarity between stands were computed using the formula:

$$\text{Index of similarity} \quad \frac{2w}{A+B} \times 100$$

where A is the sum of shrub cover and herbaceous cover for one stand, B is the sum of corresponding values for another stand and w is the sum of the lower values for the cover that the two areas have in common. This procedure was modified from the method used by Bray and Curtis (1957) wherein they used the vegetation characteristics for all species (instead of life forms as has been used in this study) in the stands.

The regression was used to find out the relationships between soil depth and total vegetation cover, between soil depth and shrub cover, and between soil depth and herbaceous cover and the best fit curves for each of these rela-

tionships were plotted.

Results: Out of 12 sampled stands, five were without any shrub species and seven had mixed shrubby and non-shrubby vegetation. From the recorded data, average total cover, shrub cover, herbaceous cover and corresponding frequency values were worked out. These are shown in Table 2. The shrubby and non-shrubby stands were separated in Table 3 and Table 4 respectively.

Table 2

Cover and frequency percentages of different stands

(C = cover % F = Frequency %)

Stand No.	Total		Shrub		Herbaceous	
	C	F	C	F	C	F
S_1	66.6	100	18.2	70	48.4	100
S_2	89.8	100	—	—	89.8	100
S_3	83.4	100	—	—	83.4	100
S_4	32.9	100	20.6	90	12.3	80
S_5	73.1	100	9.3	53	63.8	100
S_6	60.2	100	50.2	100	10.0	97
S_7	83.5	100	—	—	83.5	100
S_8	21.6	100	13.4	83	8.2	100
S_9	64.2	100	—	—	64.2	100
S_{10}	26.5	100	22.5	90	4.1	87
S_{11}	40.1	100	20.9	80	19.2	100
S_{12}	83.4	100	—	—	83.4	100
Average Cover %		60.4		12.9		47.5
Average Frequency %		100		41.9		98.5
Average Constancy %		100		58.3		100

Table 3

Cover and frequency percentage of stands having shrubby vegetation

(C = Cover % F = Frequency %)

Stand No.	Total		Shrub		Herbaceous	
	C	F	C	F	C	F
S_1	66.6	100	18.2	70	48.4	100
S_4	32.9	100	20.6	90	12.3	80
S_5	73.1	100	9.3	53	63.8	100
S_6	60.2	100	50.2	100	10.0	97
S_8	21.6	100	13.4	83	8.2	100
S_{10}	26.5	100	22.5	90	4.1	87
S_{11}	40.1	100	20.9	80	19.2	100
Average	45.9	100	22.2	80.9	23.7	94.9

Table 4

Cover and frequency percentage of stands having no shrubby vegetation

(C = Cover % F = Frequency %)

Stand No.	Total		Herbaceous	
	C	F	C	F
S_2	89.8	100	89.8	100
S_3	83.4	100	83.4	100
S_7	83.5	100	83.5	100
S_9	64.2	100	64.2	100
S_{12}	83.4	100	83.4	100
Average	80.9	100	80.9	100

The analysis of variance for the total vegetation cover of 12 stands, each having 30 observations is shown as under:

ANOVA TABLE

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between groups	11	194867	17715	95.11*
Within groups	348	64785	186.2	
Total	359	259652		

The F value of 95.1 shows that the stands are highly significantly different as regards the total vegetation cover.

The t value of 23.99 showed that average total vegetation cover of non-shrubby stands was highly significantly different from that of the shrubby stands.

The results of least Significant Difference test are shown below:

S_8^1 S_{10} S_4 S_{11} S_6 S_9 S_1 S_5 S_3 S_{12} S_7 S_2

All non-shrubby stands except S_9 were not significantly different from each other. The shrubby stand S_8 was different from all others except S_{10}, S_{10} was different from all others except S_8 and S_4, while S_{11} was different from all other shrubby stands. S_1 was not different from S_6 and S_5 but S_6 and S_5 were different from each other.

The indices of similarity are shown in Table 5. The similarity index ranged from 7.1 per cent between S_2 and S_{10} to 100% between S_3 and S_{12} with an average of 50.8 per cent for all 66 pairs. The rows for each stand were added up. The stands were then ordinated by starting with the least similar stand which was S_6. The stand most similar to S_6, i.e., S_4, was placed next to it. Similarly other stands were placed next to these in the order of their similarity to S_6. The cover and frequency data were then recorded against all these stands and are given in Table 6.

* Highly significant

1. Stands joined by the same line are not significantly different at .05 level.

Table 5

Indices of similarity, in percentages, based on cover estimates in Table 1

Stand	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	Total
S_1		61.9	64.5	61.3	82.6	44.5	64.5	49.0	74.0	47.9	70.1	64.5	684.8
S_2	61.9		96.3	20.0	78.3	13.3	96.4	14.7	83.4	7.1	29.6	96.3	597.5
S_3	64.5	96.3		21.2	81.5	13.9	99.9	15.6	87.0	7.5	31.1	100.0	618.5
S_4	61.3	20.0	21.2		40.8	65.7	21.1	45.1	25.3	83.2	90.1	21.2	495.0
S_5	82.6	78.3	81.5	40.8		29.0	81.5	37.0	92.9	26.9	50.4	81.5	682.4
S_6	44.5	13.3	13.9	65.7	29.0		13.9	52.8	16.1	61.5	61.5	13.9	386.1
S_7	64.5	96.4	99.9	21.1	81.5	13.9		15.6	86.9	7.5	31.1	99.9	618.3
S_8	49.0	14.7	15.6	45.1	37.0	52.8	15.6		19.1	72.8	70.0	15.6	407.3
S_9	74.0	83.4	87.0	25.3	92.9	16.1	86.9	19.1		9.0	36.8	87.0	617.5
S_{10}	47.9	7.1	7.5	83.2	26.9	61.5	7.5	72.8	9.0		75.1	7.5	405.9
S_{11}	70.1	29.6	31.1	90.1	50.4	61.5	31.1	70.0	36.8	75.1		31.1	577.0
S_{12}	64.5	96.3	100.0	21.2	81.5	13.9	99.9	15.6	87.0	7.5	31.1		618.5

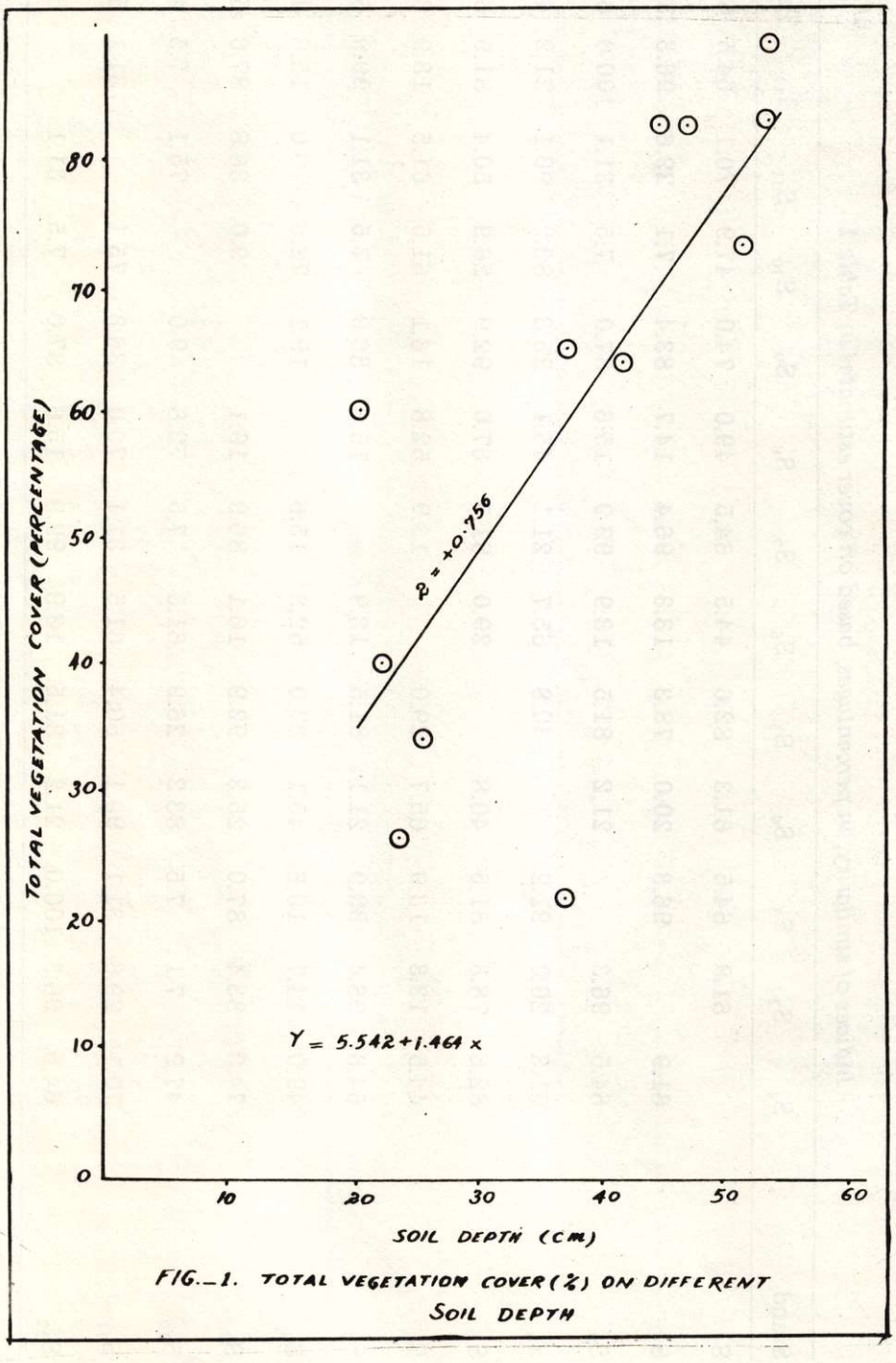

FIG._1. TOTAL VEGETATION COVER (%) ON DIFFERENT SOIL DEPTH

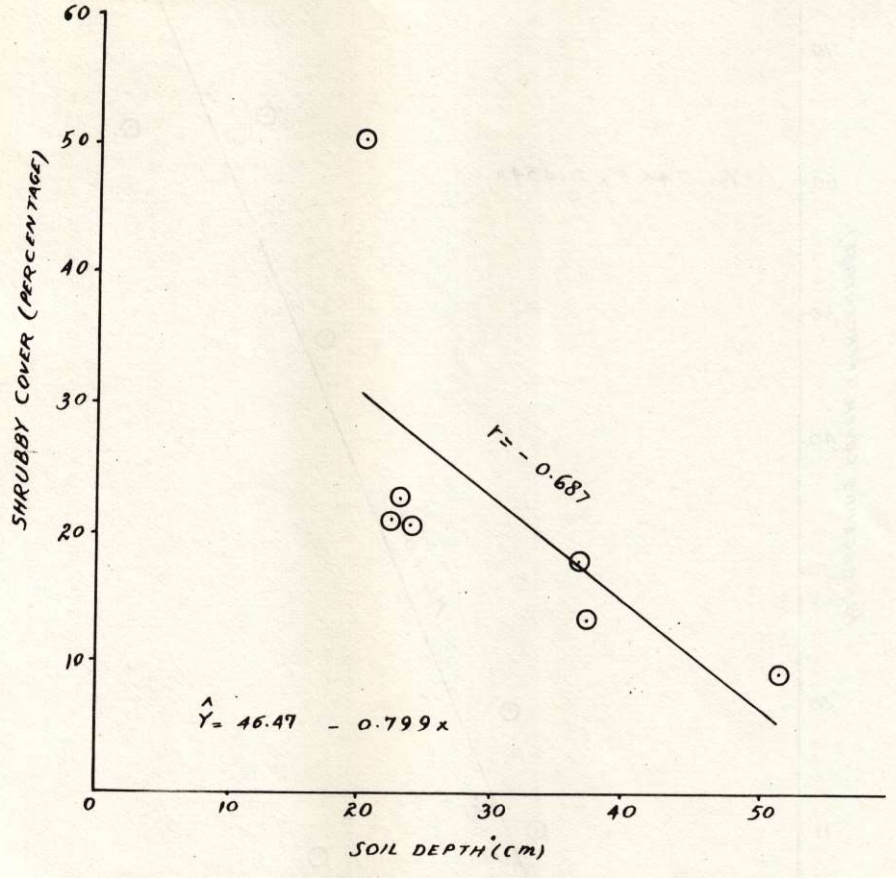

FIG.-2- SHRUBBY COVER (%) ON DIFFERENT SOIL DEPTHS

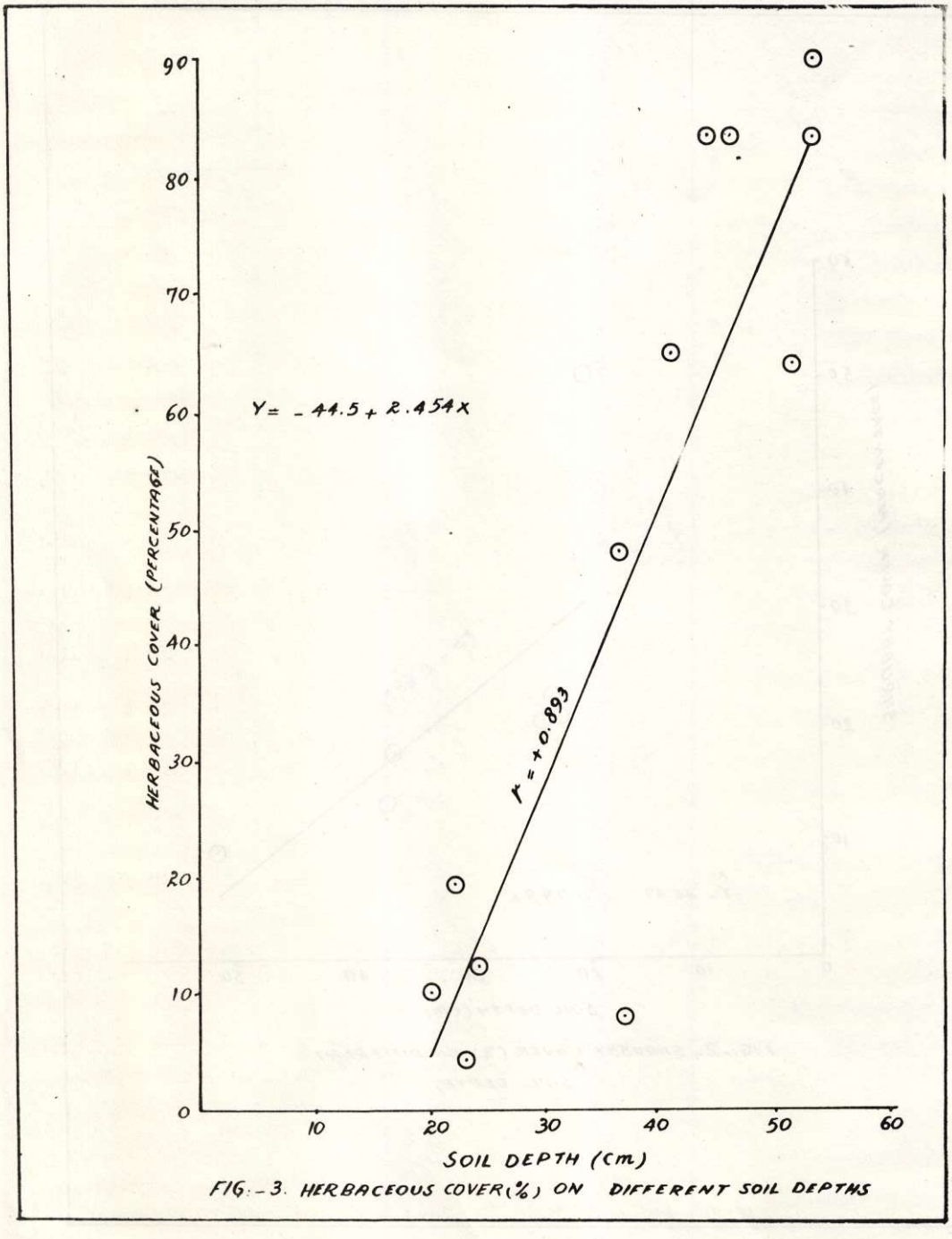

FIG.-3. HERBACEOUS COVER(%) ON DIFFERENT SOIL DEPTHS

Table 6

Matrix after ordination

Stand No.	Soil depth (cm)	Total		Shrub		Herbaceous	
		C	F	C	F	C	F
S_6	20	60.2	100	50.2	100	10.0	97
S_4	24	32.9	100	20.6	90	12.3	80
S_{11}	23	26.5	100	22.5	90	4.1	87
S_{10}	22	40.1	100	20.9	80	19.2	100
S_8	37	21.6	100	13.4	83	8.2	100
S_1	36	66.6	100	18.2	70	48.4	100
S_5	51	73.1	100	9.3	53	63.8	100
S_9	41	64.2	100	—	—	64.2	100
S_3	46	83.4	100	—	—	83.4	100
S_{12}	44	83.4	100	—	—	83.4	100
S_7	53	83.5	100	—	—	83.5	100
S_2	53	89.8	100	—	—	89.8	100

The soil depth of the 12 stands ranged from 20 cm to 53 cm, the total vegetation cover from 21.6 to 89.8, the shrub cover from 9.3 to 50.2 and herbaceous cover from 4.1 to 89.8.

There is general increase of soil depth, total vegetation cover and herbaceous cover and the general decrease of shrub cover from S_6 to S_2.

The co-efficients of correlation were calculated between soil depth and cover percentages and are shown in Table 7. There is positive relationship between soil depth and herbaceous cover while there is negative relationship between soil depth and shrub cover. The relationship between soil depth and total vegetation cover was then shown by curve in Fig. 1, between soil depth and shrub cover in Fig. 2 and soil depth and herbaceous cover in Fig. 3. These curves were plotted

according to the calculated equations of linear regression for each of these relationships shown on the respective figures. While Figs. 1 and 3 show a trend of total vegetation cover and herbaceous cover increasing with the increase in the soil depth Fig. 2 shows a trend of shrub cover decreasing with increase in the soil depth.

Table 7

Correlation between soil depth and cover percentage

Correlation between	Correlation coefficient
Soil depth and total cover	.756
Soil depth and shrub cover	— .687
Soil depth and herbaceous cover	.893

Discussion. All stands having soil depth less than 36 cm have total vegetation cover equal to or less than 60 per cent while all stands having soil depth greater than 37 cm have total vegetation cover greater than 60 per cent. All stands with soil depth less than 41 cm have shrub vegetation while all stands except S_5 with soil depth equal to or greater than 41 cm have no shrub vegetation. All stands having soil depth less than 40 cm except S_1 have herbaceous cover less than 50 per cent and all stands having soil depth greater than 40 cm have herbaceous cover greater than 50 per cent.

F for the analysis of variance for total vegetation cover of 12 stands is highly significant at the 0.01 level. The stands, therefore, significantly differ from one another in terms of total vegetation cover.

Calculated value of t in comparison of the group means is highly significant. The total vegetation cover of the non-shrubby vegetation, therefore, is highly significantly greater than that of the shrubby vegetation. All stands without shrubby vegetation are significantly different from all stands having shrubby vegetation except S_9 which is not significantly different from only two stands S_1 and S_6 having shrubby vegetation. This stand is also significantly different from all other stands having shrubby vegetation.

The herbaceous cover is strongly positively correlated with the soil depth and has +.893 as the coefficient of correlation. Therefore, with the increase in the soil depth, the herbaceous cover also increases and with the decrease of soil depth it decreases. The shrub cover is negatively correlated with the soil depth

with a coefficient of correlation of —.687. The shrub cover, therefore, decreases with the increase of soil depth and increases with decrease in the soil depth. The total vegetation cover is also positively correlated with the soil depth with the coefficient of correlation of +.756. This correlation is not as strong as that between herbaceous cover and soil depth because the shrub cover is also included in the total vegetation cover which is negatively correlated and therefore reduces the correlation coefficient. The total vegetation cover, however, also increases with the increase in soil depth and decreases with decrease in it. The results of statistically calculated correlations are also confirmed by the curves between soil depth and total vegetation cover, shrub cover and here baceous cover.

From the conclusions of this study, the general idea that the kind and density of vegetation varies with the depth of soil is confirmed. On shallow soils the vegetation consists predominantly of shrubby species and the total density of vegetation is low. With the increasing depth of the soil the shrubby species decrease and are ultimately completely replaced by herbaceous vegetation. The density of total vegetation also increases.

It also follows that, if due to faulty land management practices in good herbaceous ranges on the Colorado foothills, the soil erosion erodes away the soil and makes it shallow, these ranges will be invaded by shrubby species. This will decrease the carrying capacity and palatability of these rangelands and will also necessitate a change in the kind of suitable livestock from grazers to browsers.

The conclusions of this study have been borne out by the following comments/results:

Thin soils in the Colorado foothill region are occupied by shrublands and deep soils by grasslands (Dix, ___). Retzer (1953) pointed out that thickness of soil over the bedrock is one of the important features of soils in the foothills. Gemborys (1974) found depth of litter and depth of "A" horizon to be correlated with the structure of vegetation in the hardwood forests of Prince Edward Country, Virginia. High level association was found, by Mueggler and Harris (1969), between different levels of soil depths and various plant species in the mountain grasslands of central Idaho. In the glade region of the Missouri Ozarks, the soil depth was found greater in forest sites than in the glades (Kucera and Martin, 1957).

However, West and Kamal (1968) found in the shadscale zone of southwestern Utah that the association between depth of profile average (soil) and four plant communities was non-significant. Dyrness and Youngberg (1966), on the other hand, ascribed the shallower depths of soil within the ponderosa pine type in the central Oregon pumice region to lower density of vegetation.

Literature Cited

BRAY, J.R. and J.T. CURTIS. 1942. An ordination of the upland forest communities of Southern Wisconsin. Ecol. Mongr. 27: 325-349.

DIX, RALPH, L. Regional ecological systems of Colorado. Environment and Colorado—A handbook. Environmental Resources Centre, C.S.U., Fort Collins.

DYRNESS, G.T. and G.T. YOUNGBERG. 1966. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. Ecology 47 (1): 122-138.

GEMBORYS, STANLEY R. 1974. The structure of hardwood forest ecosystems of Prince Edward County, Virginia. Ecology 55(3): 614-621.

HARRINGTON, H.D. 1964. Manuals of the plants of Colorado. The Swallow Press Inc. Chicago. 666 p.

KUCERA, C.L. and S. CLARK MARTIN. 1957. Vegetation and soil relationships in the glade region of the southwestern Missouri Ozarks. Ecology 38(2): 285-291.

MUEGGLER, W.F. and C.A. HARRIS. 1969. Some vetgetation and soil characteristics of mountain grassland in central Idaho. Ecology 50(4): 671-678.

RETZER, JOHN L. 1953. Soil vegetation survey of wildlands. Jour. Forestry 51: 615-619.

THORNTHWAITE, C.W. 1948. An approach towards a rational classification of climate. Geog. Rev. 38: 55-94.

VESTAL, A.G. 1917. Foothill vegetation in the Colorado forest range. Bot. Gaz. 64: 353-385.

WEST, NEIL E. and KAMAL, I. IBRAHIM. 1968. Soil-vegetation relationship in the shadscale zone of soutern Utah. Ecology 49(3): 445-456.

VIRSHBORN, JAMES F. 1977. Weather records, Fort Collins, Colorado. 1887-1975. Mountain States Weather Services, Fort Collins.