Soil water, nitrate, and site characteristics of Montana foothills range
by June Gail Haigh

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soil Science
Montana State University
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Abstract:
This study was undertaken "because of the importance of water as a resource and the current interest in the natural grassland ecosystem. It provides some climatic, soil and vegetation data for eight microsites in a restricted ectone of Montana Foothills Range. Soil water was determined gravimetrically in early spring of 1970 and in late summer at 20 sites, most of which were in good to excellent range condition.

Samples for moisture and nitrate were taken with a King tube sampler and from hand dug pits. Bulk density for soils containing a large amount of coarse fragments was determined by a sand-fill excavation method.

Mean summer soil temperature at 50 cm depth ranged from 14.5 C to 17.5 G which allows the soils to be classified as Gryoborolls and Argiborolls. The study period precipitation ranged from 23.3 cm to 29.8 cm and was about normal for the general area over a I3 year period. Neither air temperature nor evaporation from a free water surface clearly stratified sites.

The growth season soil water depletion zone, and consumptive use rates varied markedly among the soils studied, but were quite similar among sites with similar soils and site factors. For all sites the consumptive use (precipitation plus soil depletion) ranged from 29.1 to 41.5 cm, or a difference of 12.4 cm. Three sites with similar deep silty soils had a range of only 2.9 cm. In these silty soils the water depletion was mainly from the upper 91 cm of soil while in soils containing many coarse fragments there was significant water depletion to 152 cm.

From these limited data it appears that soil nitrate is at a low level most of the year (less than 2 ppm). It may be in surplus for a short period in late June when the soils are both warm and moist, but is used rapidly by actively growings grasses before late July.

The average herbage production from clipped plots at the 20 sites was 1268 kg/ha (131 lb/a) ranging from 2167 kg/ha to 716 kg/ha.

Water use efficiency ranged from 20 to 58 kg/ha-cm of water used.

The highest producing site had the greatest water use efficiency and the least productive site had the lowest water use efficiency.

In the dissected upland Foothills Range of this study there is a complex of interacting soil and site factors that produce contrasting as well as intergrading micro-habitat types that need to be considered when assessing the alternative uses of these rangelands.

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by

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A thesis submitted in partial fulfillment
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ABSTRACT

This study was undertaken because of the importance of water as a resource and the current interest in the natural grassland ecosystem. It provides some climatic, soil and vegetation data for eight micro-sites in a restricted ectone of Montana Foothills Range. Soil water was determined gravimetrically in early spring of 1970 and in late summer at 20 sites, most of which were in good to excellent range condition.

Samples for moisture and nitrate were taken with a King tube sampler and from hand dug pits. Bulk density for soils containing a large amount of coarse fragments was determined by a sand-fill excavation method.

Mean summer soil temperature at 50 cm depth ranged from 14.5 C to 17.5 C which allows the soils to be classified as Cryoborolls and Argiborolls. The study period precipitation ranged from 23.3 cm to 29.8 cm and was about normal for the general area over a 13 year period. Neither air temperature nor evaporation from a free water surface clearly stratified sites.

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From these limited data it appears that soil nitrate is at a low level most of the year (less than 2 ppm). It may be in surplus for a short period in late June when the soils are both warm and moist, but is used rapidly by actively growing grasses before late July.

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INTRODUCTION

With the increasing demands on the water resources of the United States in recent years has come a closer look at the many and varied uses of water. No one has questioned the need of water for quenching human thirst but most other uses are coming under economic and environmental scrutiny.

About 70 percent (26 million hectares) of Montana is in rangeland or grazable woodland (Jackson 1970). Considering a minimum average precipitation of 30 cm, these lands receive about 7.8 million hectare meters of precipitation annually. What happens to this water, and this land, is of vital importance not only to the state's 250 million dollar livestock industry (Jackson 1970) but to the entire state economy and to the total environment. Montana State University Dean of Agriculture, writing of the Decade of the 70's. (Asleson 1970) expresses concern for rangelands:

> "Being primarily a range-livestock state... Obviously we should look at range productivity... There are real opportunities for research to develop the knowledge which can substantially increase range production... It is imperative that improvements be made in our range productivity if our livestock producers are going to continue to compete."

The current market value and the continued public interest in land, especially the natural ecosystem, also point to the need for study of rangelands.

A common system of range analysis is the Ecological Site Method (Dyksterhuis 1958). By this method range condition is defined in

relation to its potential or its pristine state. Because man has so altered vast areas by farming, grazing, industrial activities and other uses it is often difficult to recognize this "pristine" state. At times the altered condition has even becom accepted as the pristine and the real potential of the site is not realized. Over grazing has sometimes been cited to explain what is actually a limited site potential (Mason 1970). Many good documentations of pristine or near-pristine vegetation are reported in the literature of Branson and Miller (1965), Daubenmire (1942), Hulett and Tomanek (1969), Mueggler and Handl (1974), Ross et al. (1973) and others. Some of these studies have related soil and other site factors to the vegetative type. Yet, because of the complexity of natural systems and the difficulty of judging range condition without using criteria based on sound soil and plant data, Mason (1970) concludes that intensive studies of relict areas and areas with excellent vegetation condition are needed on all types of rangeland to determine range potential

The purpose of this study was to provide some benchmark data on the moisture and nitrate status of soils in native range and to document other site characteristics as a basis for predicting the environmental impact of management alternatives and to stratify sites of differing potential. More specifically, the goal of the study was to provide, for a number of near pristine range sites, specific infor-

mation on:

1. Physical soil characteristics
2. Precipitation
3. Evaporation
4. Soil temperature
5. Air temperature
6. Water stored and used from the soil
7. Soil nitrate status
8. Herbage production

THE STUDY AREA

Locations And Available Data

This study was carried out at two locations: 1. Red Bluff Ranch at Norris, Montana; and 2. North of Belgrade, Montana (Fig. 1). The Red Bluff Ranch was selected for the main part of this study because of the good condition of the range and the previous studies that have been done there.

In 1957 Van Dyne (1960-1) made a range survey of the Red Bluff Ranch by the ecological site method to evaluate the existing range condition and to determine the carrying capacity of the ranch. At that time approximately half of the nearly 400 hectare ranch was classified in good condition and about one fourth each in excellent and fair condition. In 1958, 70 locations were selected for line intercept studies (Van Dyne, 1960-2). These locations represented different range sites and varied range conditions of the ranch and were referred to as clusters. The sample area of each cluster was about one acre. Slope, aspect, elevation, and soil texture of the 5 to 46 cm layer were determined.

Ryerson et al. (1970) made soil moisture measurements in conjunction with studies of clubmoss control but no data specific to the Red Bluff Ranch was reported. Klages and Ryerson (1965) studied nitrogen and irrigating effects on yield and composition from 1959 to 1961.

In 1957 a standard Weather Bureau recording station was set up at the Red Bluff Ranch headquarters, designated as Norris 3ENE. Daily

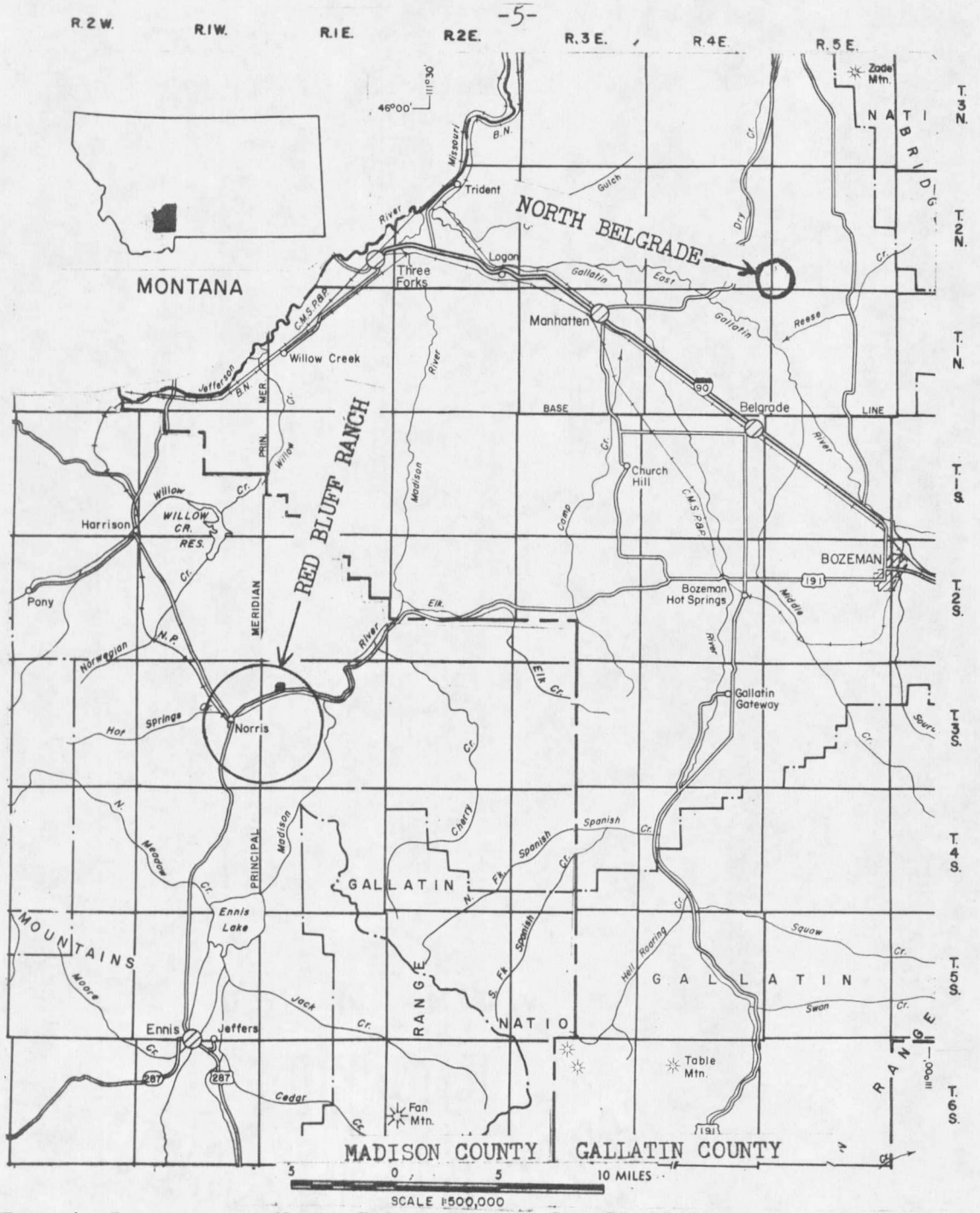


Fig. 1- Location of North Belgrade, and Red Bluff Ranch study area. Includes clusters (sites) 13,20,27.30,50,53,54,56,57,64,65,68,74,80,81, 82,and 83 at the Red Bluff Ranch, and clusters 84,85, and 86 north of Belgrade, Mt. See Appendix I for specific location of clusters.

temperature and precipitation are recorded. The mean annual precipitation for a 13 year period (1958-70) is 40.1 cm (15.78 in) (U.S. Dept. of Commerce 1970) and the mean annual air temperature is 6.6 C (43.9 F). From 1961 to 1968 soil temperature was intermittently recorded. In the summer of 1969 partial temperature, precipitation, humidity, and wind records were kept at two additional locations on the ranch; about 150 m and 300 m higher than the ranch headquarters.

My studies will add to the basic information for some permanent cluster locations and for the Ranch in general. This information is important to experimental activities at the ranch as well as to demonstration of ecological principles to students and the public.

Part of this study was carried out north of Belgrade, Montana (Fig. 1 and Appendix I) because: 1. General climatic conditions are similar to the Red Bluff Ranch area (mean annual precipitation 35.3 cm 13.91 in., mean annual air temperature 5.4 C-41.7 F). 2. There were three small near-pristine grassland areas worthy of study remaining in an intensively dry-farmed area. 3. Studies of water use and nutrition of small grains had been done and were in progress, giving a basis for comparison with grasslands (Brown 1971). 4. The soils were quite uniform and free of coarse fragments, in contrast to the relatively coarse soils at the Red Bluff Ranch. This afforded a comparison between contrasting soils and served as a check of relatively new investigative procedures for studying soils containing high proportions of coarse fragments.

Geology

Red Bluff area

The area is within a large block of dissected Pre-Cambrian gneiss and schist of mixed sedimentary and igneous origin (Tansley 1933). The rock in greatest abundance is reddish brown, gray and light gray gneisses of granitic composition (quartz-feldspar with subordinate hornblende and mica). Of lesser abundance but of common occurrence are bands of black hornblende-schist, white quartz-feldspar gneiss, hornblende-garnet schist, and mica schist. The gneiss and schist complex is literally criss-crossed by igneous injections of both Pre-Cambrian and later age. The latter is in evidence adjacent to clusters 27, 80, and 81 (see appendix I). Also included within the gneiss-schist complex are small areas of recent alluvium and some remnants of Tertiary Valley fill. The soil parent material are mainly sandy loam over partly weathered bedrock. They are well drained and in some places contain an abundance of lime.

North Belgrade area

The study area north of Belgrade is described by Perry (1962) as middle or late Tertiary Lake-bed sediments or valley fill. The area is dissected by deeply cut intermittent stream valleys with gently sloping interfluves. The soil parent materials are mainly silt and very fine sand, in places thinly stratified and containing an abundance of calcium carbonate. They are deep and well drained.

PROCEDURES

Site Selection And Monitoring

Sites for this study at the Red Bluff Ranch were inspected in April, 1970 by the author and Robert L. Ross, State Range Conservationist, Soil Conservation Service, Bozeman, Montana, to select sites of good to excellent condition that were representative of the major range sites on the ranch. Seventeen sites were selected; 13 were previously designated cluster sites (Van Dyne 1960-2) and four others designated as clusters 80,81,82, and 83. (APPENDIX I)

Seven sites were selected for temporary climatic monitoring as described by Sims and Jackson (1971). They consisted of an evaporation tub, max-min thermometer, and rain gauge. An evaporation tub was also established at the weather bureau recording station at the Ranch Headquarters. These sites were visited at near weekly intervals from May 4, through October 20 and data recorded. In addition soil temperature was determined by digging a small pit and reading temperature at 50 cm with a dial-head thermometer. Three of the seven sites were at about 1540 m elevation, two at considerably higher elevation (1750 and 1800m) and two at intermediate elevations (1600 and 1670 m).

At the time the sites were established 3 portable range cage exclosures, of varying design available at the ranch, were placed at random within the one-acre previously mentioned cluster sites. These

were staked down to prevent grazing and provide sites for herbage clippings at the end of the season of growth by the Montana State University range department.

King Tube Sampling

Soil samples were taken with a King tube sampler adjacent to each cluster exclosure. The sampler was 152 cm in length and took a sample 21 mm in diameter. This gave a core sample of 105 cc for each 30 cm depth sampled.

Spring soil moisture samples were taken between April 8, and May 20. All clusters were re-sampled between August 8, and August 25. Some clusters were also sampled in June and July.

Depths sampled were 0-15cm, 15-30cm, 30-61 cm, 61-91 cm, 91-122 cm, 122-152 cm; and in some pedons 152-183 cm. The King tube was driven to the desired depth, removed, and the soil was put in small metal cans and sealed with masking tape. The King tube was then re-inserted in the same hole and the next sampling increment removed. Soil samples were put in an insulated chest and taken to the MSU research laboratory where they were weighed, dried at 60-65C for 48 hours, and reweighed to determine moisture loss. Drying oven facilities were not always free for drying at 65 C so some samples were dried at 105 C. Checks made by Paul L. Brown (Personal Communication, March 19, 1970, Paul L. Brown, Agr. Res. Ser.) showed only slight differences in moisture percentage when dried at either temperature for 48 hours. The low drying temperature and pro-

tection from heat while in transit was to prevent changes in nitrate content. Only those samples dried at 60-65 C were use for nitrate studies. The dried samples were dry sieved to remove the greater than 2 mm fraction. This coarse fraction was weighed and percent of sample was calculated. The fine earth was bagged and saved for nitrate determination.

Coarse fragment density was determined by water displacement of dry sieved uncoated fragments. Most of the rock fragments had a density of about 2.60 g/cc but the igneous rocks were closer to 2.70 g/cc and the teritary lime cemented sandstone and conglomerate was only about 2.00. These figures were used in calculations involving coarse fragments.

Pit Sampling

A cluster sites 54, 65, 80, 81, 82, 83, 84, and 85 large pits about 60 cm by 120 cm and 150 cm deep were dug by hand. Profile descriptions were prepared using standard nomenclature (Soil Survey Staff 1951). Large samples were taken from horizons containing appreciable coarse fragments, to determine moisture content, amount of coarse fragments and bulk density. Volume of excavated soil was determined by the sand fill method of McLintock (1959). Briefly this consited of excavating about 2 to 4 kilograms (1.5 - 3 liters) of soil and coarse fragments in as nearly a cylindrical shape as possible depending on the coarse fragments. The hole was half filled with dry sand with a predetermined settled density of 1.63 g/cc (see

Appendix II). A knife blade was inserted in the sand 30 times to allow settling. The hole was filled and again settled with the knife. The sand was leveled to full by adding or removing sand and the volume calculated from the weight of sand used. Bulk samples were put into large plastic buckets or coffee cans with cover, weighed, dried to constant weight at 60 C for five to nine days, and reweighed to determine dry weight and moisture content. The bulk samples were then dry sieved to determine the greater than 2 mm coarse fractions.

Two to eight days prior to digging the pits at cluster 54, 65, 81, 82, 83, 84, and 85, the profile was wetted using steel rings driven into the surface layer. The amount of water applied or the depth of wetting was not uniform among sites. By sampling in the wetted profile an approximation of the field moisture capacity was determined. Wetting also made the soils easier to sample, especially the coarse soils which were loose when dry, and tended to slough into the sample pit.

Nitrate Analysis

Some 300 determinations of nitrate concentration were made on horizon samples from 50 cores at 10 clusters of this study. The samples were those taken for soil moisture, as mentioned previously. At the North Belgrade sites paired King tube cores to 183 cm depth were analyzed. Cluster 85 was sampled on April 8, May 25, June 23, July 21, and August 13. Cluster 86 was sampled on April 8, May 25 and August 13.

At the Red Bluff Ranch sites, samples to 152 cm depth from

clusters 13, 20, 27, 50, 54, 65, 80, and 82 were analyzed for nitrate. Clusters 54 and 65 were sampled on May 4, June 22, and August 18. Other clusters were sampled twice (April or May and August). All samples from the Red Bluff Ranch were paired cores except at clusters 80 and 82.

All nitrate analyses were run at the M.S.U. research laboratory under the direction of Dave Dickey using the phenoldisulphonic acid method of Black (1965).

Herbage Production

Herbage was clipped between August 8 and 25, 1970 by a clipping crew of the Animal and Range Science Department, Montana State University under the direction of Larry White. Clippings were made at 20 cluster locations, three north of Belgrade and 17 at the Red Bluff Ranch. Two, 930 square centimeter plots were taken from each of three exclosures at each cluster. Plant species were segregated and weighed as follows:

1. Each of the two main perennial grasses
2. Other perennial grasses and sedges
3. Bromus tectorum
4. Other annual grasses
5. Miscellaneous forbs
6. Artemesia frigida
7. Zanthocephalum sarothrae
8. Miscellaneous shrubs

Line transect studies were made at 13 of the Red Bluff Ranch clusters. They provided the species list for the study clusters (Appendix iV).

RESULTS AND DISCUSSION

Soil And Site Descriptions

Table I gives the main morphological characteristics of the soils at the seven climatic monitoring clusters (27,54,65, 80, 81, 82, and 83) at the Red Bluff Ranch; and at cluster 85 north of Belgrade. These soils are representative of the major soil groups (Soil Survey Staff. 1973) of the study. For a grouping of all clusters, see APPENDIX VI.

At cluster 85 (a deep silty soil north of Belgrade) root growth below 60 cm is limited while in the coarse soils of the Red Bluff Ranch there were more roots at deeper depths (Table 1).

Precipitation

Precipitation data for the study sites by monitoring periods from May 4 to October 20 are presented in Table 2. Totals for the full period and for the grass growth period (May 4 to August 18) are summarized. The greatest precipitation was recorded at clusters 54 and 65 and the least at clusters 27 and 81. Figure 2 shows the cumulative precipitation for the extreme sites. The maximum difference in precipitation between these two pairs of similar sites is attained by the middle of July and changes very little during the remainder of the study period.

The precipitation at clusters 80, 82, and 83 is near that at the two driest sites (clusters 27 and 81) as would be expected from their elevation and vegetative composition. Precipitation recorded at the

Table 1 -Morphological characteristics[#] of selected pedons (Clusters 27,54,65,80,81, 82,83 & 85)

Horizon	Depth (cm)	Munsell Color Dry	Munsell Color Moist	Texture	Structure	Consistence	Roots[+]	% Coarse[*] Fragments
			CLUSTER 27					
	(Aridic Argiboroll, Fine-loamy, mixed,- Elev: 1540 m - 5% south slope)							
A1	0-15	10YR 4/2	10YR 3/2	gl	vf2gr	sh,fr,ss,ps	3vf,1m	15
B2t	15-28	10YR 5/3	10YR 4/3	cl	f2sbk	h,fi,s,p	2vf,1m	10
C1ca	28-61	10YR 8/2	10YR 6/2	cl	c1pr	h,fi,s,p	2vf,1m	10
C2ca	61-152	10YR 6/2	10YR 5/2	gsl,gls	m	h,fr,so,po	1vf	20
			CLUSTER 54					
	(Argic Cryoboroll,Fine-loamy,mixed- Elev.: 1750 m - 5% north slope)							
A1	0-13	10YR 3/2	10YR 2/2	gl	vf2gr	s,vfr,so,po	3vf,1m	20
B21t	13-31	10YR 5/3	7.5YR 4/3	gcl	f2sbk	vh,fr,s,p	3vf,1m	25
B22t	31-54	10YR 6/3	10YR 4/3	gcl	f1sbk	h,fr,s,p	2vf,1m	25
B3	54-104	10YR 7/3	10YR 5/2	gsl	f1abk	h,fr,ss,pc	2vf,1m	20
C1ca	104-152	5Y 7/3	5Y 6/3	l,gsl	m	h,fr,ss,ps	1vf	5
			CLUSTER 65					
	(Typic Cryoboroll, Sandy,mixed - Elev.: 1800 m - 10% east slope)							
A11	0-15	10YR 4/2	10YR 3/2	gls	vf1gr	l,vfr,so,po	3vf,1m	15
A12	15-36	10YR 4/2	10YR 3/2	gls	f1gr	l,vfr.so.po	2vf,1m	15
A13	36-82	10YR 5/2	10YR 4/2	gls	f1gr	s,vfr,so,po	2vf,1m	15
C1	82-138	5Y 6/2	5Y 5/2	gls	sg	s,fr,so,po	2vf	20
C2	138-196	10YR 7/3	10YR 5/3	gls	sg	s,fr,so,po	1vf	45
			CLUSTER 80					
	(Aridic Argiboroll, Fine-loamy, mixed- Elev.: 1540 m - 5% west slope)							
A1	0-15	10YR 4/2	10YR 3/2	gsl	vf2gr	sh vfr,ss,po	3vf,1m	15
B2t	15-44	10YR 5/3	10YR 4/3	cl	f2sbk	h,fr,s,p	2vf,1m	10
C1ca	44-71	2.5Y 8/2	2.5Y 7/2	l	c1pr,c1pl	sh,fr,ss,ps	2vf,1m	10
C2ca	71-117	2.5Y 6/2	2.5Y 5/2	gsl	m	sh,vfr,ss,ps	1vf	20
C3ca	117-183	2.5Y 7/2	2.5Y 6/2	l,sl,gsl	m	sh,vfr,so,po	1vf	20

Table 1 -Continued

Horizon	Depth (cm)	Munsell Color Dry	Munsell Color Moist	Texture	Structure	Consistence	Roots+	% Coarse* Fragments
			CLUSTER 81					
		(Aridic Argiboroll, Fine-loamy, mixed - Elev.: 1540 m - 5% Southwest Slope)						
A1	0-10	10YR 4/2	10YR 3/2	l	vf1gr	sh,vfr,ss,ps	3vf,1m	10
B2t	10-25	10YR 5/3	10YR 4/3	cl	f2sbk	h,fr,s,p	2vf,1m	10
C1ca	25-50	2.5Y 7/2	2.5Y 6/2	l	c1pr	h,fr,ss,ps	2vf,1m	10
C2ca	50-94	2.5Y 6/2	2.5Y 5/2	gl	m	h,fr,ss,ps	2vf,1m	40
C3ca	94-160	2.5Y 6/2	2/5Y 5/2	gl	m	h,fr,ss,ps	1vf	55
			CLUSTER 82					
		(Aridic Argiboroll, Fine-loamy, mixed - Elev.: 1670 m - 5% Southeast Slope)						
A1	0-15	10YR 4/2	10YR 2/2	sl	vf2gr	s,vfr,ss,po	3vf	5
B2t	15-30	10YR 5/3	10YR 4/3	cl	m2sbk	vh,fr,s,p	3vf	5
C1ca	30-45	10YR 8/1	10YR 7/1	gl	c1pr	h,fr,so,po	2vf	15
C2ca	45-80	10YR 6/3	10YR 5/3	gls	c1pr	h,fr,so,po	2vf	15
C3ca	80-152	brown,green,black		gls	m	h,fr,so,po	1vf	15
			CLUSTER 83					
		(Argic Cryoboroll, Coarse-loamy, mixed - Elev.: 1600 m - 5% North Slope)						
A1	0-10	10YR 3/2	10YR 2/2	gsl	vf2gr	s,vfr,so.po	3vf,1m	15
B2t	10-46	10YR 5/3	10YR 4/3	gcl	m2pr	h,fr,s,p	2vf,1m	25
B3	46-92	10YR 7/3	10YR 5/3	gsl	m1sbk	sh,fr,so,po	2vf,1m	20
C1ca	92-152	5Y 7/3	5Y 6/3	l,gsl,l	m	sh,fr,so,po	1vf,1m	10

Table 1-Continued

Horizon	Depth (cm)	Munsell Color Dry	Munsell Color Moist	Texture	Structure	Consistence	Roots +	% Coarse Fragments *
			CLUSTER 85					
		(Aridic Argiboroll, Fine-silty, mixed - Elev.: 1400 m - 2% Southwest Slope)						
A1	0-6	10YR 5/2	10YR 3/1	vfsl	f1gr	s,vfr,ss,po	3vf	0
B2t	6-16	10YR 4/3	10YR 4/2	sil	m2sbk	h,vfr,ss,ps	2vf	0
B3ca	16-30	10YR 6/3	10YR 5/3	sil	m1pr	vh,vfr,ss,ps	2vf	0
C1ca	30-60	10YR 7/3	10YR 7/2	sil	m	vh,fr,ss,ps	2vf	0
C2ca	60-150	10YR 7/3	10YR 6/3	vfsl	m	s,vfr,so,po	1vf	0
C3ca	150-178	10YR 7/3	10YR 6/3	vfsl	m	s,vfr,so,po	1vf	0

#---Symbols used are those given in Agr. Handbook No. 38, p. 139-140, Soil Survey Staff 1951

+ -- 1 means there are less than 4 roots per 6 square centimeters, 2 means 4 to 12, and 3 means more than 12 -- vf means roots less than 1 mm in diameter, m is 1 to 5 mm diameter.

* -- Coarse fragments by volume of the whole soil.

Table 2 -Precipitation (cm) by monitoring periods from May 4 to October 20, 1970 for nine study locations. Totals exclude 4/18 to 5/4 period.

Period 1970	Cluster 27	Cluster 54	Cluster 65	Cluster 80	Cluster 81	Cluster 82	Cluster 83	Ranch# Hqts.	Cluster 85##
4/18-4/22									1.2
4/22-5/4	4.6*	6.4*	6.4*	6.4*	4.6*	6.4*	6.4*	4.6	1.9
5/4-5/13	2.8	4.1	4.6	4.1	2.9	4.1	4.1	2.9	2.6
5/13-5/18	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
5/18-5/24	2.8	3.6	3.0	3.4	2.8	2.5	2.4	3.0	2.4
5/24-6/2	0.9	1.9	1.7	0.8	0.9	1.1	1.8	2.0	4.0
6/2-6/7	0.1	0.7	0.2	0.0	0.1	T	0.1	0.0	1.5
6/7-6/15	3.8	4.3	4.1	4.1	3.7	3.4	3.3	3.9	1.2
6/15-6/22	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1
6/22-6/29	0.4	0.7	0.8	0.4	0.4	0.4	0.8	0.8	1.7
6/29-7/6	0.2	0.1	0.1	0.1	0.2	0.5	0.1	T	0.6
7/6-7/12	1.1	1.1	1.2	0.1	1.2	1.1	0.8	1.1	1.1
7/12-7/20	0.5	1.7	2.1	0.8	0.5	0.9	1.2	1.1	0.4
7/20-7/27	2.2	1.8	1.6	1.4	2.1	1.7	1.7	2.0	2.8
7/27-8/3	1.4	1.7	1.0	2.4	1.4	1.8	1.5	2.7	0.6
8/3-8/10	1.0	0.8	0.9	1.1	1.0	0.6	0.8	0.9	0.5
8/10-8/18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total 5/4-8/18	17.4	22.6	21.4	18.8	17.0	18.3	18.7	20.6	19.5
8/18-8/24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8/24-9/4	0.1	0.1	0.1	T	0.1	0.1	0.1	0.0	1.4
9/4-9/18	2.8	2.9	2.8	2.3	2.6	2.7	2.8	2.9	5.0
9/18-9/28	1.2	1.5	1.8	1.0	1.2	1.1	1.1	1.1	1.2
9/28-10/8	0.6	0.6	0.4	0.3	0.5	0.3	0.3	0.6	0.7
10/8-10/20	1.9	1.7	1.5	1.4	1.9	1.9	1.7	2.2	2.0
Total 5/4-10/20	24.5	29.4	28.0	23.8	23.3	24.4	24.7	27.4	29.8

* Extrapolated from Ranch Hqts. records.

#- Data from monthly climatic summaries (U.S. Dept. of Commerce 1970)

##- Personal communication from Paul Brown, Agr. Res. Ser., Bozeman, Mt.

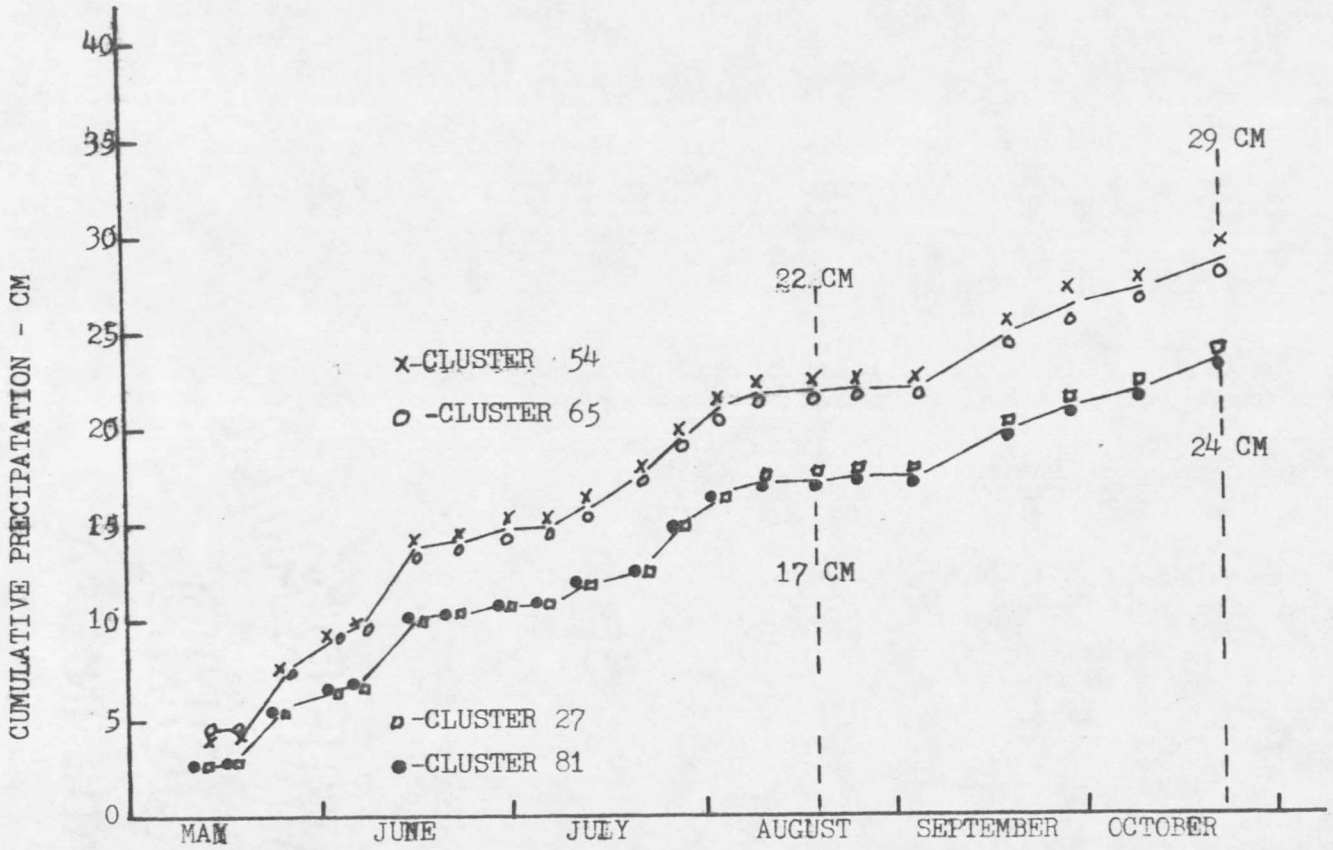


Figure 2-Cumulative precipitation May 4 through October 20,1970 at Cluster sites 54 and 65 compared to 27 and 81. Red Bluff Ranch, Norris, Mt.

ranch headquarters and also at cluster 85 north of Belgrade are slighly above what was expected for these locations, (Table 2) but is within normal variation for similar sites. Standard Weather Bureau rain gauges and their records were used for these latter two sites while Tru-check rain gauges (Sims and Jackson, 1971) were used at the other sites, which may account for some of the difference.

Precipitation at the ranch headquarters during the study period was about normal. The 13 year average (58-70) for May through October is 25.5 cm compared to 27.4 cm during the 1970 study period. May, 1970, had a little more precipitation than normal; June, a little less.

Because precipitation was not recorded until May 5 at the seven monitoring clusters it was necessary to estimate for the period 4/18 to 5/4 (Table 2). This was done by extrapolating from the weather station records at the nearby ranch headquarters. Precipitation for the period 5/4 to 5/13 for clusters 27 and 81 was about the same as the ranch headquarters and was thus considered to have received about the same from 4/18 to 5/4. The other clusters received about 60% more precipitation than the ranch headquarters.

Evaporation

Since a certain amount of evaporation also demands a definite amount of heat it would seem that the measurement of evaporation might provide a parameter for delineating different vegetative types. Table 3 gives the evaporation from a free water surface by monitor period

Table 3 -Tub evaporation (cm/day) by monitoring periods for nine study locations.

Period 1970	Cluster 27	Cluster 54	Cluster 65	Cluster 80	Cluster 81	Cluster 82	Cluster 83	Ranch Hqts.	Cluster 85
5/4-5/13	0.29	0.10	0.17	0.29	0.26	0.34	0.13	0.12	0.34
5/13-5/18	0.66	0.78	0.80	0.68	0.60	0.66	0.79	0.70	0.50
5/18-5/24	0.18	0.23	0.18	0.18	0.17	0.13	0.22	0.30	0.14
5/24-6/2	0.38	0.41	0.38	0.38	0.36	0.37	0.38	0.41	0.46
6/2-6/7	0.70	0.76	0.74	0.64	0.66	0.70	0.64	0.60	0.46
6/7-6/15	0.16	0.14	0.16	0.19	0.26	0.16	0.13	0.26	0.15
6/15-6/22	0.43	0.54	0.50	0.41	0.49	0.44	0.44	0.51	0.40
6/22-6/29	0.73	0.77	0.84	0.79	0.76	0.74	0.69	0.84	0.67
6/29-7/6	0.56	0.69	0.75	0.59	0.60	0.63	0.63	0.66	0.66
7/6-7/12	0.63	0.67	0.72	0.72	0.60	0.67	0.65	0.80	0.63
7/12-7/20	0.71	0.86	0.89	0.69	0.71	0.71	0.76	0.74	0.66
7/20-7/27	0.59	0.59	0.70	0.59	0.59	0.57	0.57	0.59	0.50
7/27-8/3	0.51	0.58	0.60	0.54	0.54	0.60	0.56	0.63	0.63
8/3-8/10	0.60	0.71	0.74	0.59	0.69	0.59	0.59	0.67	0.70
8/10-8/18	0.90	1.10	1.00	1.00	0.99	0.96	0.93	0.99	0.90
8/18-8/23	0.73	0.71	0.76	0.60	0.82	0.77	0.72	0.68	0.90
8/24-9/4	0.73	0.84	0.93	0.80	0.77	0.71	0.78	0.75	0.76
9/4-9/18	0.31	0.25	0.27	0.28	0.30	0.25	0.26	0.26	0.50
9/18-9/28	0.31	0.43	0.48	0.31	0.33	0.38	0.38	0.40	0.40
9/28-10/8	0.36	0.42	0.38	0.40	0.39	0.37	0.38	0.34	0.35
10/8-10/20	0.18	0.25	0.24	0.23	0.24	0.19	0.22	0.25	0.25
Average	0.48	0.53	0.53	0.49	0.50	0.49	0.49	0.51	0.51
Total 171 Days 5/4-10/20	82.2	90.5	90.6	84.2	85.4	84.0	83.9	89.8	87.5

in cm/day and the total for the study period. The average daily evaporation for these sites follows about the same pattern and the total evaporation for the 171 day study period (May 4-October) is not greatly different between sites. Figure 3 shows the cumulative evaporation for cluster 65 and 27. Cluster 65 and 54 were similar and had the greatest total evaporation (90.6 cm and 90.5 cm) while cluster 27 had the least (82.2 cm). The difference of 8.5 cm seems to be significant but it is in reverse of what would be expected as clusters 65 and 54 are about 200 meters higher in elevation and have about 1 C cooler mean temperature for the period. It may be that differences in wind patterns at the various study sites could account for the evaporation differences as the general area has a rather persistant wind activity. Evaporation may be of more value in comparing sites with greater differences. For example, Jones (1975) gives a value of 114 cm evaporation from April-September at Bushland, Texas. This compares with an average of 86 cm for the nine sites of this study. Bushland has July max-min air temperatures of 17 and 35 C compared to 10 and 27 C at the ranch headquarters. From figures given by Geiger (1966) for Potsdam, Germany a more humid environment, the comparable evaporation would be about 30 cm.

Soil Temperature

Mean summer soil temperature

Table 4 gives the 50 cm depth soil temperature for eight study

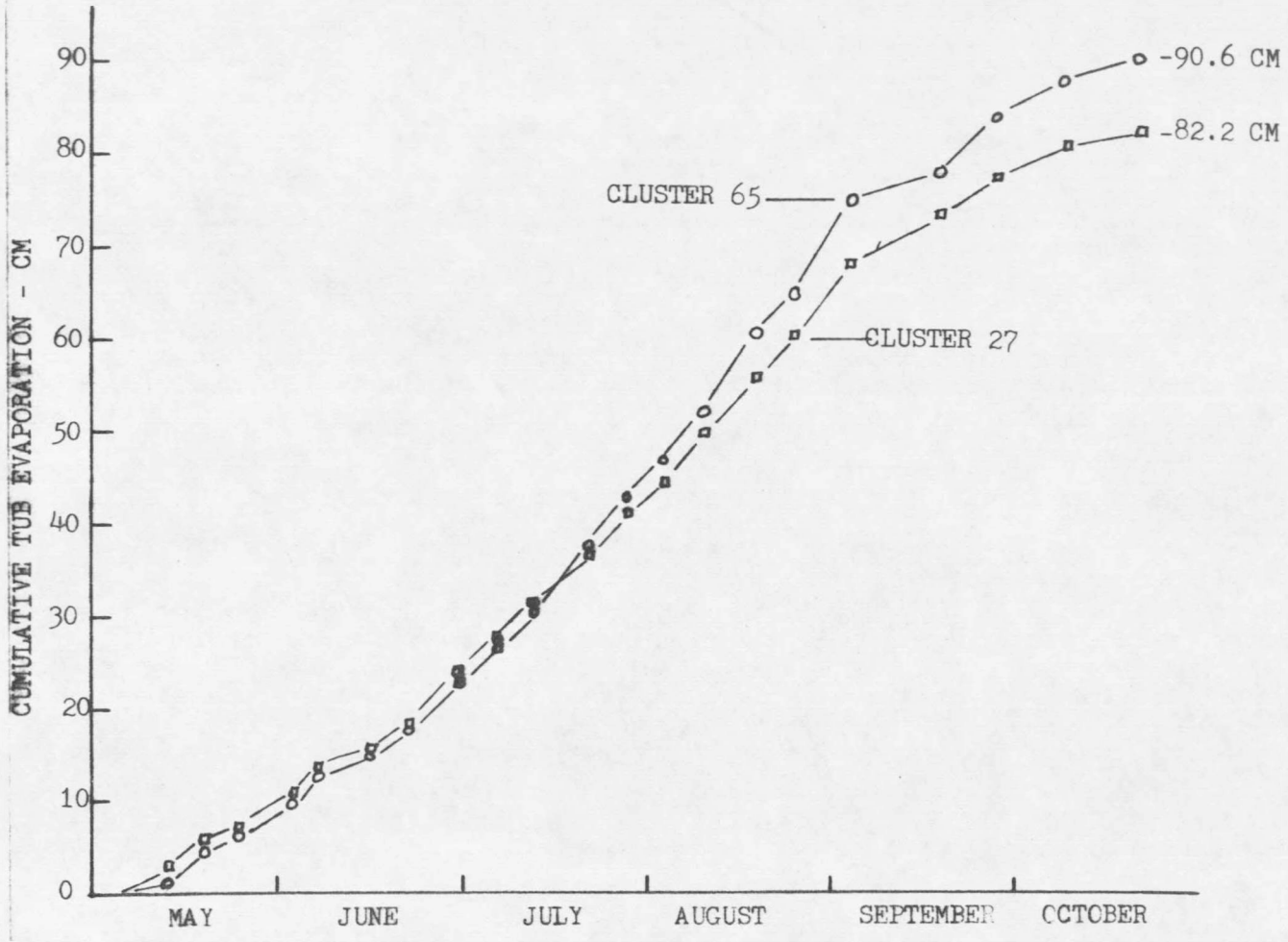


Fig. 3 -Cumulative evaporation by monitoring periods, May 4 through October 20, 1970 Red Bluff Ranch, Norris, Mt.

Table 4 -Soil temperature (C) at 50 cm depth for seven study locations, May 13 to October 20, 1970. Ranch Hqts. temperatures are means for 1961-1968. Mean summer temperature is the average of June 15, July 15, and August 15, with June 15 and July 15 interpolated.

Date 1970	Cluster 27	Cluster 54	Cluster 65	Cluster 80	Cluster 81	Cluster 82	Cluster 83	Ranch Hqts.
5/13	7.0	5.0	5.5	6.5	7.0	7.0	6.5	8.0
5/18	11.0	7.5	10.5	9.0	10.0	11.0	9.0	10.0
5/24	12.0	8.5	10.0	10.0	11.0	11.0	10.0	11.0
6/2	13.5	10.0	11.5	10.0	12.0	12.5	10.5	13.0
6/7	15.0	12.5	15.0	14.0	15.5	15.0	13.0	13.5
6/15	12.5	10.5	11.0	11.5	12.5	12.5	10.5	14.5
6/22	16.5	13.5	15.5	15.0	16.0	16.5	14.0	15.0
6/29	18.0	14.0	17.0	16.0	17.5	18.0	15.5	16.5
7/6	19.0	15.0	18.0	16.5	19.0	19.0	15.5	17.0
7/12	19.0	15.0	18.0	17.5	19.0	19.0	16.0	17.5
7/15	19.5	16.0	18.5	18.0	19.5	19.5	16.0	17.5
7/20	20.0	17.0	19.5	19.0	20.0	20.5	16.5	18.0
7/27	19.5	16.5	18.5	19.0	19.0	20.0	16.5	18.5
8/3	20.0	16.5	19.0	18.0	20.0	19.5	16.0	18.5
8/10	19.5	16.0	19.5	17.5	19.0	19.5	16.0	18.5
8/15	20.5	16.5	20.5	18.0	19.0	20.5	16.5	18.0
8/18	21.0	17.0	20.0	18.5	20.0	21.5	16.5	18.0
8/24	21.0	17.0	20.0	18.5	20.0	21.5	17.0	17.5
9/4	20.0	16.5	19.0	18.0	19.5	21.5	16.0	15.5
9/18	13.0	10.0	10.5	12.0	13.0	12.0	9.0	13.5
9/28	12.0	9.0	9.5	11.0	11.0	12.0	8.5	11.5
10/8	10.5	8.0	9.5	10.0	10.0	10.0	8.0	10.5
10/20	8.5	6.5	7.0	8.0	8.0	6.5	7.0	9.0
Mean Summer	17.5	14.5	16.5	16.0	17.0	17.5	14.5	16.5

locations by monitoring periods from May 13, to October 20, 1970; and the calculated mean for the summer. The mean summer temperature was calculated, as suggested by Smith et al. (1960), as the mean of June 15, July 15, and August 15. This is an acceptable procedure for Soil Taxonomy (Soil Survey Staff, 1973) and is reported to give a mean summer temperature within 0.6 C of that calculated from two readings each day for the three month period.

Warmest and coolest sites compared

Fig. 4 compares the two soils having the highest mean summer temperature (clusters 27 and 82-17.5 C) with the two soils having the lowest (clusters 54 and 83-14.5 C). Soil Taxonomy (Soil Survey Staff, 1973) sets 15 C mean summer temperature as the break between frigid and cryic temperature regimes. Based on the summer of 1970 the soils at clusters 27 and 82 are clearly in the frigid regime. The soils at clusters 54 and 83 are barely within the cryic regime. Because the Taxonomy intends these temperature regimes to serve a useful purpose and because there is a contrast in vegetative type between these two pairs of sites; it seems appropriate to classify the soils at clusters 54 and 83 as cryic (see discussion of vegetation).

Red Bluff ranch headquarters soil temperature

Soil temperatures were not taken at the ranch headquarters in 1970 however intermittent readings were taken from 1961 to 1968

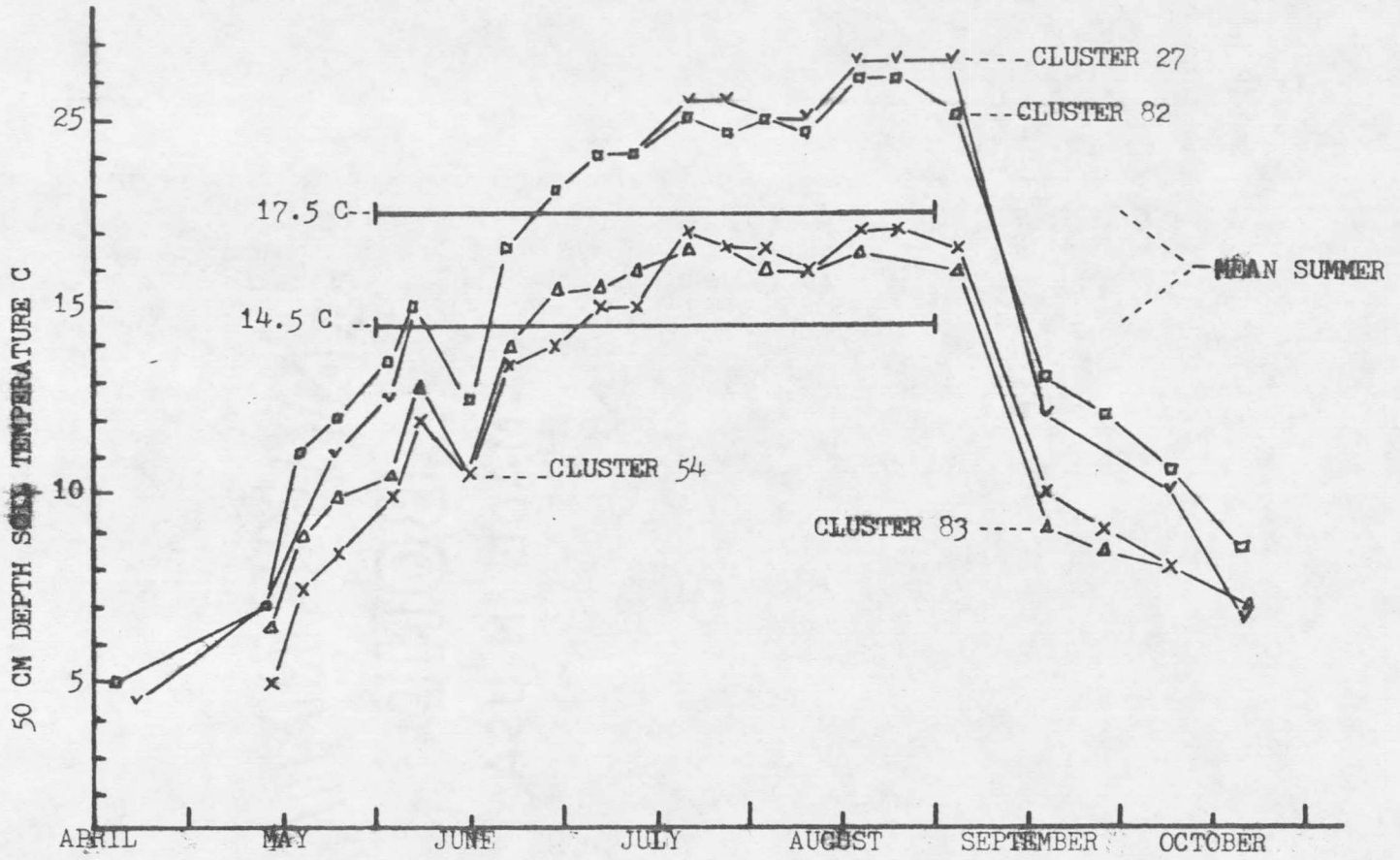


Fig. 4 -Soil temperature by monitoring period at 50 cm depth, from April 18 to October 20, 1970 at four study locations on the Red Bluff Ranch, Norris, Mt. Clusters 27 and 82, the warmest of the study sites is compared with Clusters 54 and 83, the coolest sites.

(Farnes and Shafer 1975). These were plotted and a curve established through the points (Fig. 5), taking care to give equal weight to reading of comparable dates for each year. This gives a reasonable eight year average soil temperature for comparison with the temperatures at the study sites in 1970.

Referring to Fig. 4 and Fig. 5 it will be seen that the pattern of temperature and the constructed eight year mean summer soil temperature at the ranch headquarters is similar to those at clusters 27 and 82. The relatively high temperatures in late August at clusters 27 and 82 do not show up in the eight year mean for the ranch headquarters but temperatures were as high in 1961. These three sites were expected to have about the same soil temperature because they are in close proximity (with in 2.5 kilometers), have similar elevation (within 160 meters), and have about five percent south to southeast slope.

Sites of intermediate soil temperature

Clusters 65, 80, and 81 had soil temperatures similar to those at clusters 27 and 82 (Fig. 6 and 4 and Table 4). By comparing the elevations at clusters 54 and 65 (1750 m and 1800 m respectively) similar mean summer soil temperatures might be expected. The soil temperature at cluster 65 was, however, 2 C warmer than that at cluster 54 (16.5 C & 14.5 C). This may be explained in the fact that cluster 65 has a warmer east aspect in contrast to the north aspect

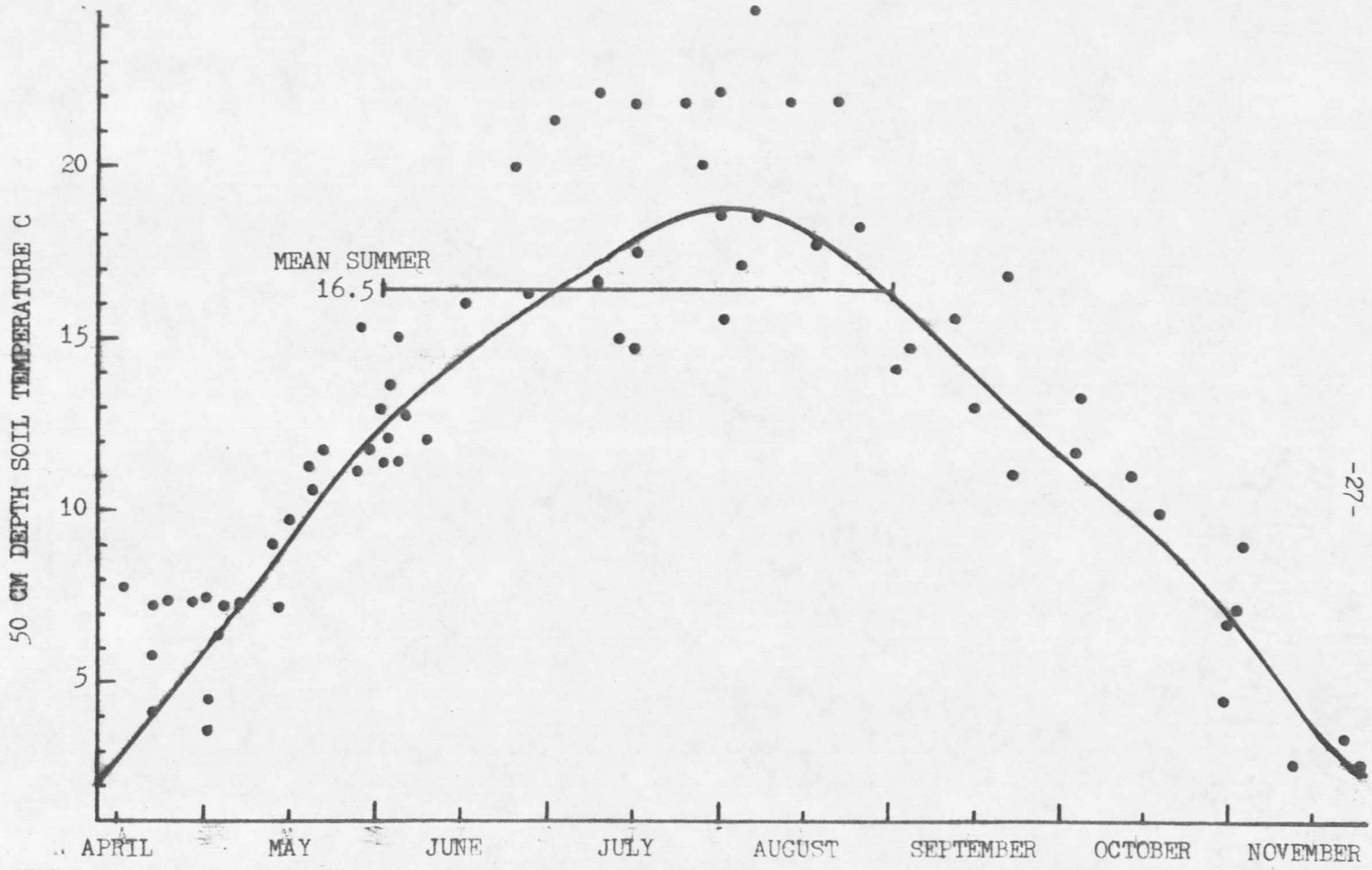


Fig. 5- Soil temperature at 50 cm depth for intermittent dates from 1961 to 1968 and projected mean for that period, Red Bluff Ranch Headquarters, Norris, Mt. The mean line appears somewhat low in the figure because of frequent readings reported for 1961.

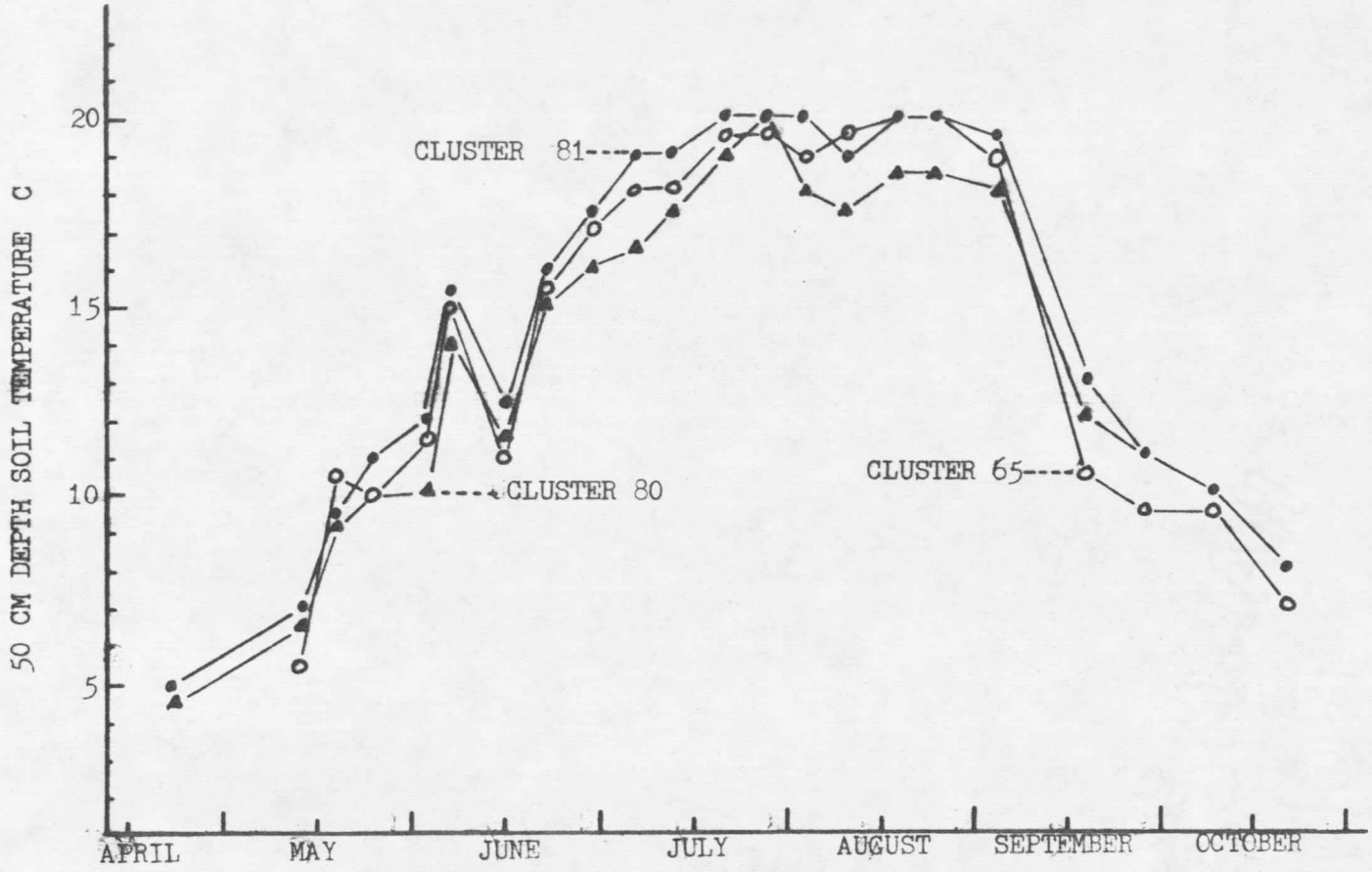


Fig. 6 Soil temperature by monitoring period at 50 cm depth, from April 24 to October 20, 1970 for clusters 65, 80, and 81 at Red Bluff Ranch, Norris, Mt.. Mean summer clusters 65, 16.5 C; 80, 16.0 C; 81, 17.0 C..

Table 5- Maximum-Minimum-Mean Air temperature (C) by monitoring period for 9 study locations

Period 1970	Cluster 27	Cluster 54	Cluster 65	Cluster 80	Cluster 81
5/4-5/13	25.5/ 0.0/12.5	24.0/-2.0/11.0	26.0/-2.0/12.0	26.5/-0.5/13.0	26.5/-1.0/12.5
5/13-5/18	28.5/-2.0/13.0	26.5/-2.0/12.0	26.0/-3.0/11.5	28.5/-3.0/12.5	28.0/-3.5/12.0
5/18-5/24	25.0/ 3.5/14.0	22.0/ 3.5/12.5	22.0/ 3.5/12.5	24.5/ 3.5/14.0	23.0/ 2.0/12.5
5/24-6/2	25.5/ 0.5/13.0	26.0/ 1.0/13.5	23.5/ 1.0/12.0	26.5/-0.5/13.0	26.0/-0.5/12.5
6/2-6/7	30.0/ 6.5/18.0	27.0/ 1.0/14.0	26.0/ 9.5/17.5	29.5/ 6.5/18.0	29.5/ 6.5/18.0
6/7-6/15	24.5/ 0.5/12.5	23.5/-0.5/11.5	19.5/-0.5/ 9.5	26.5/ 0.0/13.0	25.5/-0.5/12.5
6/15-6/22	31.0/ 6.5/18.5	29.0/ 6.0/17.5	30.0/ 5.5/17.5	30.5/ 6.5/18.5	31.0/ 5.5/18.0
6/22-6/29	34.0/10.0/22.0	33.0/ 7.0/20.0	29.0/ 8.0/18.5	34.0/ 8.5/21.0	34.5/ 9.0/21.5
6/29-7/6	33.5/ 4.5/19.0	33.5/ 0.0/16.5	31.0/ 2.0/16.5	34.5/ 4.5/19.5	34.0/ 3.5/18.5
7/6-7/12	34.0/11.0/22.5	33.0/ 5.5/19.0	30.5/ 5.5/18.0	34.5/ 5.0/19.5	34.5/10.0/22.0
7/12-7/20	34.5/ 4.5/19.5	33.5/ 4.0/19.0	32.0/ 5.0/18.5	35.5/ 3.5/19.5	34.5/ 3.5/18.5
7/20-7/27	33.5/ 5.5/19.5	32.0/ 5.5/18.5	30.0/ 5.5/17.5	35.5/ 4.5/20.0	35.0/ 5.5/20.0
7/27-8/3	31.0/ 5.5/18.0	29.5/ 7.0/18.0	29.0/ 6.0/17.5	30.0/ 4.5/1710	38.0/ 5.0/21.5
8/3-8/10	34.5/ 2.0/18.0	33.0/ 4.0/18.5	27.0/ 5.5/16.0	34.5/ 2.0/18.0	34.5/ 1.5/18.0
8/10-8/18	34.5/ 4.5/19.5	34.0/ 4.5/19.0	32.0/ 6.5/19.0	35.0/ 3.5/19.0	34.5/ 4.5/19.0
8/18-8/24	36.0/ 4.5/20.0	33.5/10.0/21.5	32.0/10.0/21.0	35.5/ 4.5/20.0	35.5/ 4.5/20.0
8/24-9/4	35.5/ 5.5/20.5	35.0/ 6.0/20.5	29.0/ 6.5/17.5	36.0/ 6.0/21.0	36.0/ 5.0/20.5
9/4-9/18	26.0/-7.0/ 9.0	24.5/-6.5/ 9.0	23.0/-6.5/ 8.0	26.0/-6.0/10.0	27.0/-6.0/10.5
9/18-9/28	27.0/-5.5/10.5	26.5/-4.0/11.0	24.5/-3.5/10.5	27.0/-5.0/11.0	27.0/-6.0/10.5
9/28-10/8	28.0/-5.5/11.0	26.5/-6.5/10.0	25.0/-7.0/ 9.0	29.0/-5.5/11.5	28.0/-6.5/10.5
10/8-10.20	19.5/-8.0/ 5.5	18.0/-8.0/ 5.0	19.5/-8.0/ 5.5	20.0/-6.5/ 6.5	19.0/-4.5/ 7.0
Mean	30.0/ 2.0/16.0	28.5/ 1.5/15.0	27.0/ 2.0/14.5	29.5/ 1.5/16.0	30.5/ 2.0/16.0

10.77

Table 5 -Continued

Period 1970	Cluster 82	Cluster 83	Ranch Hqts.	Cluster 85
5/4-5/13	19.0/ 0.0/ 9.5	26.5/-0.5/13.0	25.5/-0.5/12.5	25.5/ 0.0/12.5
5/13-5/18	26.0/ 0.0/13.0	28.5/-3.0/12.5	28.0/-0.5/13.5	27.0/ 1.0/14.0
5/18-5/24	21.5/ 4.5/13.0	23.0/ 1.0/12.0	21.5/ 0,0/10.5	19.5/ 3.5/11.5
5/24-6/2	25.5/ 1.5/14.0	25.5/-0.5/12.5	26.5/ 1.0/13.5	26.5/ 4.0/15.0
6/2-6/7	26.0/ 9.5/17.5	29.5/ 6.5/18.0	29.5/ 3.5/16.5	28.5/ 8.0/18.0
6/7-6/15	26.5/ 0.5/13.5	25.0/-1.5/11.5	25.5/ 3.0/14.0	23.0/ 3.0/13.0
6/15-6/22	28.5/ 5.5/17.0	31.5/ 5.5/18.5	33.0/ 4.5/18.5	3.05/ 5.5/18.0
6/22-6/29	28.5/10.0/19.0	34.5/ 7.0/20.5	35.0/10.5/22.5	31.5/ 7.0/19.0
6/29-7/6	33.5/ 4.5/19.0	33.5/ 3.0/18.0	33.5/ 3.5/18.5	31.5/ 4.5/18.0
7/6-7/12	30.5/11.0/20.5	34.0/ 8.5/21.0	33.5/ 8.0/20.5	31.5/11.5/21.5
7/12-7/20	35.0/ 6.0/20.5	38.0/ 3.0/20.5	35.0/ 0.5/17.5	33.5/ 4.5/19.0
7/20-7/27	35.0/ 8.5/21.5	34.0/ 3.5/18.5	33.0/ 4.0/18.5	29.5/ 6.0/17.5
7/27-8/3	30.5/ 8.0/19.0	31.0/ 4.5/17.5	30.0/ 3.5/16.5	31.0/ 8.5/19.5
8/3-8/10	35.5/ 5.5/20.5	34.5/ 2.0/18.0	35.0/ 0.5/17.5	32.0/ 4.0/18.0
8/10-8/18	34.5/ 6.5/20.5	35.0/ 4.0/19.5	34.5/ 0,5/17.5	34.0/ 6.5/20.0
8/18-8/24	35.0/ 8.0/21.5	34.5/ 6.5/20.5	35.0/ 1.0/18.0	33.5/ 6.5/20.0
8/24-9/4	28.5/ 8.5/18.5	35.5/ 6.0/20.5	36.5/ 3.0/19.5	34.5/ 6.5/20.5
9/4-9/18	24.5/-5.0/ 9.5	25.0/-8.0/ 8.5	24.5/-7.0/ 8.5	15.0/-5.0/ 5.0
9/18-9/28	24.5/-1.5/11.5	26.5/-6.5/10.0	28.0/-8.0/10.0	25.0/-4.0/10.5
9/28-10.8	24.5/-5.5/ 9.5	28.0/-7.0/10.5	27.0/-5.0/11.0	26.0/-0.5/12.5
10/8-10/20	17.0/-5.0/ 6.0	18.0/-8.5/ 4.5	18.5/-9.5/ 4.5	18.5/-6.0/ 6.0
Mean	28.0/ 4.0/15.5	30.0/ 1.0/15.5	30.0/ 0.5/15.0	28.0/ 3.5/15.5

at cluster 54. The soil at cluster 65 is also much sandier in texture than that at cluster 54 and according to Smith (1964) sands hold less water and provides less cooling from evaporation. The soil at cluster 65 was classified in the cryic group because of its similar vegetative type, high elevation, and thick, dark colored surface layer.

Soil temperature at clusters 80 and 81 were similar to the other frigid soils (clusters 27, 82) except that they did not attain the high late August temperatures of the latter (Fig. 4 and 6). Note that the mean summer soil temperatures of 16.0 C and 17.0 C at clusters 80 and 81 respectively are as might be expected. They have northwest exposures similar to the cryic soils at clusters 54 and 83 but have lower elevations similar to clusters 27 and 82.

Low mid-June soil temperatures

The marked drop in soil temperature in mid-June is conspicuous at all clusters (Fig. 4 and 6) but does not show up in the eight year mean for the ranch headquarters (Fig. 5). This period of low soil temperature is also a period of cool mean air temperature, (Table 5) high precipitation, (Table 2) and low evaporation (Table 3).

Air Temperature

Although there appears to be a significant difference in soil temperature between some of the study sites the difference in air temperature for all monitored sites is only 1.5 C (Table 5). Clus-

ter 65 had the lowest mean temperature (14.5 C) and clusters 27, 80, and 81 had the highest (16.0 C). Figure 7 shows the maximum, minimum and mean air temperature for the study period at clusters 65 and 81. While the minimum temperatures at both sites are quite similar, the maximum temperatures at cluster 81 are three degrees or more higher through July and August than at cluster 65. Cluster 65 is about 200 meters higher in elevation than cluster 81 and would be expected to have cooler maximum temperatures. The maximum temperature of 38.0 C at cluster 81 for the period ending August 3, is likely an error in recording (Figure 7). It is seven or more degrees higher than any of the other sites. Also the maximum temperature for this period was lower then the previous period at all sites except at clusters 81 and 85. There are other readings which seem to be suspect, (Figure 7 and 8) but they do not alter the general patterns. Note that air temperature differences between sites occur mainly in mid-summer and tend to be closely similar in the spring and fall (Fig 7 and 8, and Table 5).

Air temperatures at cluster 85 north of Belgrade, Montana are similar to those at the Red Bluff Ranch headquarters even though the two sites are 48 kilometers apart (Fig. 8).

Soil Water

Total soil water

In soils containing a large percentage of coarse fragments there is commonly a great variation in size and amount of fragments within

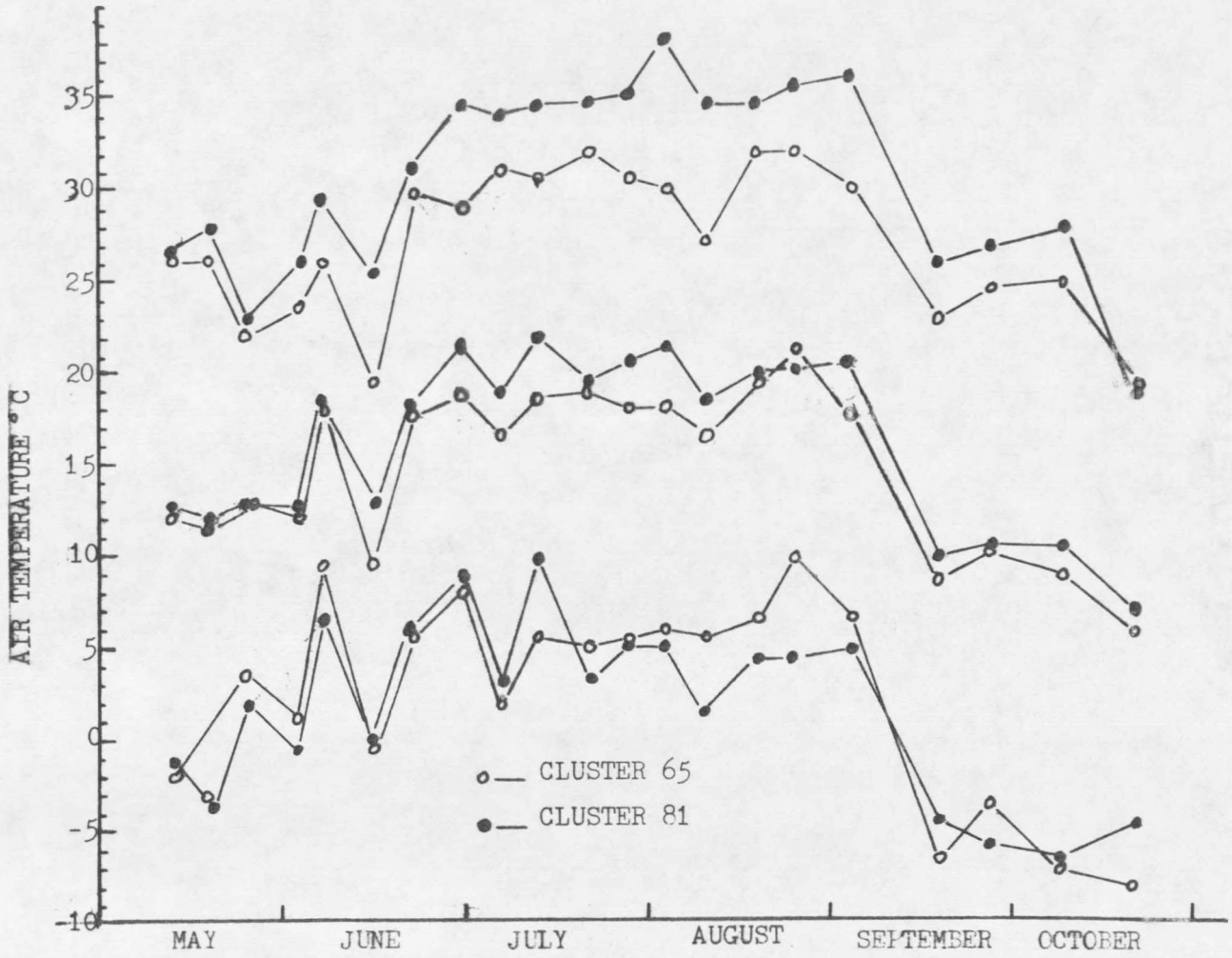


Fig. 7- Maximum, minimum and mean air temperature , clusters 65 and 81 at Red Bluff Ranch, Norris, Mt. Means for the period of study are 14.5 and 16.0 C respectively.

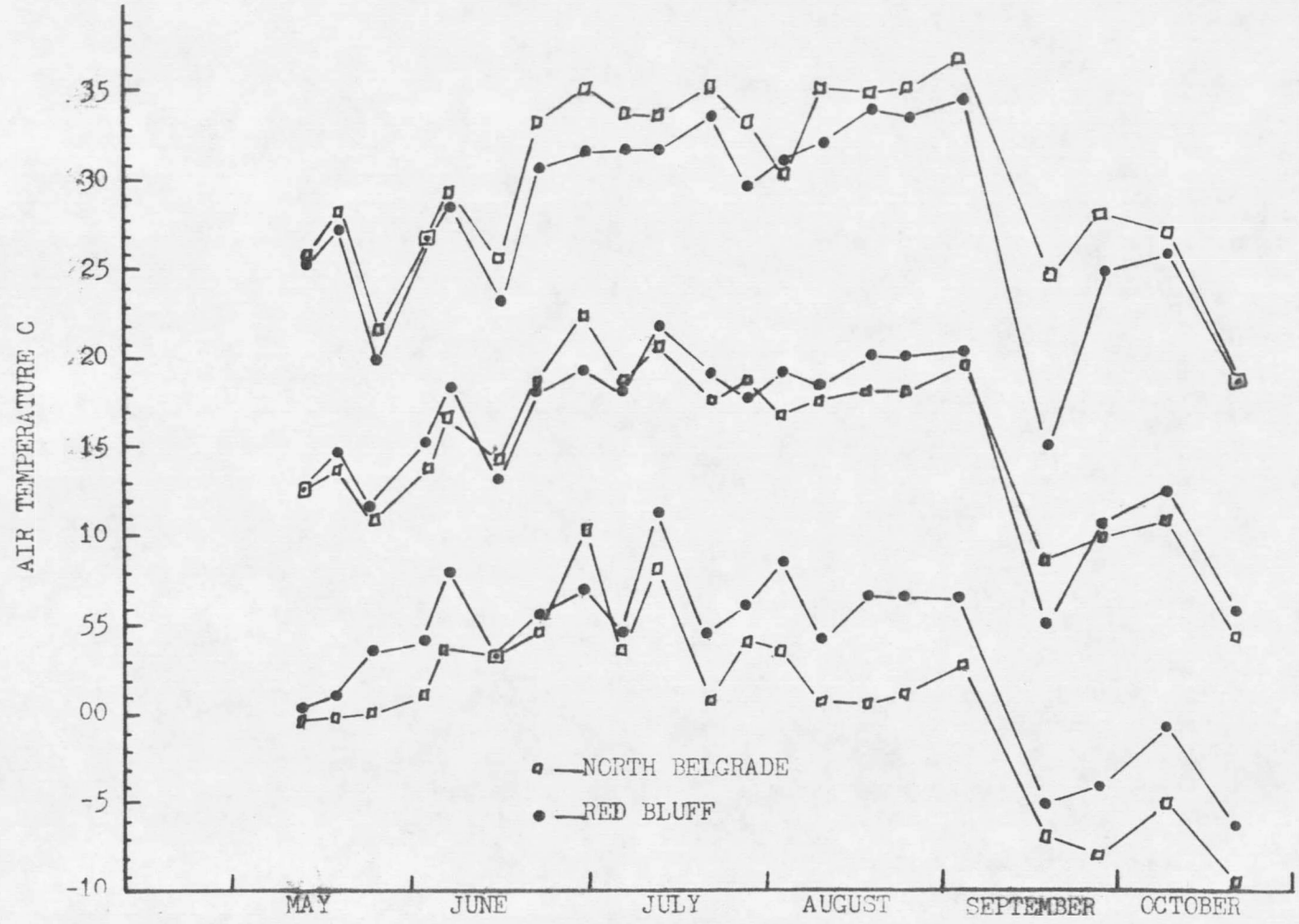


Fig. 8- Maximum, minimum and mean air temperature C, Red Bluff Ranch Headquarters, Norris, Mt., and north of Belgrade, Mt., 1970. Means for the period of study are 15.0 and 15.5 C respectively.

short distances, both horizontally and vertically. Branson et al. (1965) describes soils having 80 percent particles greater than two millimeters in areas and 10 percent in adjacent portions of the same profile. This variation is not uncommon in the Rocky Mountain Foothills of Montana with soils formed from both transported and bedrock materials. As most of the water in a soil is held in the fine earth portion, rather than by the fragments greater than 2 mm in diameter; the water available to plants within any soil column may vary widely.

After working with stony soils, Reinhart (1961) states "Measurement of soil moisture content in stony soils is at best a difficult job and accuracy obtained will of necessity be lower than for like determinations in stone-free soils" but he presents an approach to "obtain satisfactory results". Because of the prevalence of the problem and the importance of knowing the quantity of water stored and used, investigators have continued to work on improving methods (Shipp and Matelski, 1965; Coile, 1953; Cunningham, 1968; McLintock, 1959; Hillel and Tadmor, 1962 and others).

For soils studied at the Red Bluff Ranch, many of which have horizons containing an abundance of coarse fragments, the King tube sampler seems to give a reasonable sample for determining quantity of water. It will penetrate these soils, either going between coarse fragments, moving them aside, or breaking them apart; at the same time picking up small fragments along with fine material. It was

felt that three samples taken within a site at any time would give a moisture content comparable to the amount present at another time if the sampling procedure was the same. Appendix III records nearly 600 King tube soil samples used in the following soil water and nitrate comparisons.

Table 6 is a tabulation of the calculated soil water at various sampling dates, and the soil water depletion for the growth period. Fig. 9 compares graphically the soil water content at the various sampling dates, shows where water is in the profile and the main extraction zone. It shows the average soil water of the soils at clusters 84, 85 and 86, by horizons for six sampling dates from April 8, 1970 to August 13, 1970 (127 days). These three sites were grouped because they have similar water contents (Table 6), they are near each other, and the soils are similar.

Fig. 9 shows that the soil was wettest at the May 25 sampling, soil water use during June was mainly from the top 30 cm, and there was little change in moisture content below 91 cm throughout the period (less than 1 cm from 30 cm horizon). The latter was not true for many of the soils at the Red Bluff Ranch where most soils contained many coarse fragments (Fig. 1). Twelve of the 17 clusters at Red Bluff had more than one cm of water removed from the 91 to 122 cm horizons and five of the 17 had more than one cm removed from the 122 to 152 horizons (Table 6 and Fig. 10). Part of this difference is likely due

Table 6 -Total soil water (cm) by horizons at various sampling dates. and soil water depletion. Values are averages of 2 to 4 King tube cores at 20 locations.

Horizon	Soil Water by Horizons cm							
depth(cm)	0-15	30	61	91	122	152	183	Total
Date-1970			CLUSTER SITE 13					
May 4	2.1	2.2	4.6	5.3	5.3	6.1		25.6
August 21	0.4	0.9	3.0	3.8	3.3	4.6		16.0
Depletion	1.7	1.3	1.6	1.5	2.0	1.5		9.6
			CLUSTER SITE 20					
April 22	2.3	2.0	4.1	4.8	3.8	1.3		18.3
August 19	0.4	0.4	1.5	2.5	1.3	1.0		7.1
Depletion	1.9	1.6	2.6	2.3	2.5	0.3		11.2
			CLUSTER SITE 27					
April 18	2.9	1.7	7.4	6.1	3.0	3.3		24.3
August 21	1.7	1.9	2.3	3.6	2.8	4.6		16.8
Depletion	1.2	+0.2	5.1	2.5	0.2	+1.3		7.5
			CLUSTER SITE 30					
May 20 1/	3.5	2.7	6.9	6.9	6.4	7.1		33.7
August 10	1.6	1.4	3.6	3.3	2.8	4.6		16.8
Depletion	1.9	1.5	3.3	3.6	3.6	3.1		17.0
			CLUSTER SITE 50					
May 20	3.1	3.0	7.6	6.4	6.4	5.6		32.1
August 25	0.8	1.2	2.3	2.8	3.6	5.8		16.5
Depletion	2.3	1.8	5.3	3.6	2.8	+0.2		15.6
			CLUSTER SITE 53					
May 20	3.5	2.9	6.9	6.9	6.4	7.1		33.7
August 25	0.7	1.1	2.5	5.2	3.8	5.1		18.4
Depletion	2.8	1.8	4.4	1.7	2.6	2.0		15.3
			CLUSTER SITE 54					
May 4	3.7	3.2	6.6	6.1	6.6	5.1		31.3
June 22	2.2	2.1	5.1	3.3	4.8	3.6		21.1
August 19	0.8	1.0	2.8	3.0	3.6	4.8		16.0
Depletion	2.9	2.2	3.8	3.1	3.0	0.3		15.3

Table 6 -Continued

Horizons depth (cm)	0-15	30	Soil Water by Horizons cm 61	91	122	152	183	Total
Date-1970			CLUSTER SITE 56					
May 13	3.9	3.2	6.4	4.3	4.6	5.1		27.5
August 25	0.7	0.8	1.5	1.8	2.3	2.3		9.4
Depletion	3.2	2.4	4.9	2.5	2.3	2.8		18.1
			CLUSTER SITE 57					
May 6 2/	3.0	2.3	4.6	4.6	2.0	1.0		17.5
August 13	2.0	1.8	3.6	2.5	2.3	1.0		13.2
Depletion	1.0	0.5	1.0	2.1	+0.3	0.0		4.3
			CLUSTER SITE 64					
April 18 3/	2,5	1.6	2.3	2.3	2.5	2.3		13.5
August 14	0.7	0.8	1.5	1.3	1.3	2.0		7.6
Depletion	1.8	0.8	0.8	1.0	1.2	0.3		5.9
			CLUSTER SITE 65					
May 6	3.0	2.3	4.6	4.6	2.0	1.0		17.5
June 22	1.4	1.9	5.6	5.6	2.8	1.0		18.3
August 19	0.4	0.6	1.5	1.3	0.8	0.5		5.1
Depletion	2.6	1.7	3.1	3.3	1.2	0.5		12.4
			CLUSTER SITE 68					
May 20	3.6	3.8	4.6	3.6	2.8	1.0		19.3
August 23	1.0	0.3	1.5	1.3	1.5	0.8		6.4
Depletion	2.6	3.5	3.1	2.3	1.3	0.2		13.0
			CLUSTER SITE 74					
May 20	4.2	2.7	5.8	5.3	6.1	6.4		30.5
August 23	0.7	0.6	1.5	2.3	2.5	3.6		11.2
Depletion	3.5	2.1	4.3	3.0	3.6	2.8		19.3
			CLUSTER SITE 80					
April 18	3.1	3.3	6.6	4.1	3.0	2.8		22.9
June 22	2.0	3.1	7.6	6.4	7.1	6.9		33.0
August 7	1.4	2.2	4.1	2.5	2.5	4.1		16.8
Depletion	1.7	1.1	2.5	1.6	0.5	+1.3		6.1

Table 6 -Continued

Horizon depth(cm)	Soil Water by Horizons cm 0-15	30	61	91	122	152	183	Total
Date-1970			CLUSTER SITE 81					
April 18	4.7	4.4	6.6	2.3	2.3	2.0		22.3
August 21	1.1	1.9	4.8	2.0	2.5	2.0		14.3
Depletion	3.6	2.5	1.8	0.3	+0.2	0.0		8.0
			CLUSTER SITE 82					
April 22	3.5	3.6	6.6	4.8	2.5	1.5		22.5
June 22	2.2	3.9	4.1	2.3	2.0	3.0		15.0
August 13	0.9	1.4	1.8	1.5	1.5	1.8		8.9
Depletion	2.6	2.2	4.8	3.3	1.0	+0.3		13.6
			CLUSTER SITE 83					
May 20	2.9	2.7	5.8	5.3	4.8	4.8		26.4
August 25	0.6	0.9	1.5	1.8	2.0	3.8		10.7
Depletion	2.3	1.8	4.3	3.5	2.8	1.0		15.7
			CLUSTER SITE 84					
April 22	3.0	3.1	5.1	3.3	4.3	3.6	3.3	25.7
May 25	3.4	3.5	5.6	4.6	3.8	3.3	3.0	27.2
July 21	1.1	1.4	2.5	3.0	3.8	3.0	2.5	17.3
August 13	0.7	1.1	2.3	3.0	3.6	3.0	3.3	17.0
Depletion	2.3	2.0	2.8	0.3	0.7	0.6	0.0	8.7
			CLUSTER SITE 85					
April 8	3.1	4.0	6.1	3.6	3.6	4.1	3.6	28.1
May 25	3.7	4.2	7.1	5.3	3.8	3.8	3.8	31.7
June 23	2.0	2.8	5.8	5.1	4.6	3.6	3.6	27.5
July 21	1.6	1.7	3.8	4.1	3.8	4.6	4.3	23.9
August 13	1.3	1.5	3.0	3.3	4.1	4.1	4.1	21.4
Depletion	1.8	2.5	3.1	0.3	+0.5	0.0	+0.5	6.7
			CLUSTER SITE 86					
April 8	3.3	3.8	5.8	3.6	4.1	3.8	3.6	28.0
May 25	3.2	3.9	6.1	5.1	4.6	3.8	3.6	30.3
August 13	1.2	1.0	2.3	2.5	3.8	4.3	3.3	18.4
Depletion	2.1	2.8	3.5	1.1	0.3	+0.5	0.3	9.6

1/ Assuming the same moisture as cluster 53 on May 20.
2/ Assuming the same moisture as cluster 65 on May 6.
3/ Using watered profile moisture as beginning moisture

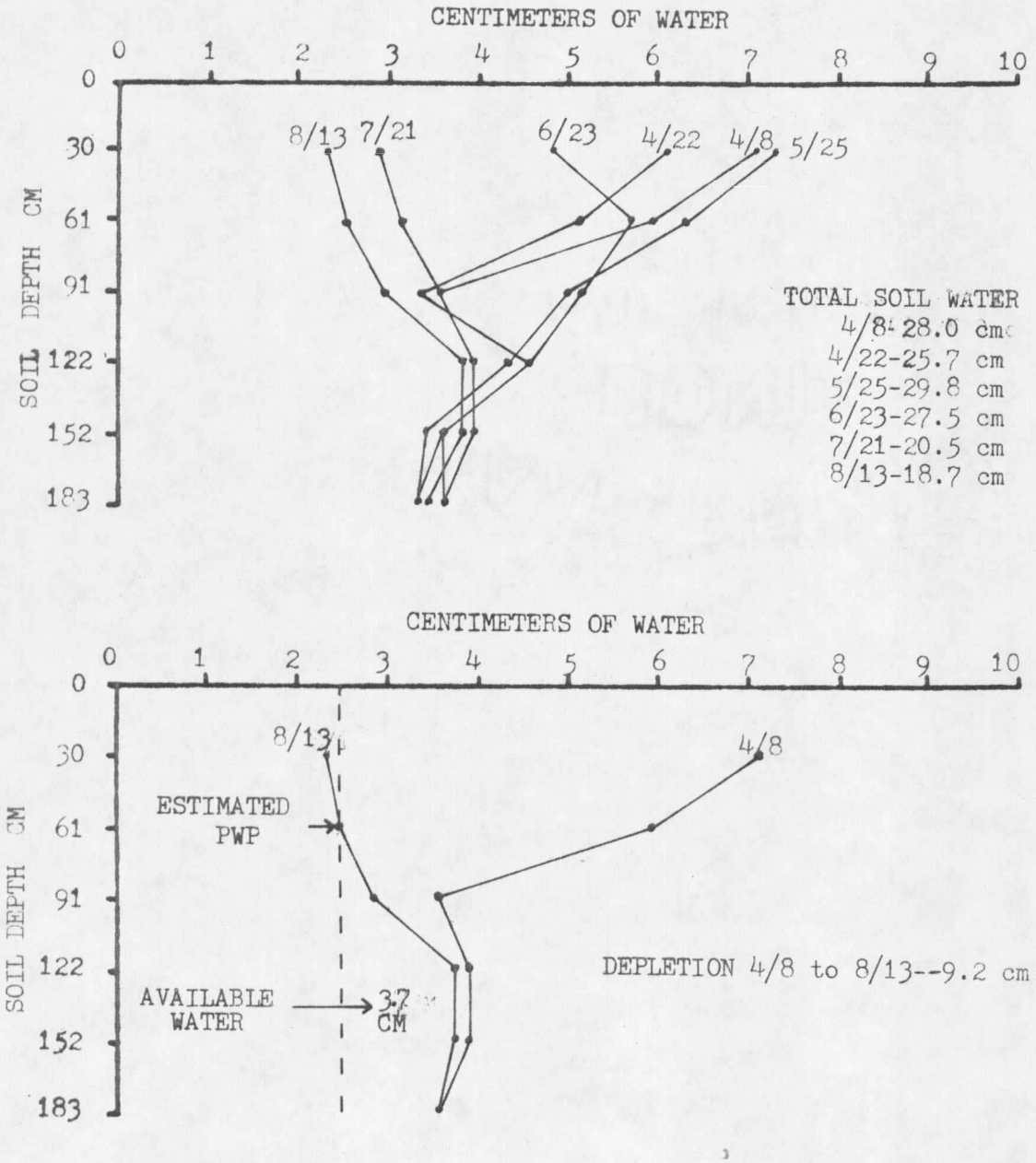
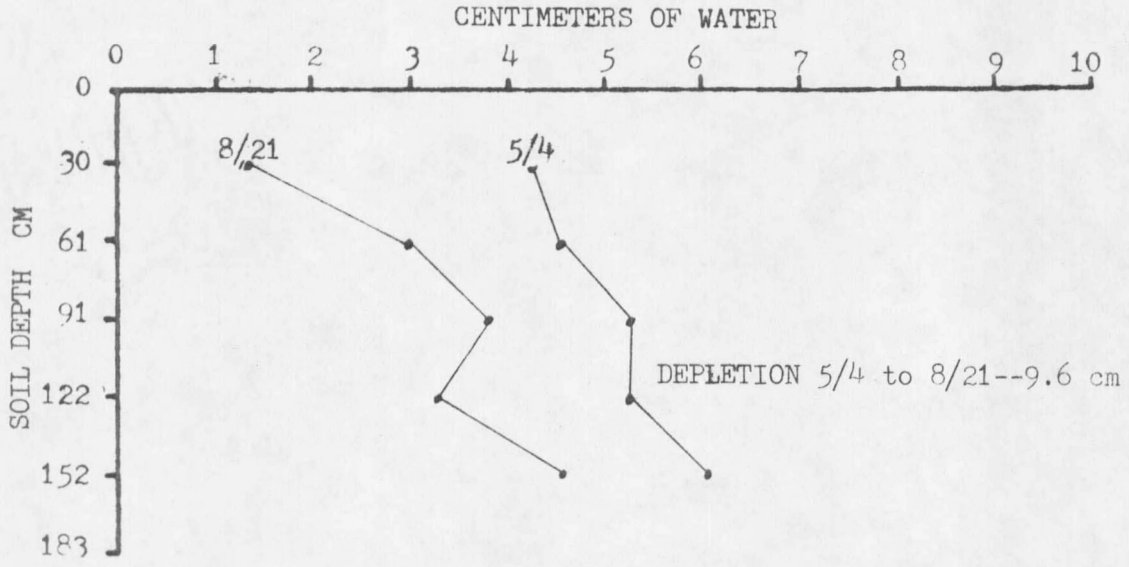
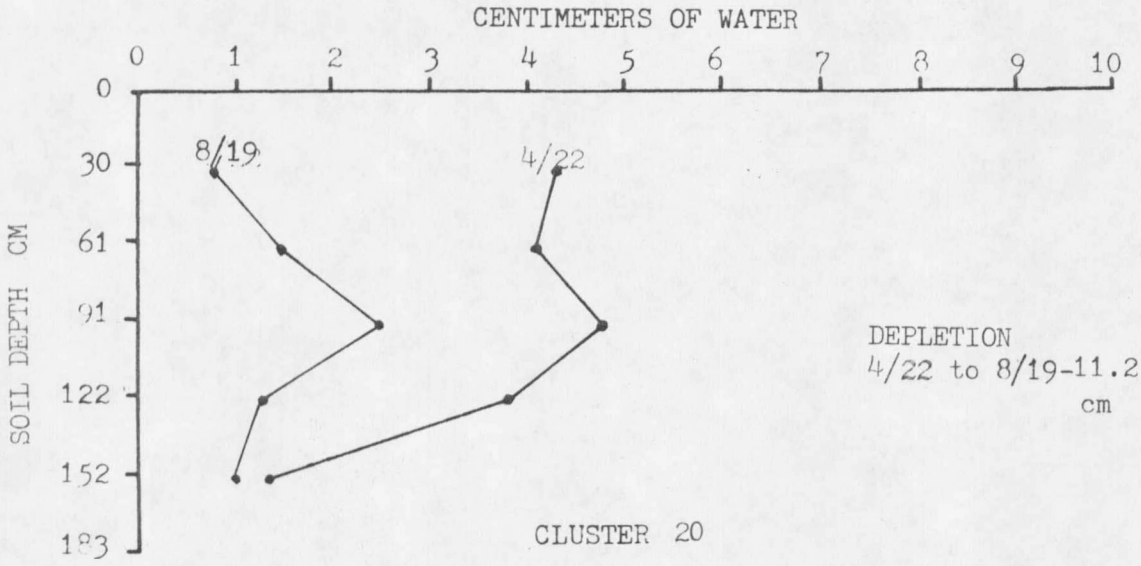


Fig. 9-Total soil water, average of clusters 84, 85, and 86, north of Belgrade, Mt., by 30 cm horizons, and the total to 183 cm at periodic sampling dates (upper graph). Lower graph shows beginning (4/8/70) and ending (8/13/70) soil water by horizons, estimated permanent wilting point, and estimated remaining available water.



CLUSTER 13

Fig. 10- Total soil water by 30 cm horizons for each sampling date for 17 clusters at Red Bluff Ranch, Norris, Mt. 1970. Depletion is the difference in soil water from spring to fall for the whole profile. Graphs for each cluster are in numerical sequence.



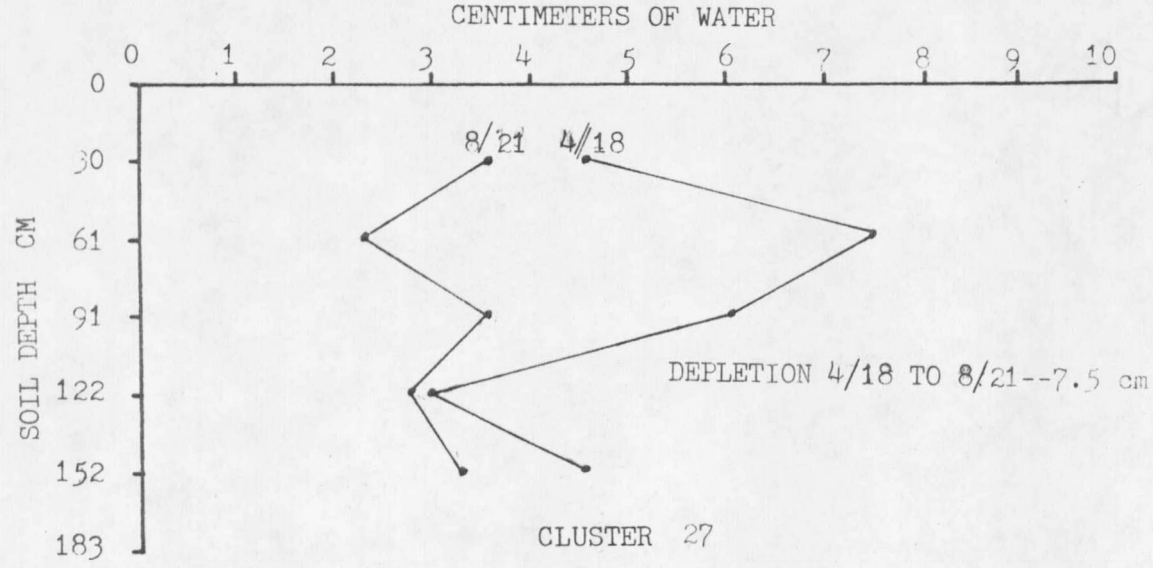
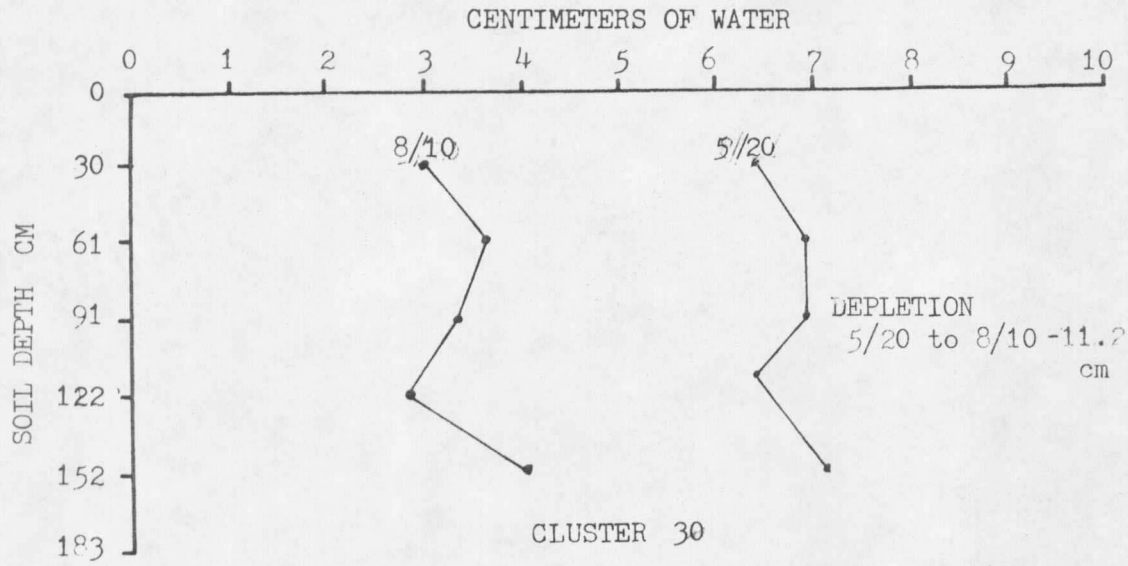


Fig. 10 continued



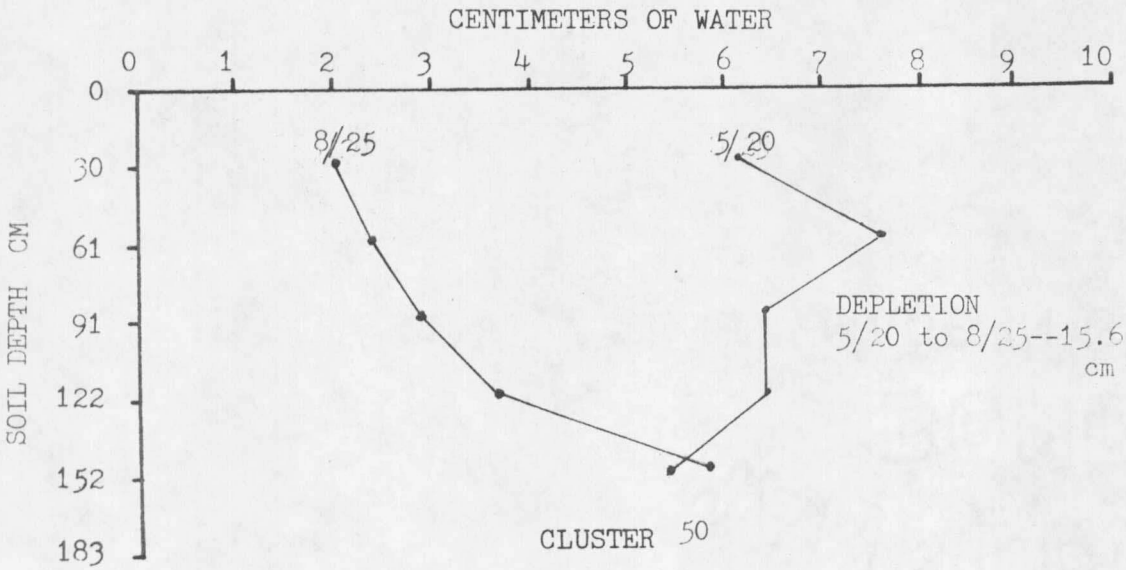
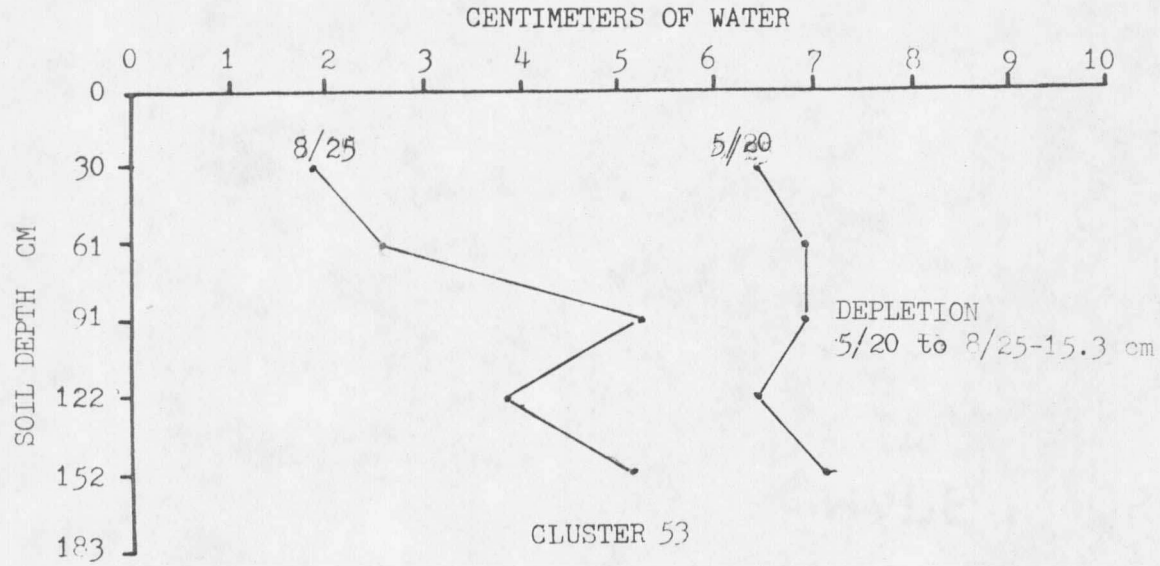


Fig. 10-continued



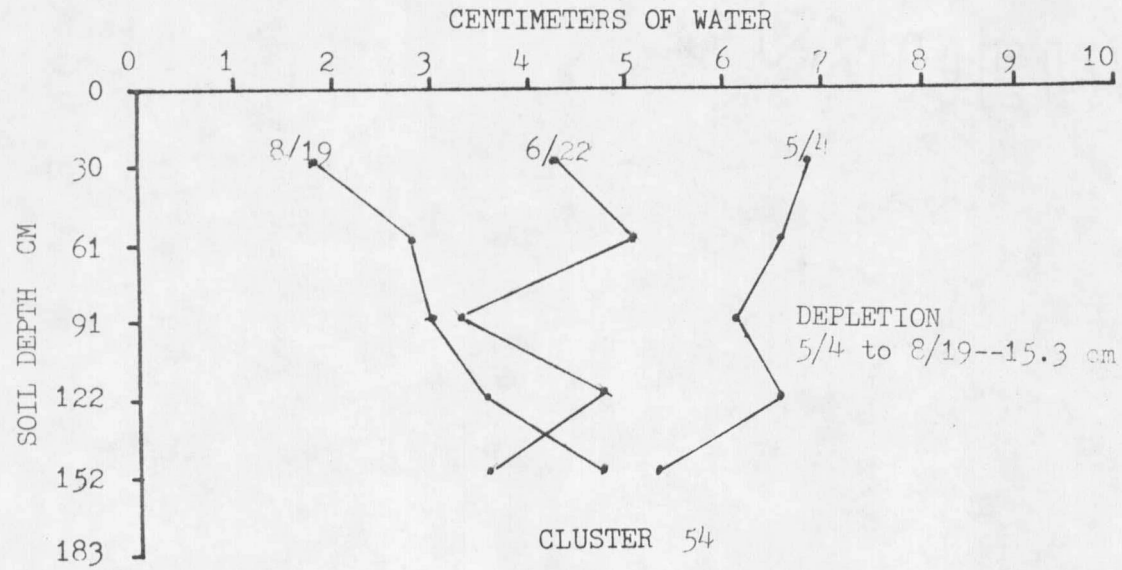
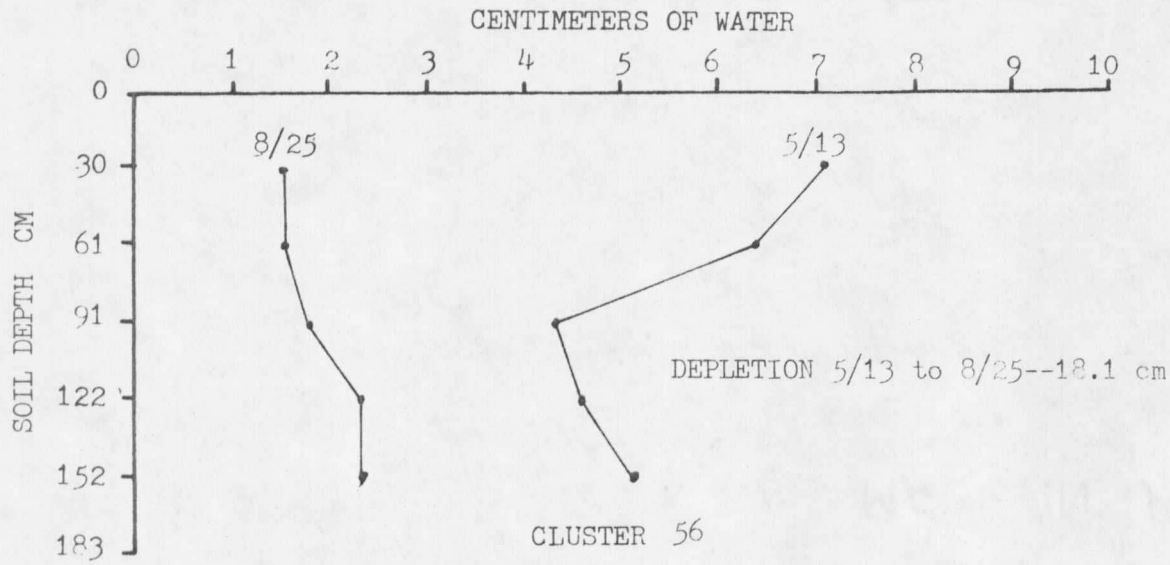


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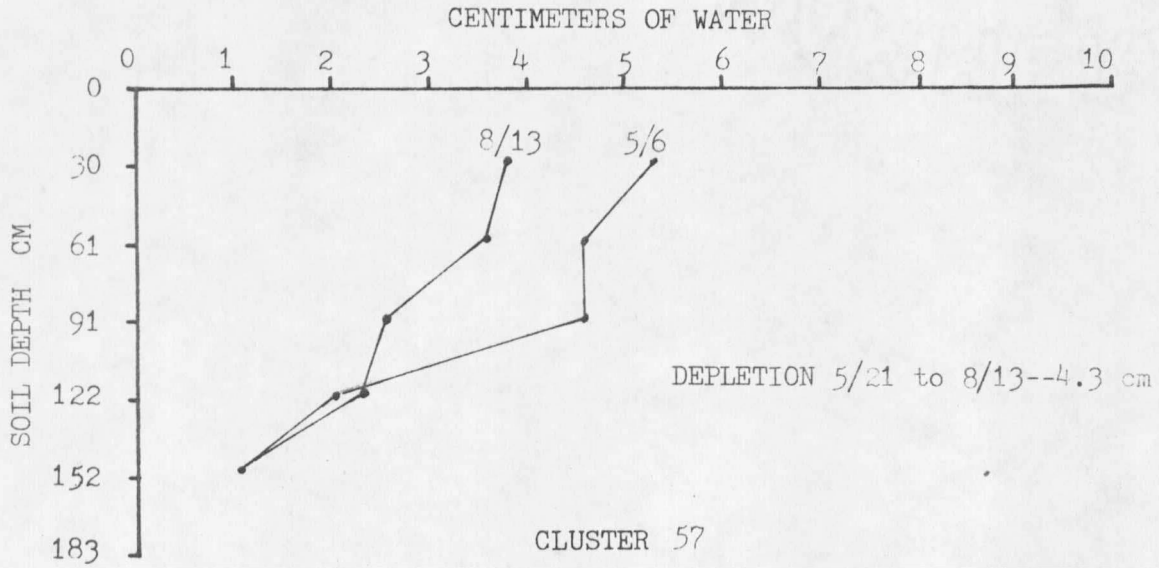
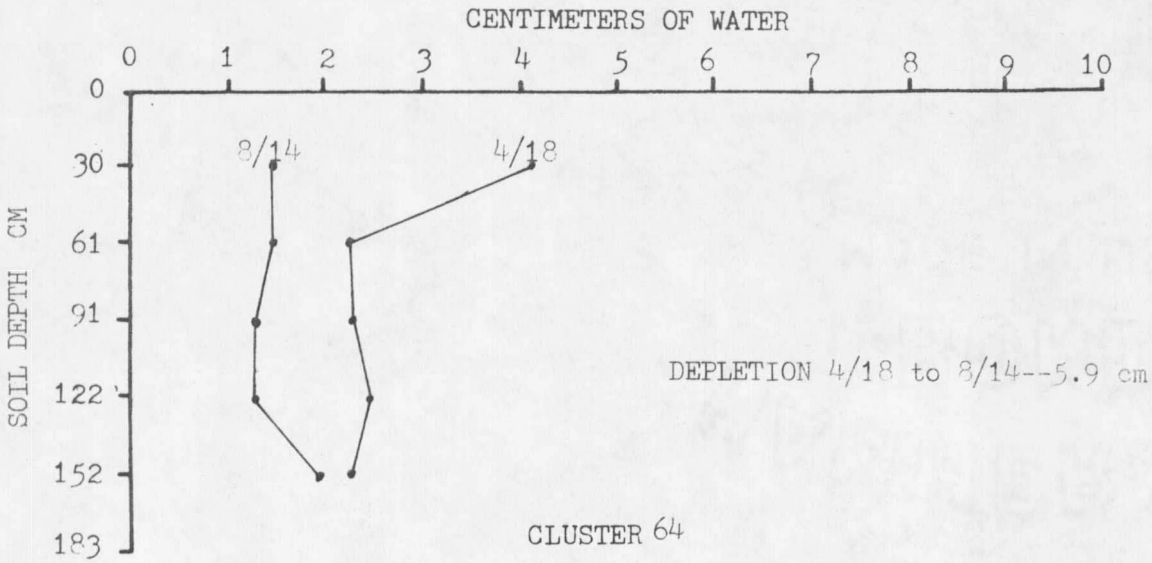


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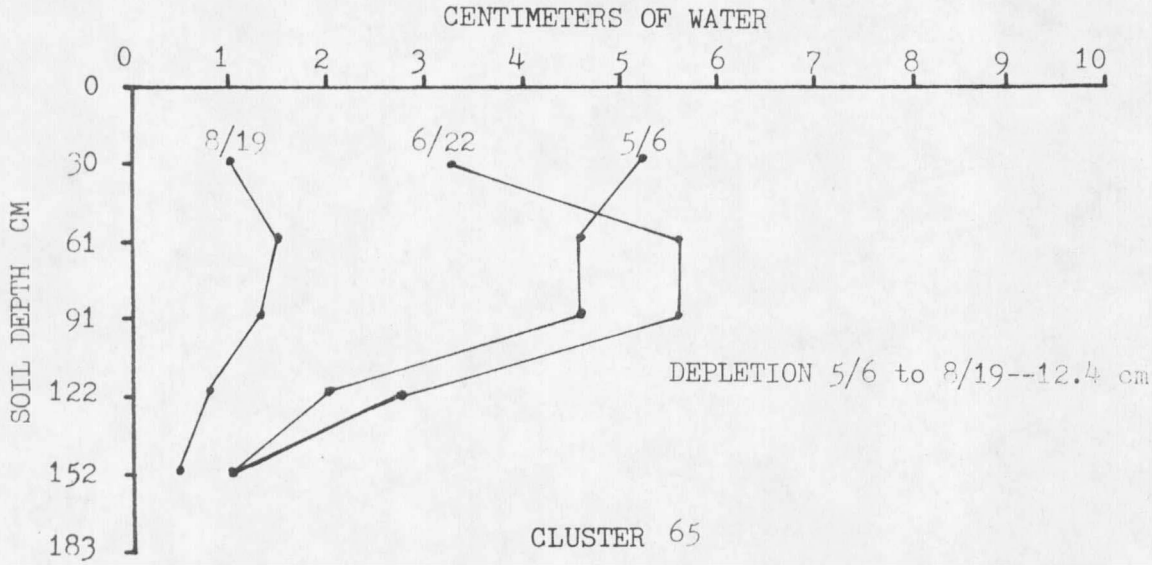
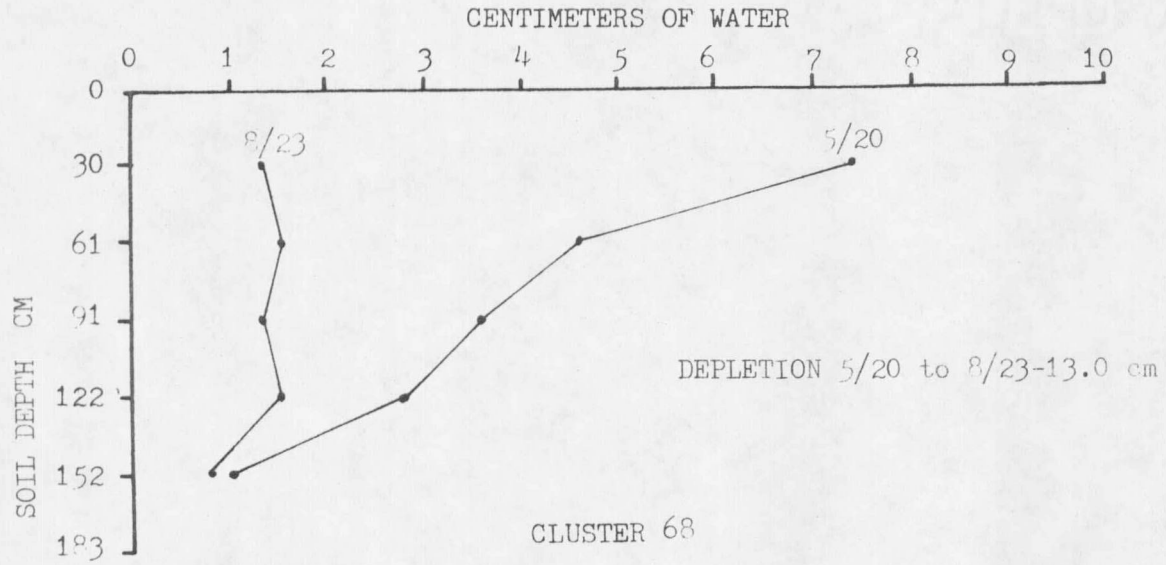


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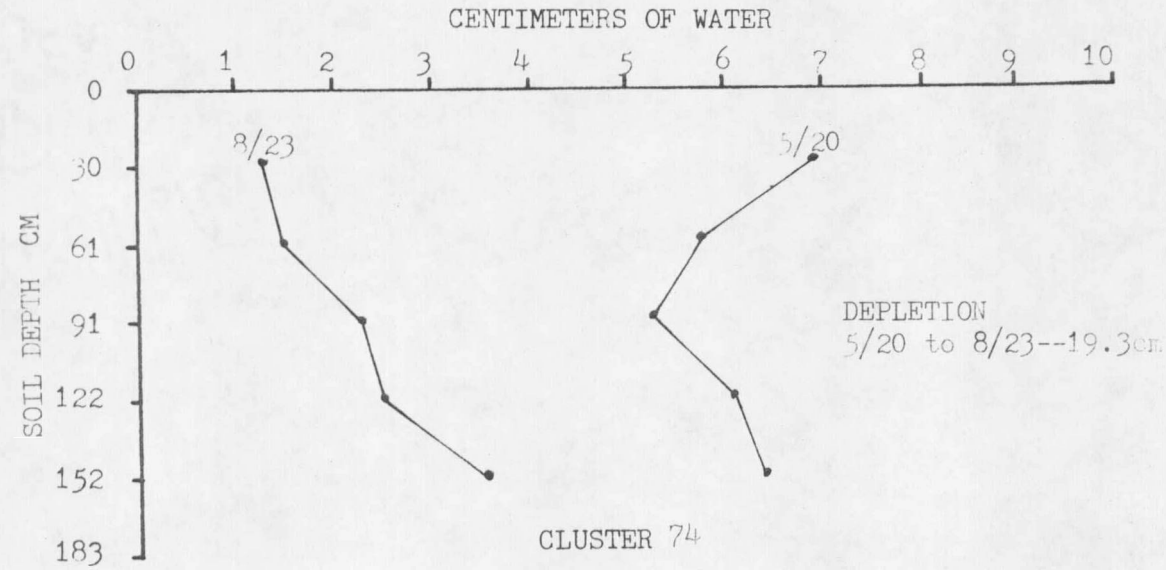
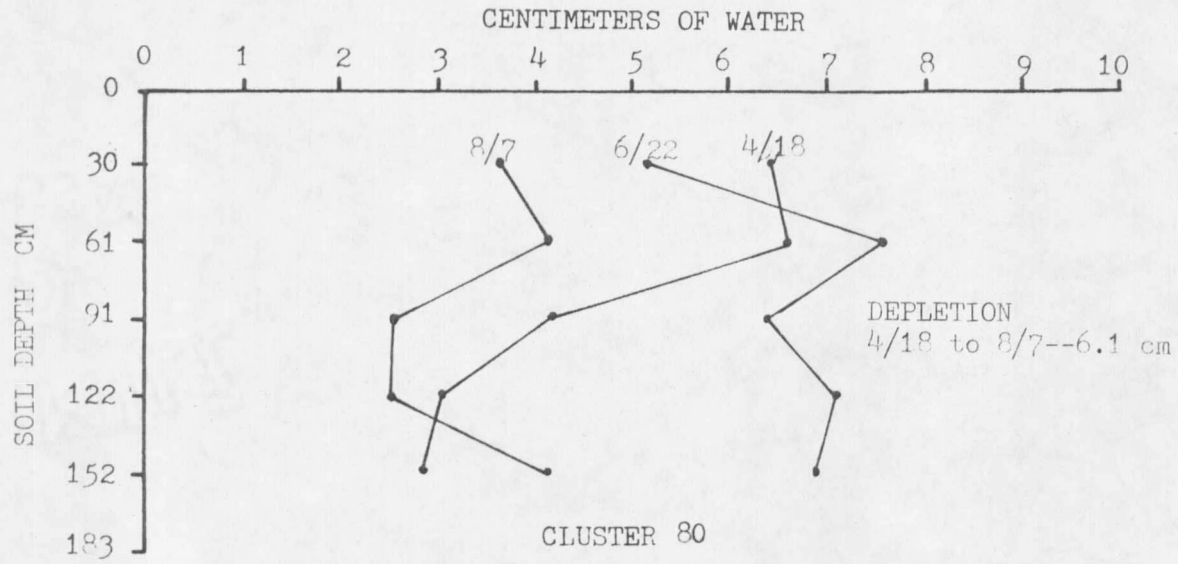


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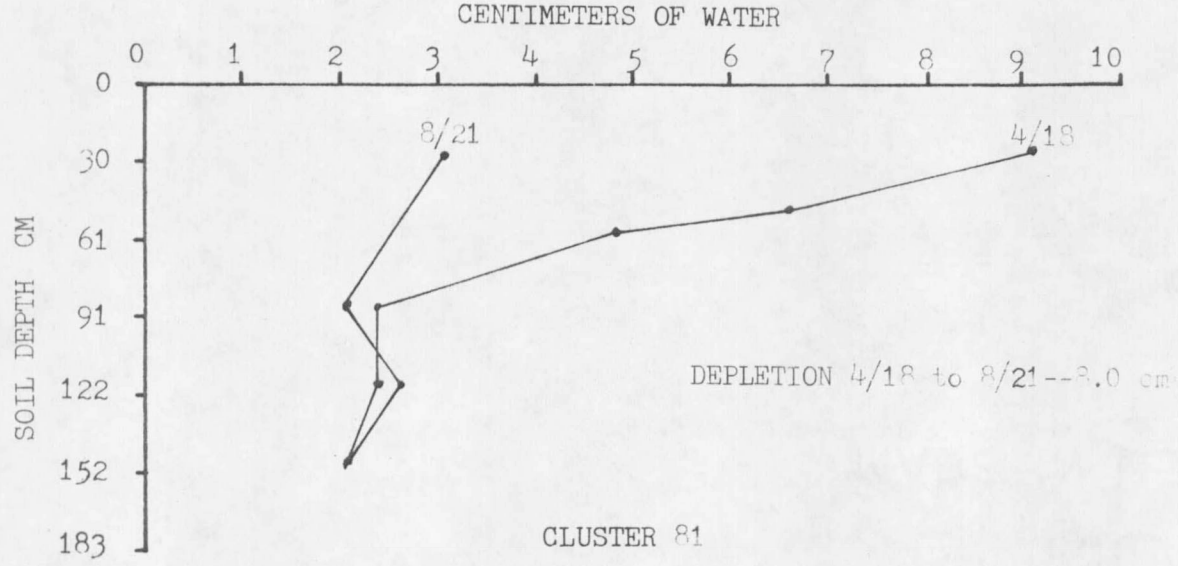
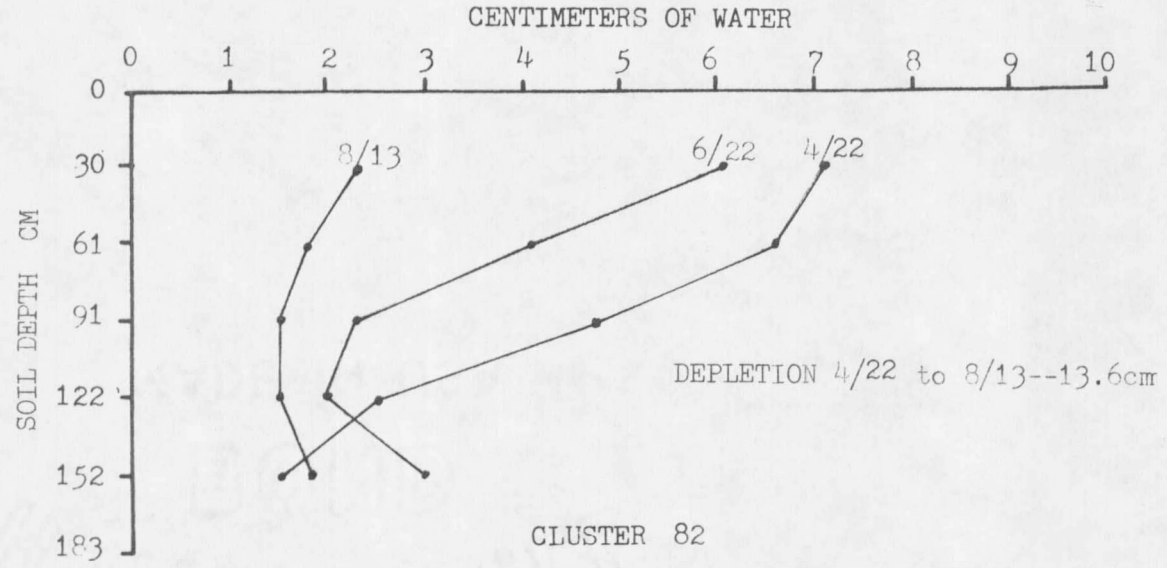


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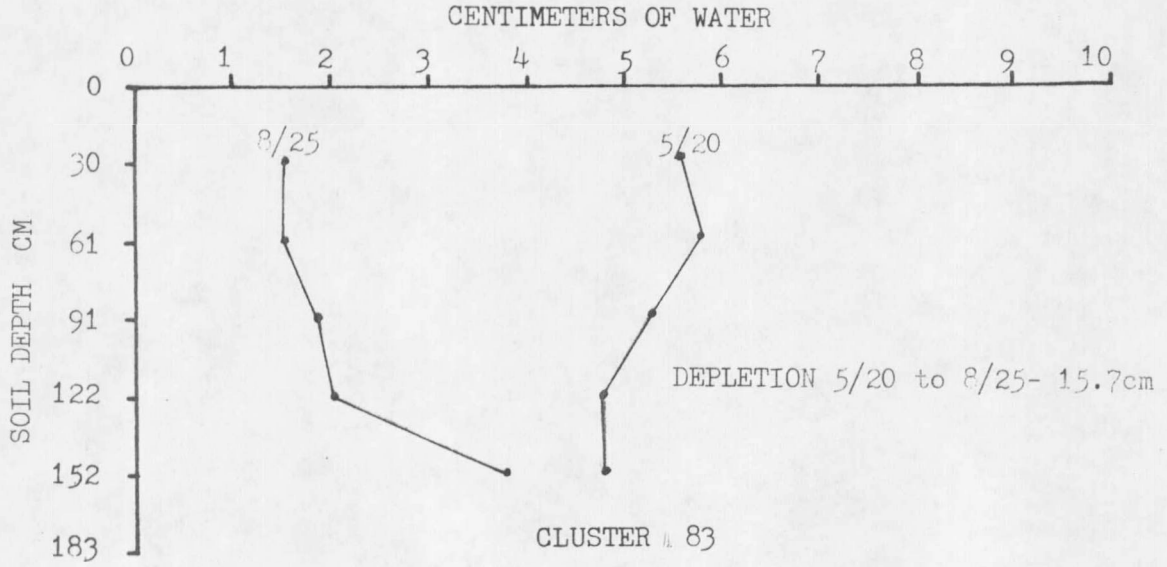


Fig. 10 -continued

to a greater error in determining water content in coarse soils in contrast to the uniform silty soils.

Soil moisture measurements were made at the Red Bluff Station intermittently from 1961 to 1968. (Farnes and Shafer, 1975) Average April total soil water to 152 cm depth was 9.1 cm. The total soil water was 4.6 cm on August 1, or a depletion of 4.5 cm. The field capacity determined in the laboratory on disturbed samples was 17.8 cm. This compares favorably with the water calculated for cluster 65, a similar loamy sand soil (17.5 cm and 18.3 cm on May 6 and June 22 respectively) (Table 6). The growth season water depletion at cluster 65, however was 12.4 cm. This is nearly three times more than the above mentioned eight year average at the ranch headquarters. The fact that the soil at the ranch never reached field capacity as it did at cluster 65 would seem to substantiate the lower precipitation at the headquarters (Table 2). An excess of water was applied to the soil at cluster 65 on July 20. Sampling on July 22 showed a field capacity of 20.1 cm to a dept of 152 cm. (Appendix III)

Unused plant available water

In Fig. 9 the estimated permanent wilting point was taken as the average dryness attained in the second 30 cm depth of soil for the three clusters (2.5 cm of water per 30 cm soil). Brown (1971) used an average of 2.2 cm for a similar soil in this same general area in work with winter wheat water use studies. This seems to be a

reasonable figure for PWP, and if so there is an average of 3.7 cm of plant available water left in the profile on August 13, mainly below 90 cm. This zone does have a few very fine roots (less than 4 roots per 6 cm^2, less than 1 mm in diameter, Table 1) but likely not enough to keep plants growing during the hot season. I have, however, observed many grassland soils over the years that were drier than these in August. It is likely that some nitrogen fertilizer would make it possible for the grasses to use this other 3.7 cm of available water and use it more efficiently. This was true of native grass fertilizer studies in North Dakota (Smika et al. 1961, Smika et al, 1965.) It is also true for winter wheat (Brown 1971).

Note in Fig. 10 and Table 6 that not all clusters were sampled the same dates. Some have common sampling dates and can be compared directly while other comparisons may need some extrapolation. In later computations and comparisons of water use efficiency, adjustments have been made to compensate for varying dates of sampling.

Estimation of the permanent wilting point and evaluation of unused plant available water is difficult for the soils at the Red Bluff Ranch, especially in the subsoil horizons, because of the variations in texture and the amount of coarse fragments. This evaluation is beyond the scope of this study. Suffice it to say that the data of this study indicates that a significant amount of water is used from horizons below 91 cm at some clusters and that there appears to be some

unused available water at some of the clusters. The amount is very small, however, in the deep sand soil at cluster 65 (Table 6) where there was only 0.5 cm of total water remaining in the 122 to 152 cm horizon on August 19.

Periodic consumptive water use

For this study the consumptive water use was taken as the precipitation at the site (Table 2) plus depleted soil water (Table 6) and was calculated for each period that the soil water was sampled. (See Appendix VII). Fig. 11 shows the cumulative consumptive use by sampling periods for clusters 84, 85, and 86 north of Belgrade, Montana. The total water used and the use rate throughout the growth period is similar for all three clusters. Average use rates per day ranged from 1.3 mm in early season to 3.6 mm after May 25. These three clusters had a common weather station and thus the differences in consumptive use are reflections of only the measured soil water differences. It is interesting to compare the consumptive use of these native grass sites with that of winter wheat on an adjacent site with similar soil (Brown 1971). The average daily consumptive use, or evapotranspiration as expressed by Brown, for unfertilized winter wheat in the period May 1 to August 13, 1968 (104 days) was 2.1 mm. In this native grass study the comparable rate was 2.5 mm per day from April 8, to August 13 (127 days). At these average consumptive use rates the grass would use 4 cm more water than the winter wheat

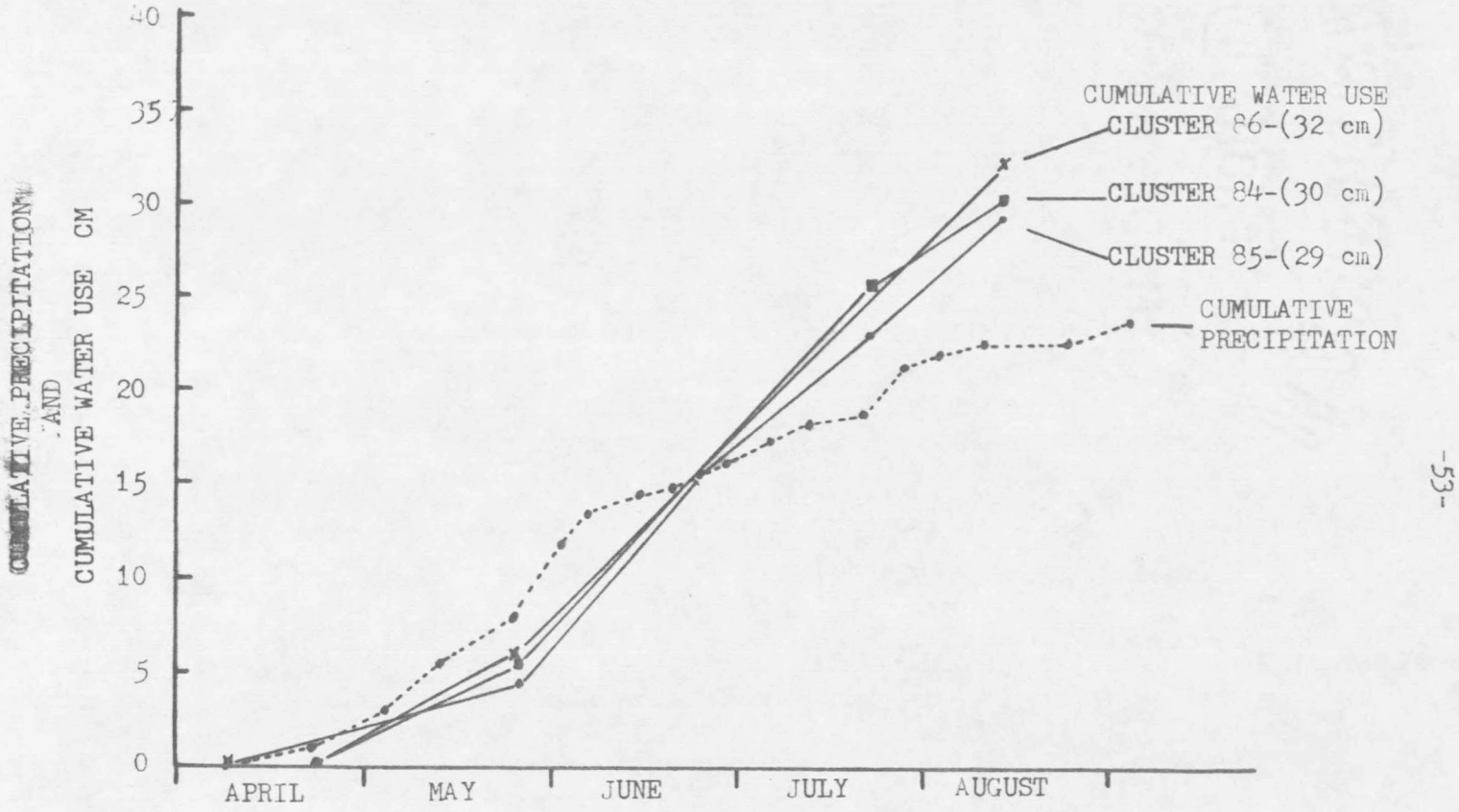


Fig. 11- Cumulative water use and precipitation by native grasses at clusters 84, 85, and 86, north of Belgrade, Montana. 1970. Average use rates per day range from 1,3 mm in early season to 3.6 mm after May 25. Precipitation kept ahead of use until about June 24.

in 104 days.

In Fig. 11 the cumulative precipitation for the North Belgrade clusters is plotted along with the cumulative water use. Note that precipitation is greater than consumptive use until about June 24. This is the same date in 1968 that consumptive use by unfertilized winter wheat exceeded precipitation (Brown 1971). Brown, however, had weekly soil moisture readings which would give a more precise date than the 30 to 60 day sampling intervals of this study.

Fig. 12 shows the cumulative consumptive use by sampling periods for clusters 54, 65, 80, and 82 at the Red Bluff Ranch. Note that there is more variation than for the three clusters north of Belgrade. This should be expected as the Belgrade clusters were selected because they had similar soil and site characteristics. Note the similarity of use rate and total water use for clusters 54 and 82 (Fig. 12). The soils at the two clusters are similar but cluster 54 is 80m higher elevation and is a north slope in contrast to a southeast slope at cluster 82. Cluster 80 has a rather low average consumptive use rate (1.3 mm/day) from April 18 to June 22. During this period the total soil water increased by 10 cm. A much higher use rate from June 22 to August 7 (5.0 mm/day) resulted in a total use for the season about the same as the other sites. The soil at cluster 65, a deep sand soil had a more uniform consumptive use rate throughout the growth period; 2.7 mm/day from May 6 to June 22, and 3.3 mm/day June 22 to August 13.

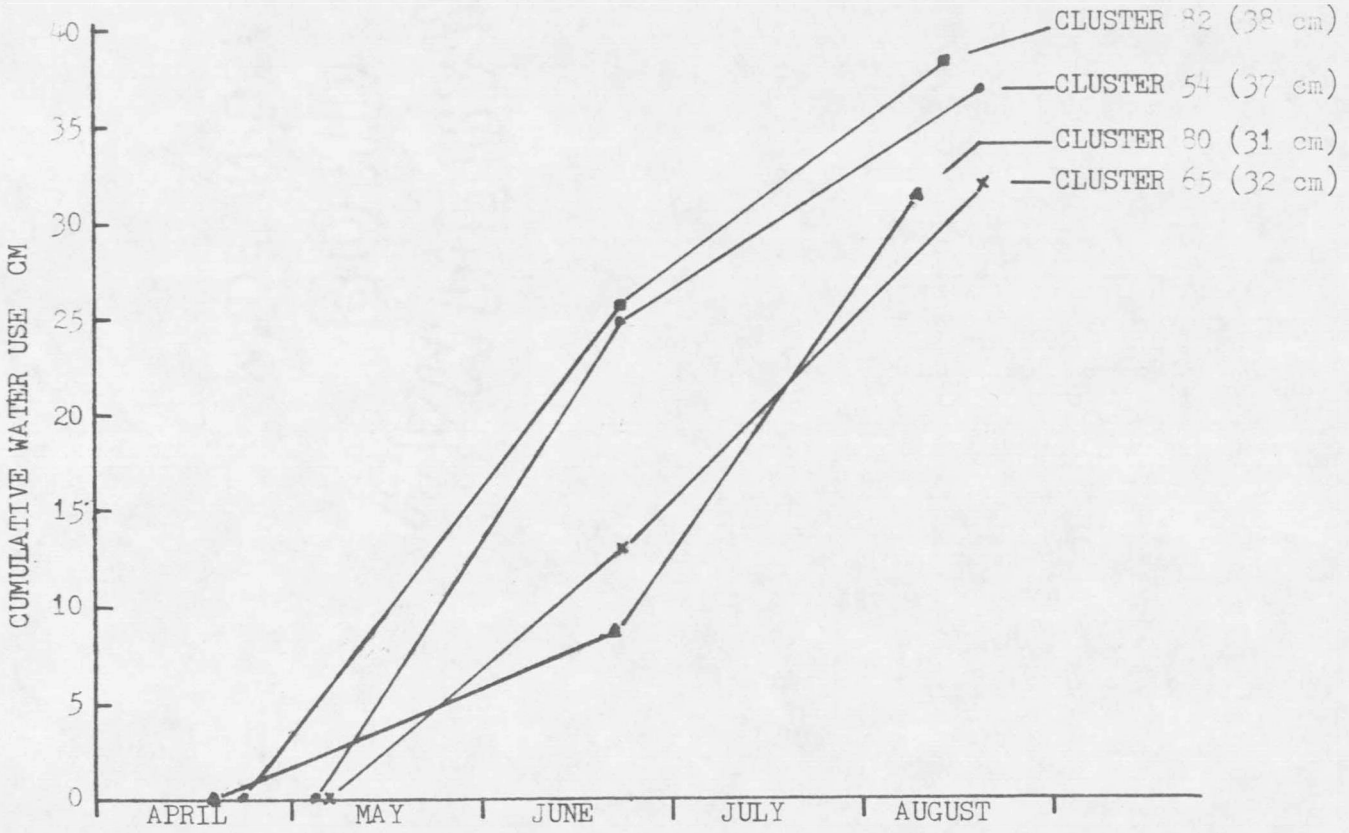


Fig. 12- Clumulative water use by native grasses at clusters 54, 65, 80, and 82, Red Bluff Ranch, Norris, Mt., 1970. Average use rates per day range from 1.3 mm to 5.1 mm.

Because of the long interval between sampling at the Red Bluff clusters the cumulative precipitation was not plotted in Fig. 12 as in Fig. 11 for the north Belgrade clusters. More frequent monitoring of soil water use might give some insight into the reasons for differences in periodic consumptive use rates for soils.

Growth season consumptive use

In order to compare the consumptive water use between clusters, it was necessary to put all clusters on an equal time period. April 18 to August 19 was taken as the common growth season for this study. Because all the sites were not sampled for moisture on these dates adjustments in soil water depletion figures given in Table 6 had to be made. This was done by assuming a consumptive use rate between actual dates of sampling and the date when precipitation recording began. For the April-May period adjustments a consumptive use rate of 1.6 mm per day was used. This was the average consumptive use rate at cluster 84 from April 22 to May 25 determined by soil water difference on these dates. In work with small grain fallow near Mandan, N. D., Hass and Willis found a consumptive use of 1.1 mm per day in April and 1.8 mm per day in May. For the August adjustments a consumptive use rate of 2.3 mm per day was used. This was the average use rate at clusters 84 and 85 from July 21, to August 13 determined by soil water difference on these dates. In calculating irrigation needs of grass pasture for this part of Montana, a peak consumptive use of 2.2 mm per day is used.

(Soil Conservation Service 1973) The total consumptive use for the common growth season (Appendix VII) was used to calculate the water use efficiency.

Soil Nitrate

Soil nitrate concentrations for the soils studied are presented in Table 7, 8, and 9. A review of these data shows:

1. The average nitrate concentration of the upper 61 cm is greater than that at deeper depths in the soil. As most of the organic matter in the soils studied is in the upper 61 cm of soil it would be expected that nitrate released through decomposition would be in this horizon.

2. Greater nitrate concentrations in April than in August. It would seem that some nitrate accumulates in the soil after grass growth is essentially completed in early August and before grass growth begins in early April the following spring. This same pattern of nitrate distribution in the profile and the average concentrations in fall and spring were reported by Wight and Black (1970) for native mixed prairie at Sidney, Montana.

3. Greater concentration of nitrate in late June than at any other sampling date. Fig. 13 and 14 show the nitrate concentration for clusters 85 and 86 north of Belgrade, Montana and clusters 54 and 65 on the Red Bluff Ranch at Norris, Montana, for various sampling dates. The contrast in nitrate concentration in late June is shown at the three clusters where there was a sampling in late June. This is likely the

Table 7. Soil nitrate concentration (ppm) by horizons to 183 cm depth for five sampling dates at cluster 85 and three sampling dates at cluster 86. North of Belgrade, Montana. 1970.

CLUSTER 85

Depth (cm)	Cores April 8			Cores May 23			Cores June 23			Cores July 21			Cores August 13		
	3	4	Ave.	44	45	Ave.	79	80	Ave.	82	83	Ave.	105	106	Ave.
	-----ppm------			-----ppm------			-----ppm------			-----ppm------			------ppm-------		
0-15	1.2	1.0	1.1	1.2	0.5	0.8	3.1	5.0	4.0	2.7	1.2	1.9	1.2	1.9	1.5
15-30	1.5	1.5	1.5	0.7	0.7	0.7	4.0	3.7	3.8	0.5	0.7	0.6	0.7	1.0	0.8
30-61	1.2	1.5	1.3	0.5	1.5	1.0	3.1	2.1	2.6	1.2	0.5	0.9	0.5	0.5	0.5
61-91	1.0	1.0	1.0	0.2	1.2	0.7	2.9	1.9	2.4	0.5	0.2	0.3	0.2	0.2	0.2
91-122	1.0	1.0	1.0	0.2	0.9	0.6	1.5	1.5	1.5	0.2	0.2	0.2	0.2	0.2	0.2
122-152	1.0	1.2	1.1	0.2	0.5	0.3	1.9	2.1	2.0	0.2	0.5	0.3	0.2	0.5	0.3
152-183	1.0	1.0	1.0	0.5	0.5	0.5	2.9	1.2	2.0	0.2	0.2	0.2	0.2	0.2	0.2
Average 0-152 cm			1.1			0.7			2.5			0.6			0.5
Average 0- 61 cm			1.3			0.9			3.2			0.9			0.8

CLUSTER 86

Depth (cm)	Cores April 8			Cores May 23			Cores August 13		
	7	8	Ave.	46	47	Ave.	100	101	Ave.
0-15	1.2	1.0	1.1	0.7	1.0	0.8	0.5	0.5	0.5
15-30	2.1	0.7	1.4	0.5	0.7	0.6	0.2	0.2	0.2
30-61	2.1	1.0	1.6	0.5	0.7	0.6	0.5	0.5	0.5
61-91	1.0	0.5	0.7	0.2	0.5	0.3	0.2	0.2	0.2
91-122	0.5	0.2	0.3	0.3	0.2	0.2	0.2	1.0	0.6
122-152	0.2	0.2	0.2	0.2	0.2	0.2	0.2	3.0	1.6
152-183	0.2	0.2	0.2	0.2	0.2	0.2	0.2	8.0	4.1
Average 0-152 cm			0.8			0.4			0.6
Average 0- 61 cm			1.4			0.6			0.4

Table 8. Soil nitrate concentration (ppm) by horizons to 152 cm depth for three sampling dates at clusters 54 and 65. Red Bluff Ranch, Norris, Montana. 1970.

CLUSTER 54

Depth (cm)	Cores May 4			Cores June 22			Cores August 18		
	37	38	Ave.	74	75	Ave.	118	117	Ave.
	ppm			ppm			ppm		
0-15	1.7	2.4	2.0	2.8	2.8	2.8	0.5	1.0	0.7
15-30	0.8	0.8	0.8	2.2	4.8	3.5	0.3	0.7	0.5
30-61	0.3	0.5	0.4	2.0	2.2	2.1	0.5	0.7	0.6
61-91	0.2	0.3	0.2	1.9	1.0	1.4	0.2	0.3	0.2
91-211	0.2	0.2	0.2	0.5	0.9	0.7	0.2	0.3	0.2
122-152	0.2	0.2	0.2	0.4	1.1	0.7	0.2	2.8	1.5
Average 0-152 cm			0.5			1.6			0.6
Average 0- 61 cm			0.9			2.6			0.6

CLUSTER 65

Depth (cm)	Cores May 4			Cores June 22			Cores August 18		
	28	30	Ave.	76	77	Ave.	114	115	Ave.
0-15	2.0	1.5	1.7	3.5	3.2	3.3	0.8	0.7	0.7
15-30	3.2	0.7	1.9	3.2	2.4	2.8	0.7	0.8	0.7
30-61	1.9	0.3	1.1	2.0	2.6	2.3	0.5	0.5	0.5
61-91	1.3	0.1	0.7	1.5	1.7	1.6	0.3	0.8	0.6
91-122	0.5	0.1	0.3	0.8	1.5	1.1	0.1	0.3	0.2
122-152	0.3	0.1	0.2	0.7	0.4	0.5	0.1	0.1	0.1
Average 0-152 cm			0.9			1.7			0.4
Average 0- 61 cm			1.4			2.6			0.6

Table 9. Soil nitrate concentration (ppm) by horizons to 152 cm depth for various sampling dates at clusters 13, 20, 27, 50, 80, 82. Red Bluff Ranch, Norris, Montana. 1970.

CLUSTER 13

Depth (cm)	Cores May 4			Cores August 2		
	50	52	Ave.	128	130	Ave.
	------ppm-------			--------ppm--------		
0-15	1.4	0.8	1.1	0.7	0.8	0.7
15-30	1.5	0.5	1.0	0.5	1.0	0.7
30-61	0.7	0.3	0.5	0.3	0.3	0.3
61-91	0.7	0.1	0.4	0.3	0.1	0.2
91-122	0.8	0.1	0.4	0.1	0.3	0.2
122-152	0.3	0.1	0.2	0.1	0.3	0.2
Average 0-152 cm			0.5			0.3
Average 0- 61 cm			0.8			0.5

CLUSTER 20

Depth (cm)	Cores April 22			Cores August 19		
	18	19	Ave.	111	112	Ave.
0-15	0.4	0.3	0.3	1.3	1.3	1.3
15-30	0.3	0.3	0.3	1.3	1.9	1.6
30-61	0.3	0.1	0.2	0.6	0.7	0.6
61-91	0.1	0.1	0.1	0.6	0.4	0.5
91-122	0.1	0.1	0.1	1.0	0.3	0.6
122-152	0.0	0.1	0.1	0.3	0.3	0.3
Average 0-152 cm			0.2			0.7
Average 0- 61 cm			0.2			1.0

CLUSTER 27

Depth (cm)	Cores April 18			Cores August 21		
	12	13	Ave.	125	127	Ave.
0-15	1.7	1.2	1.4	2.2	0.6	1.4
15-30	1.0	1.2	1.1	1.0	0.4	0.7
30-61	0.6	0.8	0.7	0.6	0.2	0.4
61-91	0.4	1.2	0.8	0.2	0.2	0.2
91-122	0.4	1.0	0.7	0.2	0.2	0.2
122-152	0.4	1.0	0.7	0.2	0.2	0.2
Average 0-152 cm			0.9			0.4
Average 0- 61 cm			1.0			0.7

Table 9. Soil nitrate concentration (ppm) by horizons to 152 cm depth for various sampling dates at clusters 13, 20, 27, 50, 80, 82. Red Bluff Ranch, Norris, Montana. 1970. (continued)

CLUSTER 50

Depth (cm)	Cores May 20			Cores August 25		
	64	65	Ave.	137	138	Ave.
	------ppm--------			--------ppm---------		
0-15	1.0	0.7	0.8	0.5	0.5	0.5
15-30	0.5	0.3	0.4	0.3	0.3	0.3
30-61	0.3	0.3	0.3	0.3	0.3	0.3
61-91	0.5	0.3	0.4	0.1	0.1	0.1
91-122	0.4	0.1	0.2	0.1	0.1	0.1
122-152	0.6	0.2	0.4	0.4	0.2	0.3
Average 0-152 cm			0.4			0.2
Average 0- 61 cm			0.4			0.3

CLUSTER 80

Depth (cm)	Cores April 18			Core May 22
	9	11	Ave.	70
0-15	4.0	0.7	2.3	1.7
15-30	3.3	0.5	1.9	1.7
30-61	1.0	0.3	0.6	0.8
61-91	0.7	0.5	0.6	1.3
91-122	0.7	0.5	0.6	1.5
122-152	0.5	0.5	0.5	0.7
Average 0-152 cm			0.9	1.2
Average 0- 61 cm			1.3	1.2

CLUSTER 82

Depth (cm)	Cores April 22			Core May 22
	23	24	Ave.	72
0-15	1.3	1.7	1.5	2.6
15-30	1.3	1.0	1.2	2.4
30-61	1.0	1.3	1.2	0.8
61-91	1.2	0.7	0.9	0.5
91-122	1.0	0.5	0.7	0.3
122-152	1.3	0.3	0.8	0.1
Average 0-152 cm			1.0	0.8
Average 0- 61 cm			1.2	1.6

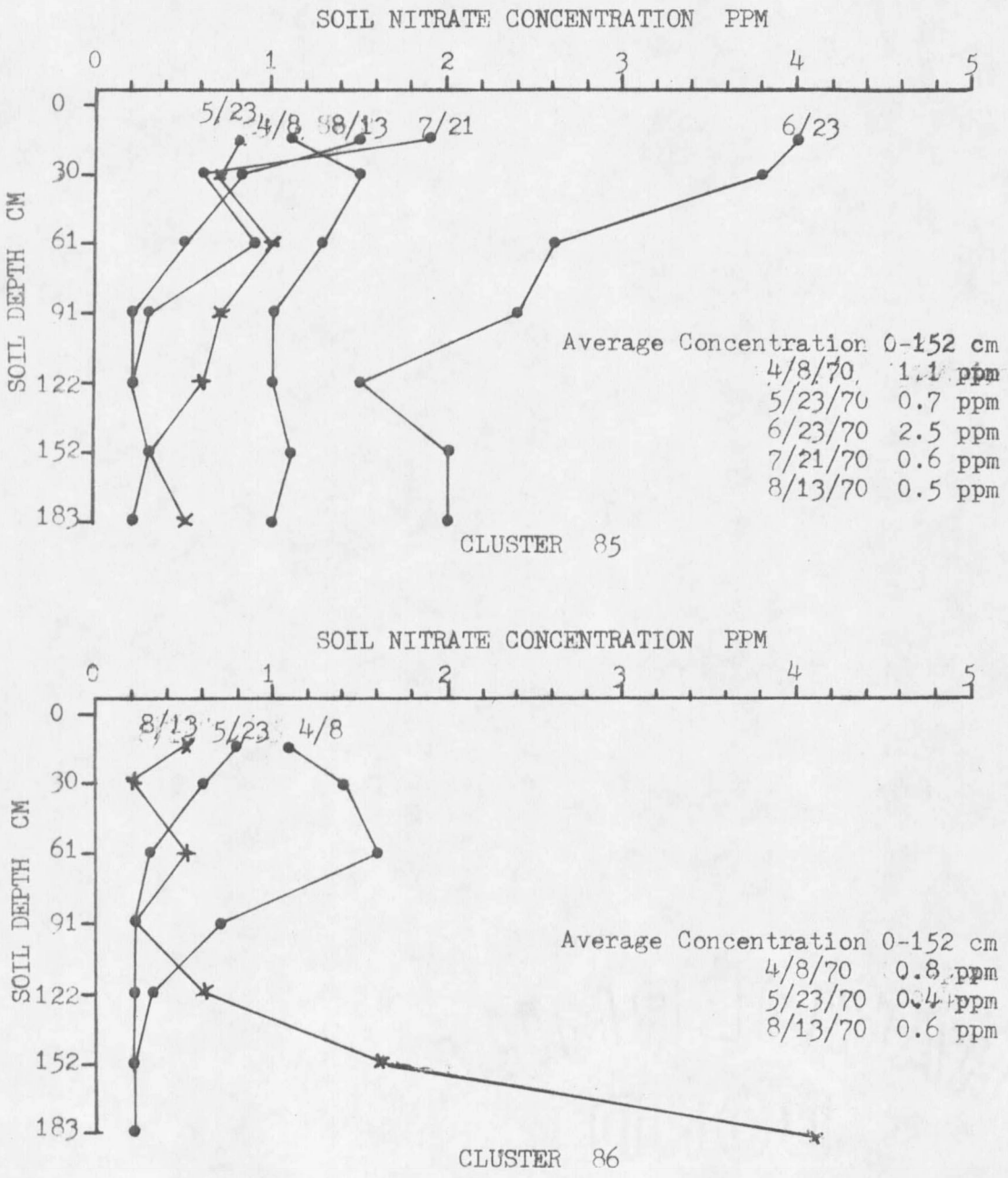


Fig. 13- Soil nitrate concentration in parts per million by horizons for several sampling dates at clusters 85 and 86 north of Belgrade, Mt. Average concentration in the 0 to 152 cm depth on June 23 was more than double that in April or August.

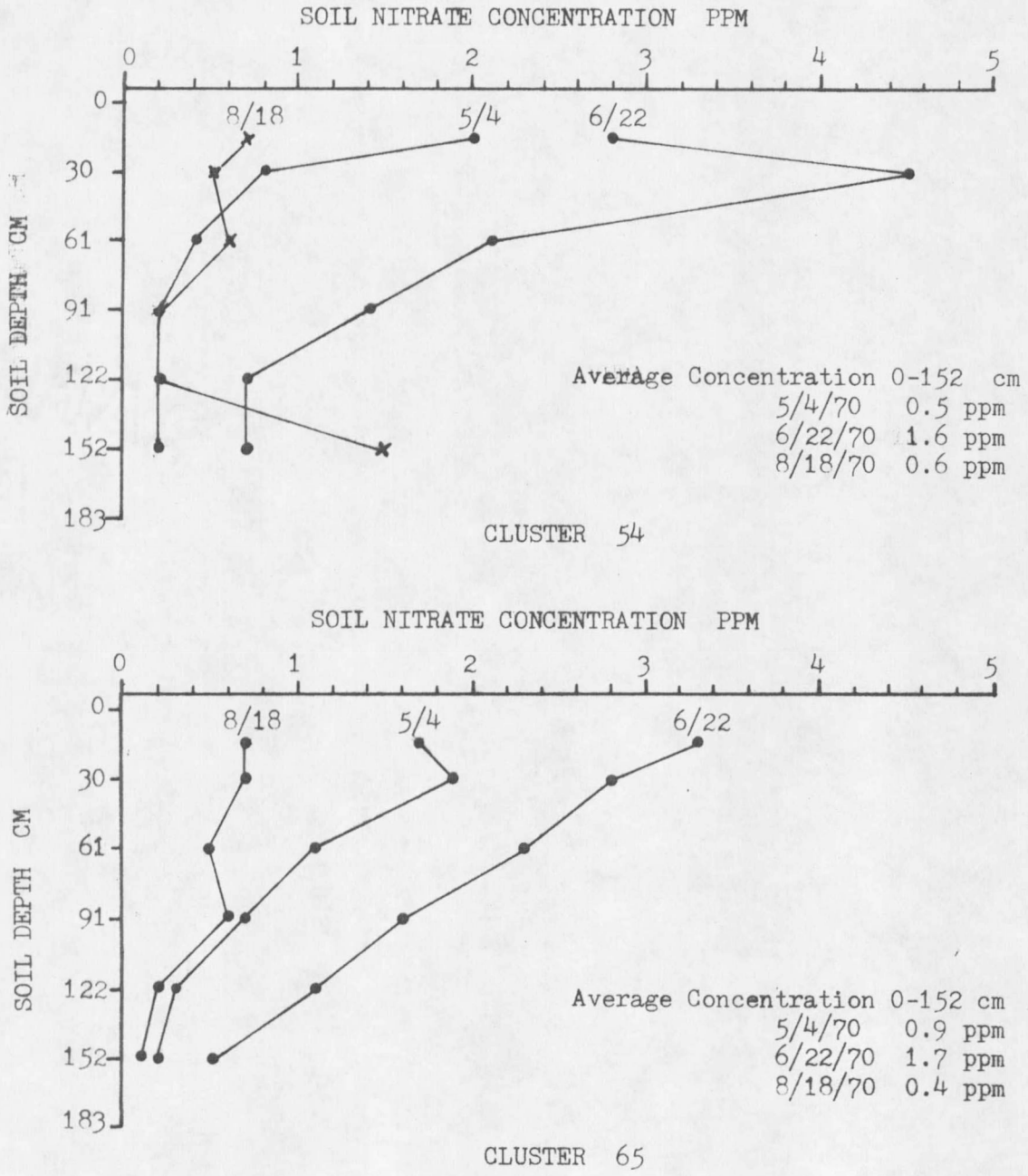


Fig. 14-Soil nitrate concentration in parts per million by horizons for several sampling dates at clusters 54 and 65 on the Red Bluff Ranch, Norris, Mt. Average concentration in 0 to 152 cm depth on June 22 was about double that in May or August.

most optimum time for microbial production of nitrate as soil moisture is high (Table 6) and the soils have warmed up (Table 4). With rapid plant growth at this period the nitrate level is quickly reduced to the low level by late July. From these limited data it seems likely that soil nitrate is at a low level most of the year; it may be in surplus for a short period but, is used rapidly by native range plants when it becomes available. It also seems that in late June there would be a potential for nitrate loss through deep leaching if above normal rainfall occurred at this time, if soils were shallow, or if weak shallow rooted grasses occupied the site.

The nitrate level of these grassland soils seems low in comparison to grain cropland as reported by Black and Ford (1975).

"U S D A Agricultural Research Service researchers at Sidney, Mt. have sampled hundreds of soil profiles on recrop land for nitrate to a depth of 4 feet. The mean level for all of those profiles was about 30 pounds per acre with a deviation of only plus or minus 7 lb/acre." Using a standard conversion bulk density (4 million pounds per acre foot) this is equivalent to approximately 2 ppm in the upper 120 cm of grainland soil compared to less than one ppm for the grasslands studied.

4. A surprisingly high nitrate concentration at 183 cm depth in core sample 101, cluster 86, Table 7. This is likely the result of sampling a filled rodent burrow; common in this deep silty soil.

Herbage Production

Total herbage production

The herbage production for the 20 clusters of the study are tabulated by species or group of species in Table 10. All but three clusters (13, 56, and 83) had Agropyron spicatum as one of the two main grass producing species and it was present in minor amounts at these three clusters. Festuca idahoensis was one of the two main grasses at 11 of the 17 Red Bluff Clusters. There was no Festuca idahoensis clipped and it was not observed at the clusters north of Belgrade, Montana or at clusters 13, 20, or 27 at Red Bluff Ranch. Festuca idahoensis was not one of the two major species clipped at clusters 80, 81, and 82 but it was observed at these clusters.

The total herbage production from a particular site varies greatly depending on yearly growing conditions. Total production for 1970 is given in Table 10. It ranged from a low of 726 kg/ha at cluster 20 to 2167 kg/ha at cluster 54. The herbage production in 1970 at most clusters was reasonably close to the average of three to six years production.(Personal communication, Animal & Range Science Dept. Montana State University, Bozeman, Mt.)

Table 11 is a tabulation of the herbage production by species or group of species as percent of the total production; used mainly in calculating range condition.

Table 10-Average herbage production(kg/ha) for 17 clusters at the Red Bluff Ranch, Norris, Mt. and 3 clusters north of Belgrade, Montana 1970.

	CLUSTERS									
	13	20	27	30	50	53	54	56	57	64
	kg/ha									
Agropyron smithii (Whestern Wheatgrass)	97									
Agropyron spicatum (Bluebunch Wheatgrass)		22	317	407	72	536	276		215	150
Festuca idahoensis (Idaho Fescue)				588	587	254	1022	411	610	334
Koeleria cristata (Prairie Junegrass)										
Stipa comata (Needleandthread)	197	60	31					305		
Misc. Perennial Grasses and Sedges	220	216	162	55	229	158	158	117	83	193
Total Perennial Grasses and Sedges	514	299	511	1050	888	948	1456	833	908	677
Misc. Annual Grasses	353	T							37	
Misc. Forbs	227	365	216	195	169	262	632	436	164	343
Artemisia frigida (Fringed Sagebrush)	3	62	103	10	20	150	65	25	103	30
Xanthocephalum sarothrae (Broom Snakeweed)			28			40				
Misc. Shrubs			39			49	13	158		
Total Production	1097	726	896	1255	1077	1448	2167	1452	1213	1050

Table 10-continued

	CLUSTERS									
	65	68	74	80	81	82	83	84	85	86
	kg/ha									
Agropyron smithii (Western Wheatgrass)							100			296
Agropyron spicatum (Bluebunch Wheatgrass)	315	257	166	775	464	556		137	454	
Festuca idahoensis (Idaho Fescue)	519	462	559				965			
Koeleria cristata (Prairie Junegrass)									71	
Stipa comata (Needleandthread)				60	15	47		398		134
Misc. Perennial Grasses and Sedges	92	119	122	143	233	244	132	308	152	261
Total Perennial Grasses and Sedges	926	837	847	979	712	847	1188	843	677	692
Misc. Annual Grasses	40	1				49			6	
Misc. Forbs	301	327	362	451	917	583	222	180	160	91
Artemisia frigida (Fringed Sagebrush)	110	54	10	64	19	71	45	3		
Xanthocephalum sarothrae (Broom Sankeweed)										
Misc. Shrubs	49	67	210		47					
Total Production	1424	1287	1429	1493	1694	1550	1455	1027	843	782

Table 11-Percent of total, and total (kg/ha) herbage production for 17 clusters at Red Bluff Ranch, Norris, Mt. and three clusters north of Belgrade, Mt., 1970.

	CLUSTERS									
	13	20	27	30	50	53	54	56	57	64
	%									
Perennial Grasses										
Agropyron smithii (Western Wheatgrass)	9									
Agropyron spicatum (Bluebunch Wheatgrass)		3	35	32	7	37	13		18	14
Festuca idahoensis (Idaho Fescue)				47	54	17	47	28	50	32
Koeleria cristata (Prairie Junegrass)										
Stipa comata (Needleandthread)	18	8	4					21		
Misc. Perennial Grasses and Sedges	20	30	18	5	21	11	7	8	7	18
Total Prenennial Grasses and Sedges	47	41	57	84	82	65	67	57	75	64
Misc. Annual Grasses	32	1							3	
Misc. Forbs	20	50	24	15	16	18	29	30	13	33
Artemisia frigida (Fringed Sagebrush)	1	8	12	1	2	11	3	2	9	3
Xanthocephalum sarothrae (Broom Sankeweed)			3			3				
Misc. Shrubs			4			3	1	11		
Total Production .. (kg/ha)	1097	726	896	1255	1077	1448	2167	1452	1213	1050

Table 11-continued

	CLUSTERS									
	65	68	74	80	81	82	83	84	85	86
	%									
Perennial Grasses										
Agropyron smithii (Western Wheatgrass)										38
Agropyron spicatum (Bluebunch Wheatgrass)	22	20	12	52	27	36		13	54	
Festuca idahoensis (Idaho Fescue)	37	36	39				66			
Koeleria cristata (Prairie Junegrass)									8	
Stipa comata (Needleandthread)				4	1	3		39		17
Misc. Perennial Grasses and Sedges	6	9	8	10	14	16	16	30	18	33
Total Perennial Grasses and Sedges	65	65	59	66	42	55	82	82	80	88
Misc. Annual Grasses	2	1				3			1	
Misc. Forbs	21	25	25	30	54	38	15	17	19	12
Artemisia frigida (Fringed Sagebrush)	8	4	1	4	1	4	3	1		
Xanthocephalum sarothrae (Broom Sankeweed)										
Misc. Shrubs	4	5	15		3					
Total Production (kg/ha)	1424	1287	1429	1493	1694	1550	1455	1027	843	782

Range condition

Table 12 gives the range condition expressed in percent of annual herbage production of climax species for the site. It is based on Soil Conservation Service Technicians Guides To Range Condition (U.S.D.A. 1971) and the herbage production data presented in Table 11. The main reasons for departure from climax are also given. Two items should be noted:

A high percentage of the herbage produced at a number of the clusters is by Festuca idahoensis (clusters 30, 83, etc.,) and by forbs (clusters 20, 81, etc.). As the technicians guides limit Festuca idahoensis to 20% and there is a total of 66% at the site, the condition at cluster 83 is only 54 per cent (Table 12). It is interesting to note that cluster 83 is located in a permanent exclosure about 15 meters square; fenced in the fall of 1959. It was noted at that time that the vegetation was "dominated by a bluebunch wheatgrass type... and no extra snow was trapped". In 10 years this site has apparently changed from a dominance of Agropyron spicatum to a dominance of Festuca idahoensis. There may be a need to reconsider the proportion of Festuca idahoensis considered as part of the climax vegetation. From field notes taken during this study it appears that Lupinus sericeus is the main forb contributing to the high production from forbs at clusters 80, 81, 82, etc.; and the low range condition at cluster 13 is mainly due to the high amount of annual grasses, mainly Bromus tectorum.

Production per unit of water

The water use efficiency (WUE) in this study is defined as the dry

Table 12 -Range Condition and reason for departure from climax for 17 clusters at Red Bluff Ranch, Norris, Mt. and 3 clusters north of Belgrade, Mt.,1970.

CLUSTERS	Range Condition %*	Reason For Departure From Climax
13	58	32% Annual grasses
20	56	50% Forbs
27	68	43% Forbs and shrubs
30	68	48% Festuca Idahoensis
50	60	54% Festuca Idahoensis
53	80	11% Artemisia frigida
54	59	47% Festuca Idahoensis and 29% forbs
56	66	21% Stipa comata & 30% forbs
57	60	50% Festuca Idahoensis
64	65	32% Festuca Idahoensis and 33% forbs
65	73	37% Festuca Idahoensis and 21% forbs
68	73	36% Festuca Idahoensis and 25% forbs
74	55	39% Festuca Idahoensis and 16% shrubs
80	80	30% forbs
81	56	54% forbs
82	69	38% forbs
83	54	66% Festuca Idahoensis
84	69	39% Stipa comata and 17% forbs
85	79	17% forbs
86	80	33% Misc. Perenniel grasses

*--Percent of annual production from species considered climax for the site (U.S.D.A. 1971).

weight of clipped herbage per hectare-centimeter of consumptive water use, kg/ha-cm. The WUE's for the 20 study clusters are given in Table 13 along with the consumptive water use. The listing by clusters is from least to greatest efficiency. The WUE's range from 20 to 58 kg/ha-cm with an average of 37 kg/ha-cm. These are within the range reported bor the northern Great Plains. Johnson et al. (1969) reported 15 kg/ha-cm, and (Black 1968) reported 92 kg/ha-cm production of native grass.

The average WUE of clusters 85 and 86 north of Belgrade was 29 kg/ha-cm. Unfertilized winter wheat on fallow in this same general area on a similar soil produced 73 kg/ha-cm of grain in 1968 (Brown 1971). Assuming there would be as much straw produced as grain, the total plant material produced by the winter wheat is more than four times as great as the native grass. In making this comparison one should keep in mind that the grain is produced in alternate years, that plant nutrients accumulate during the fallow year, and that good fertility management usually increases water use efficiency.

The average WUE for the clusters at the Red Bluff Ranch was 38 kg/ha-cm.

Fig. 15 shows a direct relationship between WUE and total herbage production. The high producing sites used little more water than the low producing sites. This might suggest that some factor other than water is controlling the producing level; plant composition or vigor,

Table 13-Consumptive Water Use and Water Use Efficiency for 17 clusters at the Red Bluff Ranch and 3 clusters north of Belgrade, Mt., from April 18 to August 19, 1970. Clusters are listed in order of increasing water use efficiency.

CLUSTER	Consumptive Use Total-cm	mm/day	Water Use Efficiency kg herbage/ha-cm water
20	36.5	2.7	20
86	31.2	2.5	25
64	36.2	2.9	29
85	28.5	2.3	30
27	29.0	2.4	30
50	34.5	2.8	31
30	38.8	3.1	32
84	32.2	2.6	32
74	41.5	3.4	34
56	39.9	3.2	36
68	35.2	2.9	37
13	29.1	2.4	38
65	36.7	3.0	39
82	39.8	3.2	39
57	30.0	2.4	40
53	34.2	2.8	42
80	34.1	2.8	44
83	31.9	2.6	46
54	40.5	3.3	53
81	29.1	2.4	58
Average:			
North Belgrade	30.6	2.5	29
Red Bluff Ranch	35.1	2.9	38

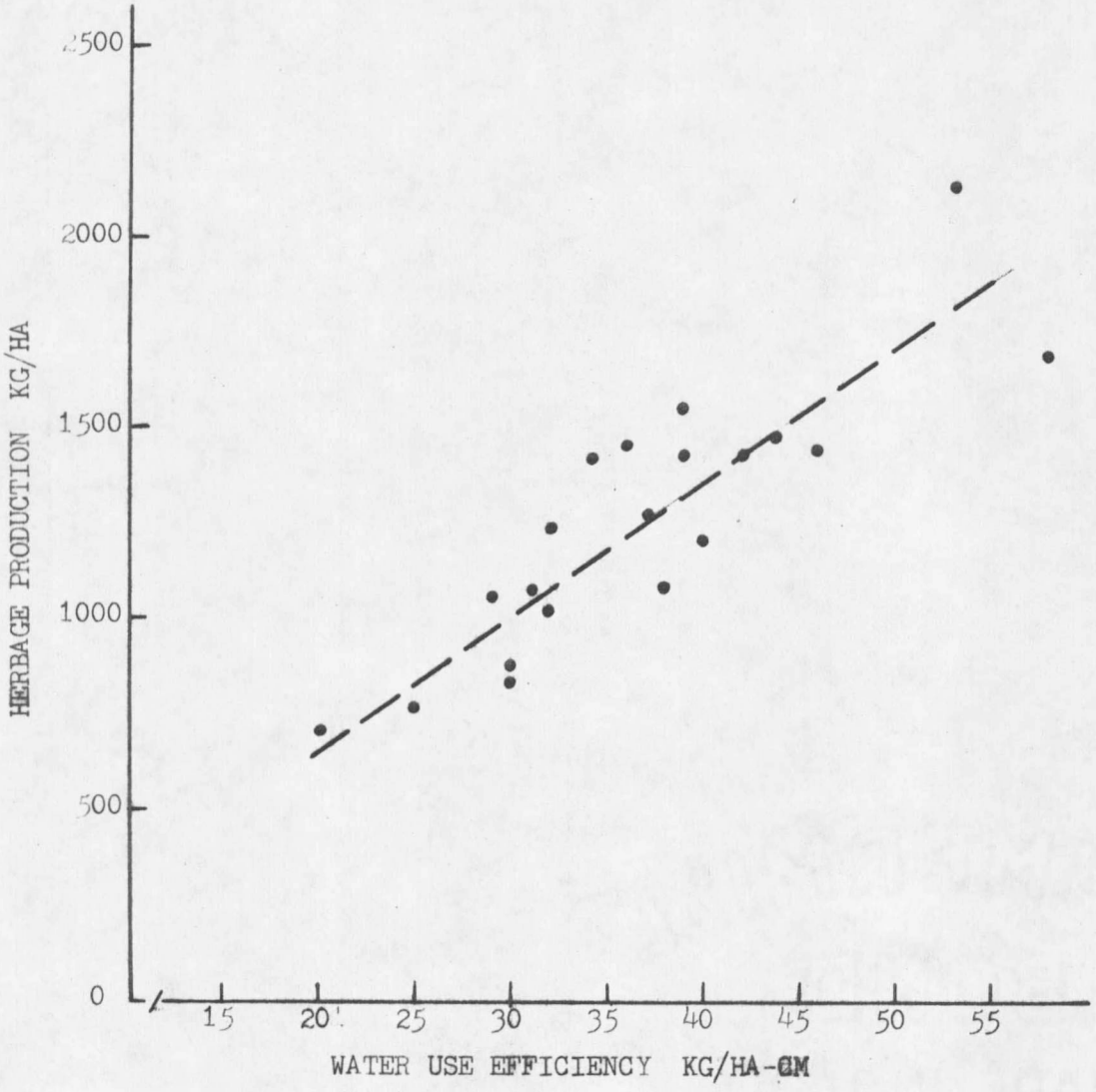


Fig. 15 - Total Herbage production and water use efficiency for 17 clusters at Red Bluff Ranch and 3 clusters north of Belgrade, Mt. 1970

temperature, or available nutrients. Fertility was suggested by Klages and Ryerson (1965) as more limiting than water in range production studies at the Red Bluff Ranch.

CONCLUSIONS AND RECOMMENDATIONS

Demands for water call for an analysis of water use efficiency of the rangeland resource of Western United States. Water use efficiencies ranging from 30 to 58 kg/ha-cm revealed by this study, on sites with similar soil and site characteristics, suggest a need to determine the specific reason or reasons for these differences. Are they pedologic, genetic, cultural, climatic, or mainly an interaction of these? The data in this thesis can be used to plan further studies to answer these questions.

The intensive areal climatic monitoring at the Red Bluff Ranch points to the inadequacy of the present widely spaced, and often convenience located, climatic recording stations for this type of study.

Because soil temperature is an integrator of some other more erratic climatic variables (air temperature-evaporation); and because of its importance in the current soil classification system; it should be incorporated into all soil-vegetation-climatic studies.

To be of greatest value, the water regime of soils needs to be monitored at close intervals during research studies. The gravimetric methods used in this study are not adapted to frequent monitoring, especially for the coarse soils of the Red Bluff Ranch. Water measurements using neutron-scatter or moisture tension methods and using the methods of this study for calibration, would be suitable. This would allow close interval assessments of soil water for all depths of the soil, for several years with a minimum of effort. Yearly climatic extremes dictate

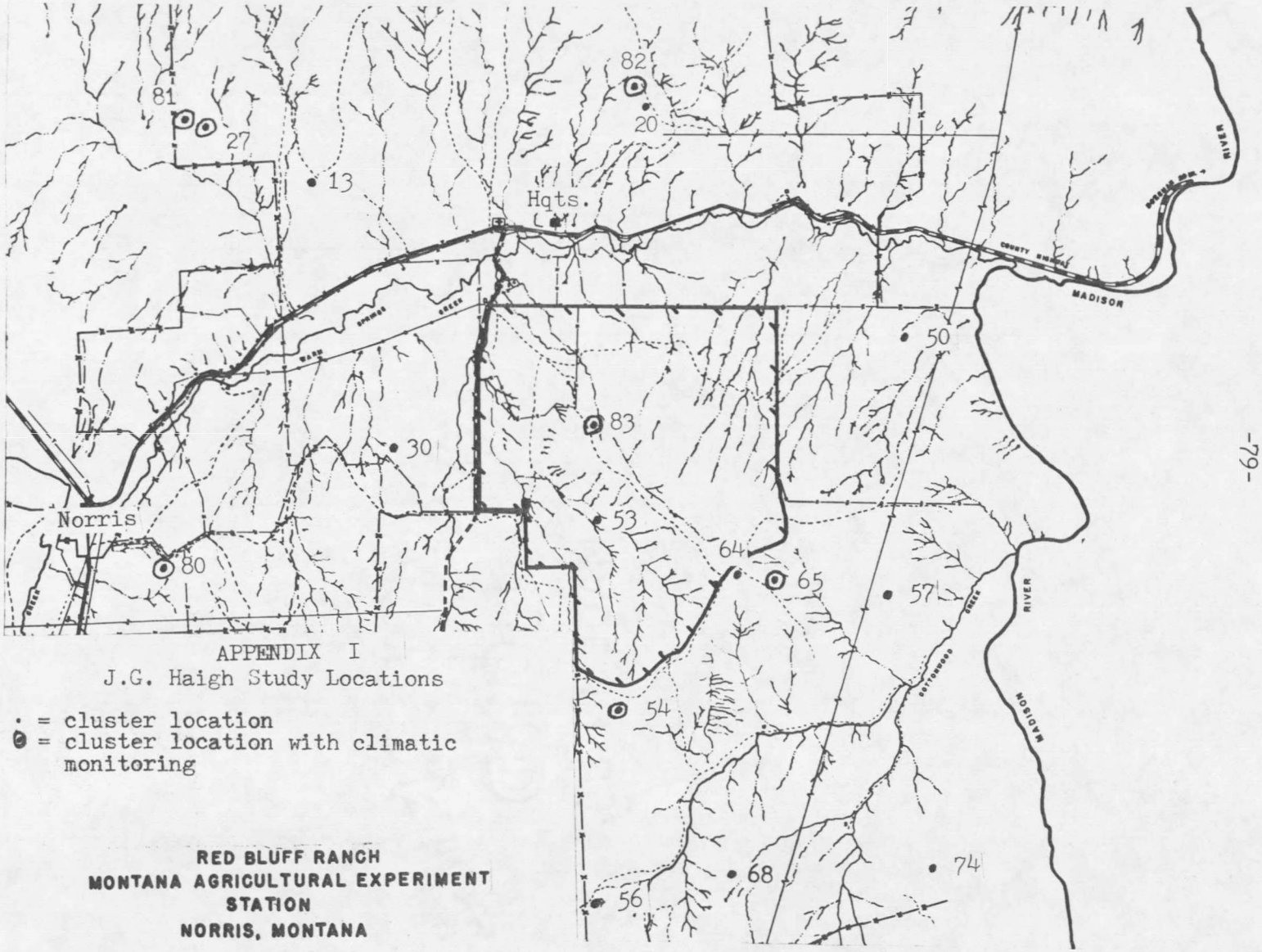
multiple year data.

The soil nitrate data of this study can be considered as benchmarks for native range in good to excellent condition and can be compared with other investigations, especially those concerned with fertilization, forage quality, and groundwater nitrate pollution.

The production data show that high producing sites use less or little more water than low producing sites suggesting something other than water controls the production level.

This study provides soil-site data needed to interpret several years of range production records available for some sites on the Red Bluff Ranch.

APPENDICES



APPENDIX I

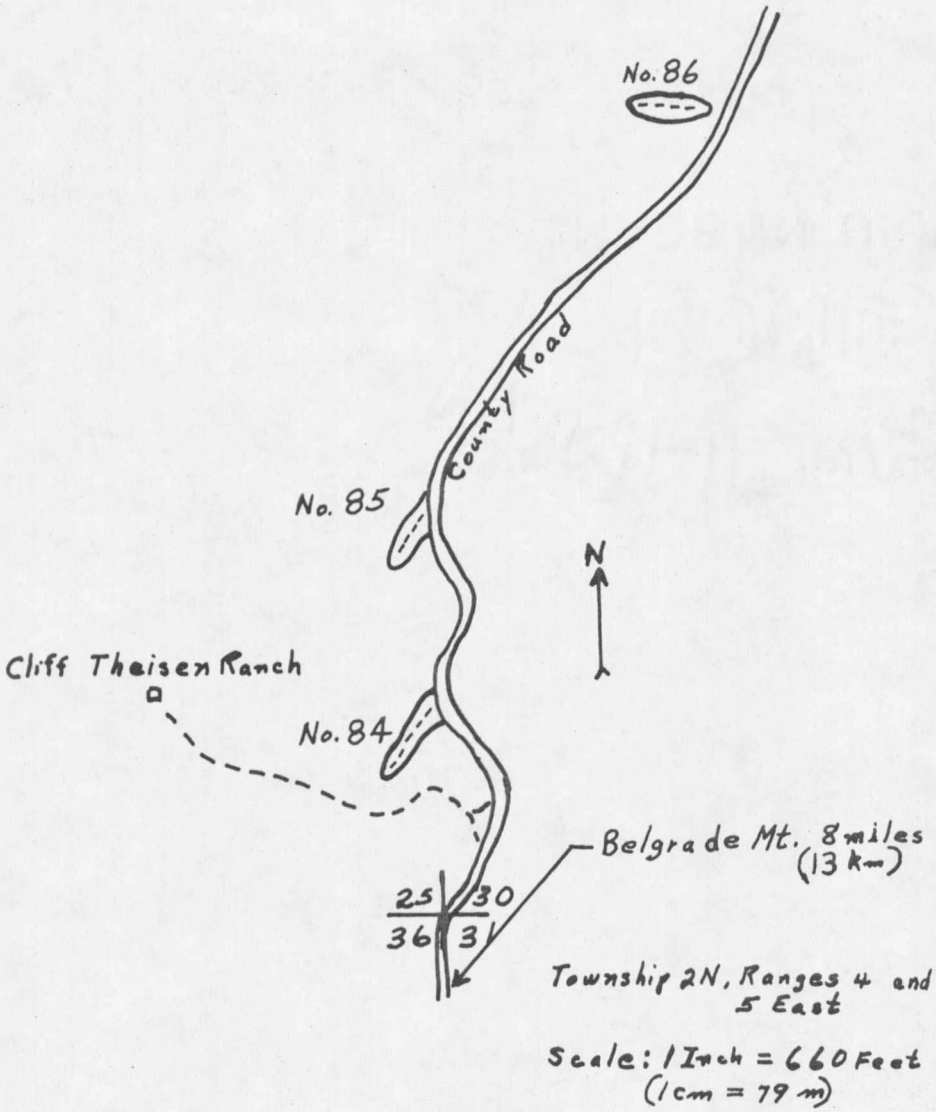
J.G. Haigh Study Locations

• = cluster location

◉ = cluster location with climatic monitoring

RED BLUFF RANCH
MONTANA AGRICULTURAL EXPERIMENT STATION
NORRIS, MONTANA

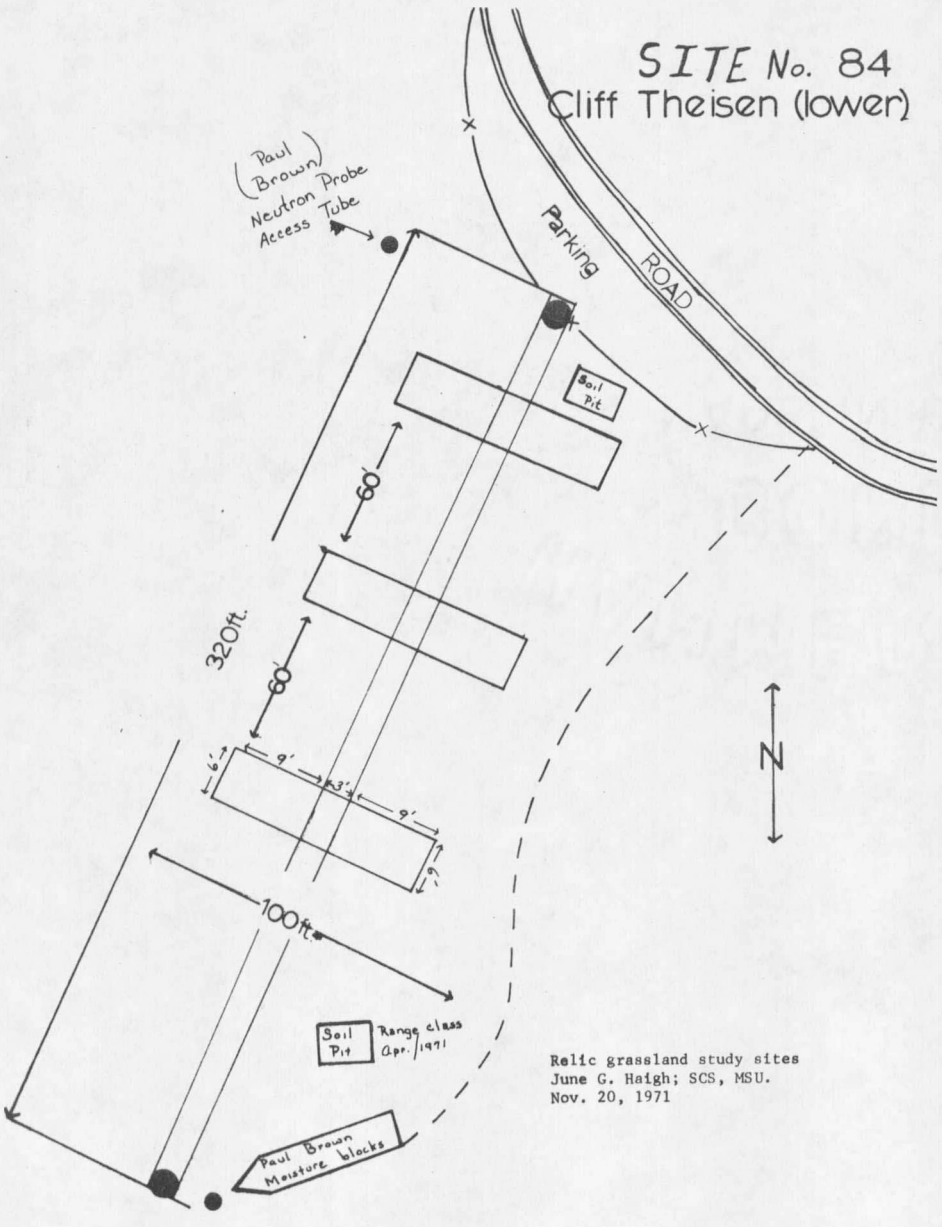
APPENDIX I



North Belgrade Study Sites

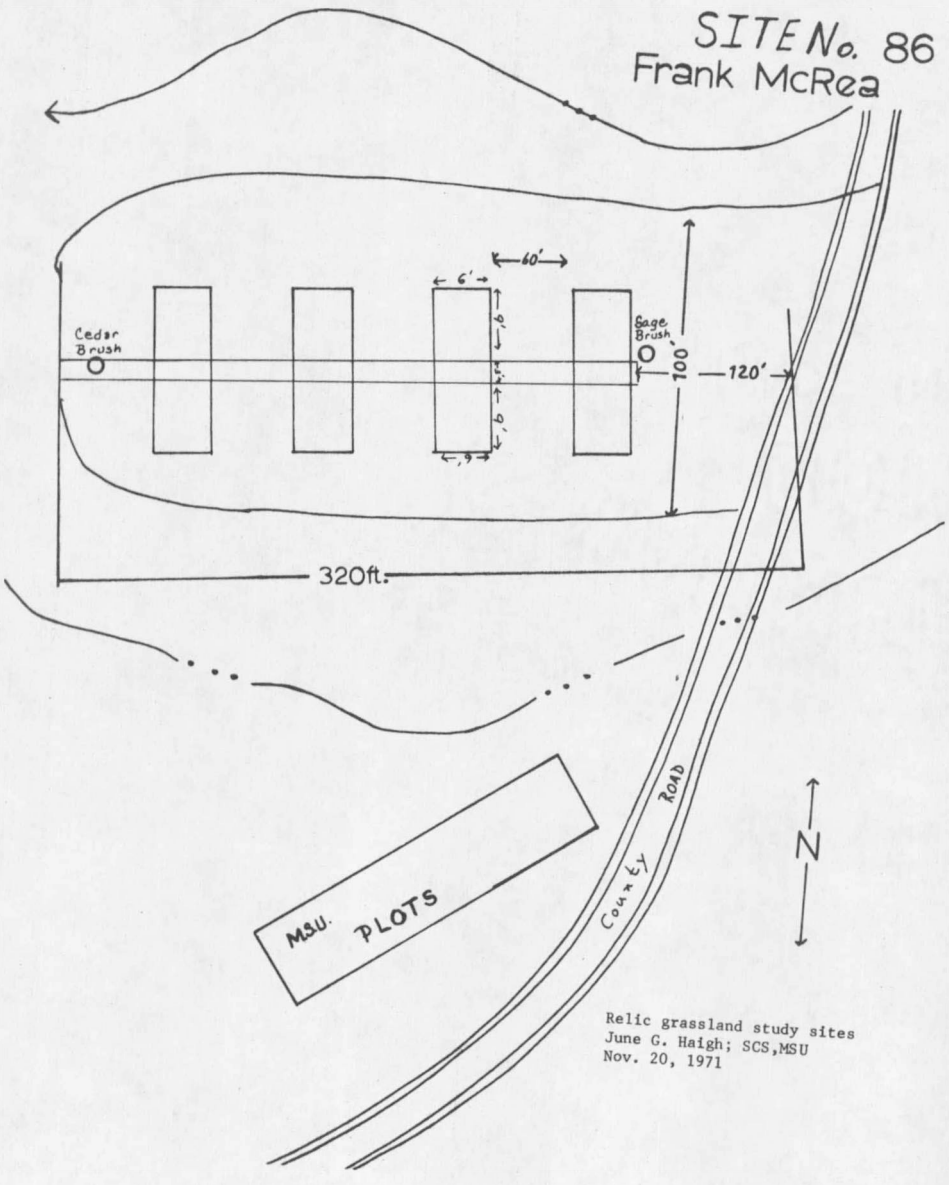
Relic grassland study sites June G. Haigh; SCS, MSU. Nov. 20, 1971

APPENDIX I



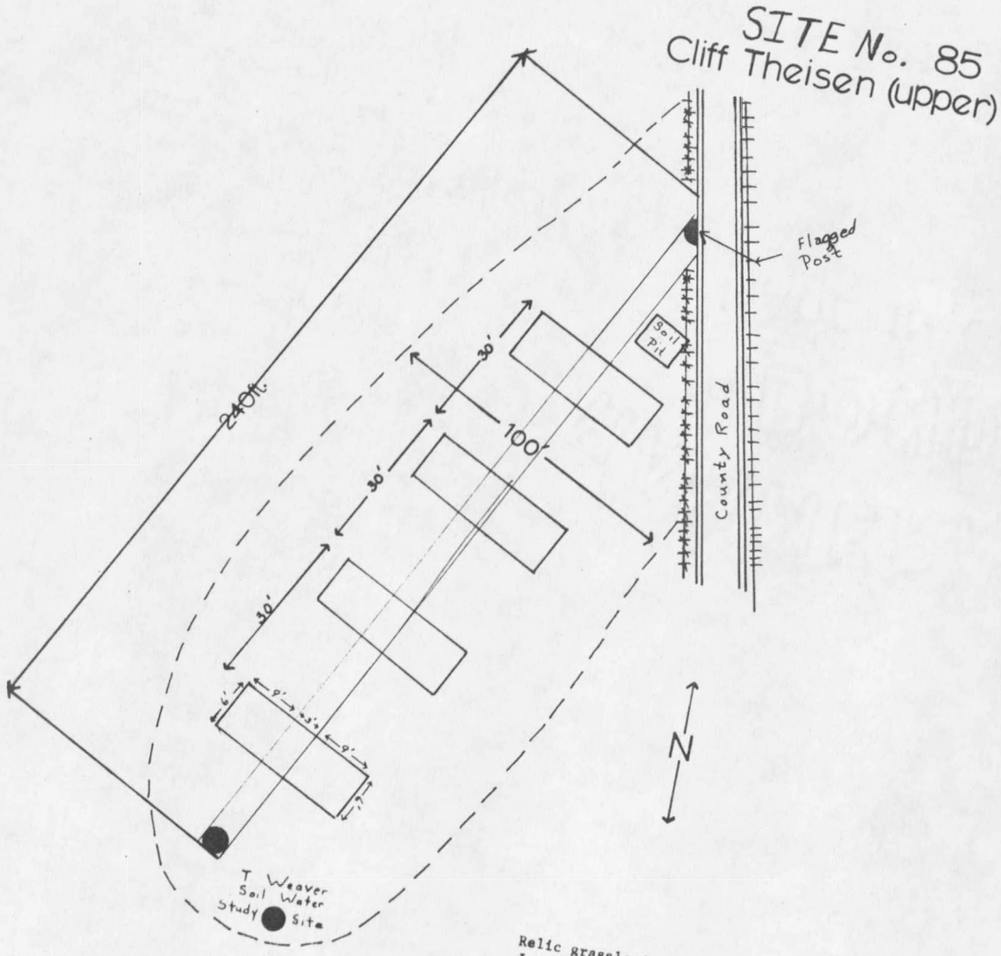
Relic grassland study sites
June G. Haigh; SCS, MSU.
Nov. 20, 1971

APPENDIX I



Relic grassland study sites
June G. Haigh; SCS,MSU
Nov. 20, 1971

APPENDIX I



Relic grassland study sites
June G. Haigh; SCS, MSU.
Nov. 20, 1971

Appendix II

Bulk Density of Sand Used For Excavation Volume Determinations

A bulk supply of sand was obtained from a dry wash on the Red Bluff Ranch and sieved to remove material greater than two mm. The sand had little dust. A Large coffee can was filled ten times with sand; half full at first and settled by stroking lightly with a butcher knife 30 times. The remainder of the volume was then filled and settled once more. The sand was leveled full and weighed. The average weight of settled sand was 5220 grams with a range of less than 2% for the ten samples. The volume of the can was then measured with water and determined to have a capacity of 3200 cc. Thus;

$$\frac{5220g}{3200cc} \doteq \text{BD. } 1.63$$

APPENDIX III

Basic Soil-Water Data

The basic soil water data for 17 clusters at the Red Bluff Ranch, and three clusters north of Belgrade, Mt., Norris, Montana, 1970. The data are arranged by clusters. The dry weight of King tube sample, water loss, and the amount of material greater than 2 mm in diameter are given in cm. The percent water on the basis of the dry weight of fines is calculated as follows:

$$\text{Wt. \% water, fines} = \frac{\text{Wt. of water}}{\text{Sample dry Wt. - Wt. of 2 mm material}} \times 100$$

The percent water by volume adjusted to the amount of fines found in the pit samples was calculated as follows:

$$\text{Vol. \% water fines} = \text{Wt. \% water fines} \times \text{Pit density of fines} \times \text{Vol. \% fines in Pit}$$

For the silty soils north of Belgrade the bulk density of the King tube samples was used rather than a pit excavation density to calculate volume of water. There were no coarse fragments.

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm+(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 13			
5/4	50	0-15	76.3	7.1	2.6	9.6	14.5
		30	69.8	9.2	6.6	14.6	14.1
		61	136.9	12.7	19.5	10.8	12.4
		91	164.7	20.2	9.8	13.0	15.2
		122	148.0	19.5	13.7	14.5	18.1
		152	144.4	17.9	17.2	14.1	18.0
		183	124.1	13.0	8.5	11.3	14.4
	51	0-15	73.5	8.6	3.3	12.3	12.1
		30	76.9	10.4	1.7	13.8	12.8
		61	155.3	17.5	15.3	11.2	12.8
		91	158.6	23.1	2.8	14.8	17.3
		122	121.6	20.8	.9	17.2	21.4
		152	123.7	21.5	1.4	17.6	22.5
		183	122.4	20.4	.1	16.7	21.3
	52	0-15	79.9	12.5	.2	15.7	15.4
		30	80.8	14.2	1.0	17.8	17.2
		61	174.5	29.4	.5	16.9	19.4
		91	169.3	27.5	2.3	16.5	19.3
		122	144.0	12.0	22.9	9.9	12.4
		152	133.2	19.2	.4	14.5	18.5
		183	117.7	17.4	0.0	14.8	18.9
8/21	128	0-15	79.3	1.1	3.4	1.4	1.4
		30	64.2	4.9	4.5	8.2	7.9
		61	162.4	11.1	16.4	7.6	8.7
		91	148.1	6.9	27.5	5.7	6.7
		122	164.9	4.2	36.4	3.3	4.1
		152	135.0	2.8	55.0	3.5	4.5
		183	137.4	3.4	25.7	3.0	3.8
	129	0-15	81.7	1.5	5.7	2.0	2.0
		30	67.4	3.5	1.6	5.3	5.1
		61	146.5	7.5	7.8	5.4	6.2
		91	140.8	9.4	11.5	7.3	8.6
		122	143.6	17.4	14.8	13.5	16.8
		152	107.1	15.3	.5	14.4	18.4
		183	148.8	23.6	2.2	16.1	20.5
	130	0-15	78.8	1.5	3.9	2.0	2.0
		30	70.0	3.3	2.6	4.9	4.7
		61	167.9	21.9	5.7	13.5	15.5
		91	151.9	23.8	25.1	18.8	22.0
		122	121.5	9.5	29.2	10.3	12.8
		152	155.0	24.6	22.9	18.6	23.7
		183	158.3	24.8	17.4	17.6	22.5

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm+(g)	Water % WT. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 20			
4/22	18	0-15	57.1	8.1	0.0	14.2	19.6
		30	47.4	4.7	9.6	12.4	17.1
		61	122.9	13.8	12.1	12.5	17.3
		91	117.0	14.6	11.2	13.8	19.0
		122	133.1	13.4	17.0	11.5	14.1
		152	172.5	8.7	33.0	6.2	3.5
		183	83.9	4.8	6.8	6.2	3.5
	19	0-15	68.0	5.9	7.6	9.8	13.5
		30	60.5	5.1	5.1	9.2	12.7
		61	128.9	10.5	15.3	9.2	12.7
		91	124.4	10.8	16.2	9.9	13.6
		122	143.0	10.4	26.6	8.9	10.9
		152	144.3	9.0	61.9	10.9	6.2
	20	0-15	61.2	5.1	4.0	8.9	12.2
		30	63.3	4.2	7.9	7.6	10.5
		61	138.4	9.4	11.6	7.4	10.2
		91	136.0	11.4	21.7	10.0	13.8
		122	136.0	12.3	23.8	11.0	13.4
		152	136.8	6.8	26.1	6.1	3.5
8/19	111	0-15	51.7	1.1	3.5	2.3	3.1
		30	72.1	1.9	6.1	2.9	4.0
		61	149.2	4.7	22.7	3.7	5.1
		91	165.7	5.7	22.2	4.0	5.5
		122	135.2	4.3	35.3	4.3	5.3
	112	0-15	66.2	1.0	5.3	1.6	2.2
		30	100.5	1.9	10.0	2.1	2.9
		61	172.7	4.6	28.7	3.2	4.4
		91	190.5	4.7	25.4	2.8	3.8
		122	196.4	3.9	30.2	2.3	2.8
	113	0-15	48.8	0.7	2.8	1.5	2.0
		30	93.4	2.4	5.4	2.7	3.7
		61	153.0	6.6	21.3	5.0	6.9
		91	156.3	6.6	11.4	4.9	6.7
		122	150.7	6.1	23.5	4.8	5.8
		152	182.8	6.1	10.9	3.5	2.0
		183	190.7	7.1	39.6	4.7	2.7

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm$^+$(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 27			
4/18	12	0-15	65.6	11.2	2.9	17.9	17.2
		30	31.1	6.7	3.5	24.3	16.1
		61	108.0	14.5	29.1	18.4	22.3
		91	125.4	15.3	20.7	14.6	16.3
		122	107.7	5.4	16.5	5.9	6.6
		152	172.8	10.7	51.3	8.8	9.8
		183	144.3	9.8	32.2	8.7	9.8
	13	0-15	72.0	12.5	6.0	18.9	18.2
		30	54.5	11.3	.2	20.8	23.4
		61	133.2	22.1	21.3	19.8	24.0
		91	146.3	9.8	49.4	10.1	11.3
		122	161.9	16.1	4.3	10.2	11.4
		152	142.9	10.4	31.9	9.4	10.6
	14	0-15	66.8	14.7	4.5	23.6	22.6
		30	65.1	13.0	3.5	21.1	23.8
		61	138.5	24.6	25.0	21.7	26.4
		91	114.4	23.2	35.0	29.2	32.7
		122	122.2	11.8	10.0	10.5	11.8
		152	120.2	8.7	32.1	9.9	11.1
8/21	125	0-15	62.6	3.0	15.1	6.3	6.1
		30	76.9	2.7	33.9	6.3	7.1
		61	147.4	2.2	73.9	3.0	3.7
		91	98.4	1.4	48.3	2.8	3.1
		122	220.7	4.8	104.7	4.1	4.6
		152	285.0	6.9	141.7	4.8	5.4
	126	0-15	57.6	11.7	7.8	23.5	22.6
		30	58.2	6.0	15.1	13.7	15.7
		61	133.0	8.3	39.2	8.8	10.7
		91	148.2	16.2	28.9	13.6	15.2
		122	148.8	15.3	35.6	13.5	15.1
		152	157.3	15.7	71.5	18.3	20.5
		183	140.3	13.8	58.6	16.9	19.0
	127	0-15	61.4	2.9	7.6	5.4	5.2
		30	67.6	7.7	9.3	13.2	14.9
		61	139.6	7.4	28.9	6.7	8.1
		91	131.2	12.5	41.6	14.0	15.7
		122	154.4	5.7	64.1	6.3	7.0
		152	160.3	16.9	52.7	15.7	17.6

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 30			
8/10	92	0-15	54.3	3.8	5	7.7	7.4
		30	70.9	4.1	15	7.3	8.2
		61	139.4	7.9	52	9.0	11.3
		91	147.4	9.4	26	7.7	8.6
		122	153.8	17.7	26	13.8	15.2
		152	127.2	15.9	52	21.1	23.3
		183	153.0	16.8	26	11.0	12.2
	93	0-15	61.5	5.3	8	9.9	9.5
		30	45.3	3.4	21	14.0	15.6
		61	140.1	7.0	65	9.3	11.5
		91	59.2	3.8	26	11.4	12.6
		122	122.6	2.9	26	3.0	3.3
				-watered-			
	94	0-15	59.7	8.2	7	15.6	15.0
		30	67.0	7.4	22	16.4	18.5
		61	174.4	11.8	69	11.3	14.0
		91	136.8	7.8	29	7.2	7.9
		122	110.0	6.6	26	7.9	8.7
		152	143.2	11.3	67	14.8	16.3
		183	139.8	11.3	44	11.8	13.0

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 50			
5/20	64	0-15	56.9	8.2	10.0	17.5	19.5
		30	66.4	13.3	7.2	22.5	22.5
		61	133.8	17.4	36.8	17.9	16.2
		91	145.4	19.2	47.1	19.5	16.5
		122	150.5	35.9	18.1	27.1	25.3
		152	147.5	26.4	4.2	18.4	21.9
	65	0-15	57.5	8.9	10.7	19.0	21.2
		30	68.8	12.1	2.7	18.3	18.3
		61	108.9	13.7	48.1	22.5	20.4
		91	150.4	14.4	58.2	15.6	13.2
		122	61.8	6.1	33.5	21.6	20.1
		152	86.8	8.9	33.0	16.5	19.6
	66	0-15	52.3	8.0	10.4	19.1	21.3
		30	56.0	8.1	5.0	15.9	15.9
		61	125.6	34.0	42.5	40.9	37.1
		91	137.9	32.3	52.7	37.9	32.0
		122	146.6	16.0	63.1	19.2	18.0
		152	157.9	9.4	72.2	11.0	13.1
		183	153.8	13.7	68.6	16.1	19.0
8/25	137	0-15	53.3	2.3	9.8	5.3	5.9
		30	55.8	4.1	14.1	9.8	9.8
		61	113.6	6.0	23.4	6.7	6.1
		91	156.1	9.8	50.7	9.3	7.8
		122	160.9	26.1	30.1	20.2	18.9
		152	122.1	16.3	16.6	15.5	19.3
	138	0-15	70.8	2.5	20.4	5.0	5.6
		30	66.8	4.3	7.2	7.2	7.2
		61	144.0	5.8	66.0	7.4	6.7
		91	156.4	9.1	55.3	9.0	7.6
		122	153.6	11.4	61.5	11.2	10.4
		152	155.0	13.1	77.2	16.8	19.9
	139	0-15	50.8	1.0	18.3	3.1	3.5
		30	67.8	3.6	14.4	6.7	6.7
		61	106.6	6.7	43.7	10.7	9.7
		91	141.1	16.0	24.1	13.7	11.6
		122	160.0	13.4	72.1	15.2	14.2
		152	147.4	12.0	69.1	15.3	18.2

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm$^+$(g) CLUSTER	Water % Wt. Fine 53	Water % Vol. Adj. Pit Fines
5/20	61	0-15	56.9	10.2	8.9	21.7	24.2
		30	74.3	10.9	10.8	17.2	17.3
		61	141.6	24.9	54.5	28.6	25.9
		91	138.4	21.7	43.8	22.9	19.4
		122	139.2	19.8	51.6	22.6	21.1
		152	129.0	16.0	63.3	24.4	28.9
	62	0-15	67.4	10.7	15.2	20.5	22.8
		30	62.6	8.4	19.1	19.3	19.3
		61	152.1	28.8	40.6	25.8	23.3
		91	151.5	30.7	39.6	27.4	23.1
		122	158.9	20.9	64.5	22.1	20.7
		152	153.8	17.5	48.2	16.6	19.7
		183	160.0	10.5	43.3	9.0	10.6
	63	0-15	52.5	8.2	11.7	20.1	22.4
		30	68.3	10.5	7.5	17.3	17.3
		61	140.3	22.5	34.5	21.3	19.2
		91	111.5	20.6	40.7	29.1	24.6
		122	132.5	17.3	51.7	21.4	20.0
		152	170.1	17.5	67.1	17.0	20.1
		183	146.3	8.9	51.0	9.3	11.0
8/25	143	0-15	60.7	2.0	10.8	4.0	4.4
		30	46.0	3.5	5.1	8.6	8.6
		61	101.6	5.9	43.6	10.2	9.2
		91	142.1	15.8	38.5	15.3	12.9
	144	0-15	68.1	1.8	9.2	3.1	3.5
		30	70.0	4.1	22.5	8.6	8.6
		61	128.5	9.8	36.6	10.7	9.7
		91	108.9	12.5	56.8	24.0	20.2
		122	203.1	9.7	90.6	8.6	8.0
		152	159.5	14.2	77.3	17.3	20.4
	145	0-15	63.6	1.7	10.3	3.2	3.6
		30	184.1	7.6	34.6	5.1	5.1
		61	119.7	8.4	31.8	9.6	4.7
		91	165.6	18.5	70.1	19.4	16.3
		122	152.5	24.2	58.6	25.8	54.1

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 54			
5/4	37	0-15	56.5	11.4	11.1	25.1	25.0
		30	67.9	11.2	16.0	21.6	20.9
		61	118.6	13.7	44.7	10.9	12.5
		91	146.7	12.7	35.6	11.4	13.4
		122	136.5	13.3	33.7	12.9	16.0
		152	170.2	9.3	45.8	7.5	9.6
		183	144.5	11.8	2.8	8.3	10.6
	38	0-15	56.8	12.2	9.9	26.0	25.5
		30	73.2	10.8	26.5	23.1	22.4
		61	156.7	18.0	51.3	17.9	20.6
		91	103.0	7.0	30.0	9.6	11.3
		122	172.9	17.9	32.1	12.7	15.8
		152	145.6	14.8	34.0	13.3	17.0
		183	160.5	16.3	43.0	13.9	17.8
	39	0-15	39.4	9.1	12.5	33.8	33.2
		30	54.0	5.7	27.1	21.1	20.6
		61	151.4	20.9	56.0	21.9	25.2
		91	126.2	14.7	64.3	23.7	27.8
		122	113.5	14.6	44.5	21.1	26.3
		152	139.9	10.2	61.0	12.9	16.5
8/19	118	0-15	64.6	2.3	13.4	5.6	5.5
		30	69.1	3.0	23.8	6.6	6.4
		61	171.8	4.9	88.5	5.9	6.8
		91	182.9	8.5	55.8	6.7	7.9
		122	164.2	5.1	60.4	4.9	6.1
		152	94.0	2.3	33.7	3.8	4.9
	117	0-15	59.9	1.9	12.2	4.0	3.9
		30	85,8	3.9	23.7	6.3	6.1
		61	168.2	5.4	51.0	4.6	5.3
		91	173,9	5.5	22.6	3.6	4.2
		122	168.1	9.2	30.2	6.7	8.3
		152	179.4	15.9	19.2	9.9	12.7
		183	159.7	14.8	15.9	10.3	13.2

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 54--continued			
8/19	119	0-15	55.9	2.5	14.6	6.1	6.0
		30	80.4	4.0	28.5	7.7	7.5
		61	148.7	6.4	49.6	6.5	7.4
		91	141.2	7.6	48.4	8.2	9.6
		122	140.9	7.7	75.0	11.7	14.5
		152	108.5	9.5	54.9	17.7	22.6
6/22	74	0-15	50.2	5.7	12.9	15.3	15.0
		30	65.3	7.8	15.5	15.7	15.2
		61	146.7	17.8	34.9	15.9	18.2
		91	154.5	8.8	53.9	8.7	10.2
		122	130.9	10.6	34.4	12.3	15.2
		152	125.8	9.4	28.9	9.7	12.4
		183	154.5	14.5	39.6	12.6	16.1
	75	0-15	49.5	5.3	8.2	12.8	13.1
		30	50.7	4.6	15.7	13.1	12.7
		61	80.5	8.2	14.9	12.5	14.3
		91	170.3	14.0	17.4	9.2	10.8
		122	145.7	19.1	6.4	13.7	17.0
		152	171.9	12.2	21.7	8.1	10.4
				watered			
8/12	120	0-15	36.2	5.5	8.7	20.0	19.6
		30	61.9	8.3	26.8	23.6	22.9
		61	141.2	11.5	52.4	13.0	14,9
		91	112.1	4.6	35.5	6.0	7.0
		122	123.8	18.5	49.8	25.0	31.0
		152	141.7	19.0	23.6	16.1	20.6
		183	168.5	19.5	32.2	14.3	18.3

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm$^+$ (g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
					CLUSTER 56		
5/13	34	0-15	45.9	14.1	4.5	34.8	34.3
		30	63.7	8.7	17.5	18.8	18.2
		61	143.6	28.4	15.1	22.1	25.4
		91	142.3	13.2	30.6	11.8	13.8
		122	148.4	12.2	46.2	11.9	14.9
		152	164.6	14.1	51.0	12.4	15.8
		183	172.6	14.5	36.6	10.7	13.6
	35	0-15	49.8	13.2	6.1	30.2	29.7
		30	67.6	9.7	6.1	18.3	23.6
		61	148.2	14.7	45.6	14.3	16.4
		91	129.1	11.5	39.2	12.8	15.0
		122	103.5	8.5	36.0	12.6	15.7
		152	111.2	9.2	48.9	14.8	18.9
		183	156.1	14.6	66.1	16.2	20.7
	36	0-15	52.3	5.7	7.7	12.8	12.6
		30	63.0	10.7	19.6	24.7	23.8
		61	142.1	19.1	39.5	18.6	21.3
		91	157.9	11.7	60.5	12.0	14.0
		122	163.3	10.9	67.5	11.4	14.2
		152	167.9	13.3	50.4	11.3	14.4
		183	157.8	12.9	45.6	11.5	14.7
8/25	146	0-15	60.6	2.1	9.2	4.1	4.0
		30	70.5	3.2	10.4	5.3	5.1
		61	184.3	6.1	55.2	4.7	5.4
		91	174.6	5.2	61.4	4.6	5.4
		122	189.6	7.3	74.9	6.4	7.9
		152	189.2	8.7	60.3	6.7	8.6
	147	0-15	60.0	1.7	13.9	3.7	3.6
		30	63.8	2.4	17.7	5.2	5.0
		61	177.2	5.2	36.1	3.7	4.2
		91	154.7	5.0	57.7	5.2	6.0
		122	170.6	4.7	76.6	5.0	6.2
		152	178.4	6.6	47.9	5.1	6.5
					CLUSTER 57		
8/15	109	0-15	66.5	5.5	12.2	10.1	13.9
		30	102.0	6.8	20.9	8.4	11.5
		61	82.0	5.8	21.9	9.7	13.3
		91	135.2	6.4	17.4	5.5	7.5
		122	148.1	6.8	29.5	5.7	7.0
		152	225.4	8.8	47.0	4.9	2.8

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
					CLUSTER 57		
8/15	110	0-15	76.9	5.6	13.1	8.8	12.1
		30	111.9	7.0	31.4	8.7	12.0
		61	180.2	9.2	41.8	6.6	9.2
		91	154.6	7.2	31.6	5.9	8.1
		122	124.3	6.9	13.5	6.8	8.4
		152	161.9	7.8	20.2	5.5	3.1
					CLUSTER 64		
8/14	Hand Dug	0-15	3762	118.	830.	4.0	5.5
		30	6812	208	2780	5.2	5.3
		61	15312	413	8010	5.7	4.9
		91	6920	150	2280	3.2	3.9
		122	16970	375	9020	4.7	4.3
		152	7908	252	2425	4.6	6.3

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 65			
5/6	28	0-15	50.2	4.3	2.9	10.0	13.8
		30	49.8	3.8	12.6	10.2	14.0
		61	130.1	5.4	18.0	4.8	6.6
		91	89,5	6.8	21.2	10.0	13.6
		122	152.5	7.0	50.8	6.9	8.4
		152	139.5	6.4	32.4	6.0	3.4
	29	0-15	65.9	8.7	9.1	15.3	21.1
		30	62.3	5.8	9.8	11.0	15.1
		61	137.9	18.7	17.0	15.5	21.3
		91	138.0	11.4	45.4	12.3	16.9
		122	77.3	2.1	30.7	4.5	5.5
		152	136.5	5.6	34.6	5.5	3.1
	30	0-15	44.5	6.6	7.1	17.6	24.2
		30	69.1	7.0	13.0	12.5	17.3
		61	148.5	12.1	43.6	11.5	15.8
		91	160.0	15.3	20.2	10.9	15.0
		122	141.9	6.4	22.7	5.4	6.6
		152	138.0	6.0	33.5	5.7	3.2
8/19	114	0-15	71.8	.9	13.8	1.6	1.1
		30	85.4	1.5	15.2	2.1	2.9
		61	155.2	3.0	29.1	2.4	3.3
		91	126.9	2.5	26.3	2.5	3.5
		122	271.5	4.4	60.7	2.1	2.6
		152	180.3	5.7	49.7	4.4	2.5
	115	0-15	75.1	1.3	10.8	2.0	2.7
		30	82.8	1.9	9.7	2,6	3.6
		61	162.0	6.6	21.9	4.7	6.5
		91	158.6	5.1	50.1	4.7	6.5
		122	233.7	3.3	59.6	1.9	2.3
		152	194.6	4.8	50.7	3.3	1.9

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm+ (g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 65 -- continued			
8/19	116	0-15	69.1	1.1	10.7	1.9	2.6
		30	92.6	1.9	13.8	2.4	3.3
		61	179.7	5.2	32.8	3.4	4.7
		91	172.0	2.1	47.3	1.7	2.4
		122	195.8	2.1	58.4	1.5	1.9
		152	208.2	4.5	51.6	2.9	1.7
6/22	76	0-15	55.0	2.8	10.7	6.3	8.7
		30	60.7	3.6	13.6	7.6	10.5
		61	100.9	6.9	19.1	8.4	11.6
		91	134.3	9.0	36.0	9.2	12.7
		122	178.2	13.4	39.5	9.0	11.0
		152	97.8	4.5	23.1	6.0	3.4
	77	0-15	62.7	3.9	10.4	7.5	10.4
		30	71.2	5.3	14.0	9.3	12.8
		61	123.9	15.9	34.2	17.7	24.4
		91	137.6	11.5	73.1	17.8	24.5
		122	121.9	5.7	29.7	6.2	7.6
		152	185.3	6.2	50.2	4.6	2.6
		183	121.9	3.3	42.8	4.2	2.4
				WATERED PROFILE			
7/		0-15	179.5	16.9	33.4	11.6	15.7
		30	185.9	15.3	31.8	9.9	12.7
		91	281.7	23.5	51.1	10.2	13.0
		122	7080.0	265.0	2280.0	5.5	8.3
		152	15285.0	740.0	10275.0	14.8	18.6

APPENDIX III continued

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	$+2$ mm (g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 68			
5/20	56	0-15	53.3	6.5	12.8	16.0	21.5
		30	64.6	6.6	34.0	21.6	29.1
		61	164.9	10.2	53.6	9.2	12.4
		91	158.2	6.8	43.6	5.9	8.0
		122	88.7	2.5	44.7	5.7	7.0
		152	184.5	7.1	75.6	6.5	3.7
		183	175.3	5.4	88.1	6.2	3.5
	57	0-15	58.6	6.4	15.9	15.0	20.2
		30	70.1	8.9	23.9	19.3	26.0
		61	142.3	11.2	80.3	18.1	24.3
		91	102.3	7.6	45.8	13.5	18.2
		122	124.1	6.4	69.6	11.7	14.3
		152	78.7	4.2	32.1	9.0	5.1
	58	0-15	65.5	9.3	21.7	21.2	28.5
		30	77.3	6.4	36.6	15.7	21.1
		61	154.6	6.6	48.8	6.2	8.4
		91	135.6	6.3	43.8	6.9	9.3
		122	130.8	5.8	18.2	5.2	6.4
		152	55.1	1.7	15.0	4.2	2.4
8/23	134	0-15	47.7	.5	17.5	1.7	2.3
		30	71.0	2.8	23.5	5.9	8.0
		61	178.1	2.8	38.6	2.0	2.7
		91	140.9	3.0	13.8	2.4	3.2
		122	184.2	3.1	75.1	2.8	3.4
		152				2.8	1.6
	135	0-15	46.3	.3	13.4	1.0	1.3
		30	77.8	2.6	15.5	4.2	5.6
		61	136.2	5.4	44.1	5.9	8.0
		91	196.4	5.0	61.1	3.7	5.0
		122				3.7	4.5
		152				3.7	2.1
	136	0-15	39.4	.5	6.8	1.5	2.0
		30	65.9	1.8	23.3	4.2	5.6
		61	215.1	3.6	61.0	2.3	3.1
		91	172.2	3.7	54.9	3.1	4.2
		122	229.5	8.6	146.5	4.6	6.9
		152				4.6	2.7

Date	Core	Depth cm	Weight Dry-g	Water Loss-g	2 mm$^+$(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 74			
5/20	53	0-15	54.9	10.0	10.3	22.4	22.1
		30	52.8	6.3	11.7	15.3	14.7
		61	142.5	18.9	23.8	15.9	18.2
		91	162.4	18.4	43,3	15.4	18.0
		122	134,8	15.8	28.4	14.9	18.6
		152	147.4	10.4	73.1	14.0	17.9
		183	159.8	12.2	86.6	16.7	21.3
	54	0-15	40.1	9.9	10.4	33.3	32.8
		30	55.0	10.4	13.8	25.2	24.3
		61	154.9	17.9	52.6	17.5	20.1
		91	173.6	20.3	31.8	14.3	16.8
		122	168.0	17.4	72.7	18.3	22.8
		152	161.6	20.2	57.7	19.4	24.8
		183	134.9	9.2	52.5	11.2	14.3
	55	0-15	53.8	12.5	10.0	28.5	28.1
		30	65.2	8.5	12	16.0	15.4
		61	141.0	16.9	38	16.4	18.8
		91	162.1	18.8	37	15.0	17.6
		122	159.7	17.3	50	15.8	19.7
		152	152.1	12.6	65	14.5	18.5
		183	153.4	17.6	65	20.9	26.7
8/23	133	0-15	52.9	1.1	13.3	2.8	2.7
		30	66.5	1.6	11.5	2.9	2.8
		61	163.2	5.9	34.9	4.6	5.3
		91	142.8	5.9	43.7	6.0	7.0
		122	154.9	6.5	39.6	5.6	6.9
		152	191.6	9.8	64.4	7.7	9.8
	132	0-15	46.0	1.7	7.8	4.5	4.4
		30	71.3	2.8	27.7	6.4	6.2
		61	175.2	5.4	40.5	4.0	4.6
		91	174.8	7.1	55.4	5.9	6.9
		122	186.9	10.5	21.1	6.3	7.8
		152	167.0	14.6	54.1	12.9	16.5
	131	0-15	49.6	1.7	12.6	4.6	4.6
		30	79.1	3.5	24.3	6.4	6.2
		61	176.9	6.1	41.3	4.5	5.2
		91	185.5	11.1	41.5	7.7	9.0
		122	182.5	12.3	53.4	9.5	11.8
		152	161.8	9.0	34.4	7.1	9.0
		183	167.6	14.6	51.5	12.6	16.1

Date	Core	Depth cm	Weight Drying	Water Loss	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 80			
4/18	9	0-15	66.8	12.9	8.1	22.0	21.1
		30	69.3	10.5	7.6	17.0	19.2
		61	124.2	17.3	22.1	16.9	21.3
		91	141.6	13.0	32.0	11.9	13.4
		122	113.0	8.5	25.9	9.8	11.0
		152	134.4	10.0	12.2	8.2	9.2
		183	134.2	9.7	9.3	7.8	8.7
	10	0-15	60.4	12.2	7.3	23.0	22.1
		30	61.5	11.7	7.1	21.5	24.2
		61	132.9	16.9	25.8	15.8	12.8
		91	134.1	10.3	43.4	11.4	12.8
		122	144.2	10.2	35.8	9.4	10.6
		152	136.0	9.4	13.7	7.7	8.6
		183	149.5	11.2	25.5	9.0	10.1
	11	0-15	69.0	11.4	6.4	18.2	17.4
		30	58.5	9.0	6.5	17.3	19.4
		61	141.1	20.9	29.4	18.7	23.6
		91	156.0	12.0	54.7	11.8	13.2
		122	154.4	8.0	44.7	7.3	8.2
		152	134.0	9.7	28.4	9.2	10.3
		183	134.0	9.7	28.4	9.2	10.3
8/7	89	0-15	57.6	4.2	16.2	10.1	9.7
		30	48.0	4.1	9.2	10.6	12.0
		61	124.4	9.6	40.3	11.4	14.1
		91	159.0	6.6	66.2	7.1	7.9
		122	99.0	6.0	32.4	9.0	10.1
		152	165.0	17.5	41.7	14.2	15.9
		183	139.6	13.2	3.7	9.7	10.9
	90	0-15	51.5	3.2	18.7	9.8	9.4
		30	62.7	5.8	10.5	10.9	12.2
		61	135.0	8.7	33.1	8.5	10.7
		91	142.6	7.5	42.8	7.5	8.4
		122	155.8	10.8	36.9	9.1	10.2
		152	132.0	7.8	50.1	9.5	10.6
		183	170.4	15.3	53.7	13.1	14.6
	91	0-15	59.7	4.3	17.7	10.2	9.8
		30	54.2	5.3	13.0	12.9	14.5
		61	132.8	10.8	36.2	11.2	14.1
		91	156.2	9.1	45.9	8.3	9.3
		122	167.0	6.3	51.2	5.4	6.1
		152	177.6	14.2	61.1	12.9	14.5
		183	163.6	14.8	55.0	13.6	15.2

APPENDIX III continued

Date	Core	Depth cm	Weight Drying	Water Loss	2 mm+ (g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 81			
4/18	15	0-15	63.7	14.1	3.9	23.6	30.3
		30	55.1	11.7	3.1	22.5	28.9
		61	137.1	23.5	13.1	19.0	24.4
		91	120.6	19.4	5.9	16.9	7.6
		122	116.2	14.0	41.9	18.8	9.4
		152				13.0	6.5
	16	0-15	63.4	13.1	3.2	21.8	27.9
		30	34.6	7.9	.8	23.4	30.0
		61	115.1	24.2	12.5	23.6	30.3
		91	143.7	18.2	62.5	22.4	10.1
		122				15.0	7.5
		152				13.0	6.5
	17	0-15	61.0	15.3	.7	25.4	32.6
		30	51.0	10.8	.1	21.2	27.2
		61	87.8	13.6	.2	15.5	19.9
		91	134.1	14.3	6.0	11.2	5.0
		122	110.1	10.8	24.3	12.6	6.3
		152				13.0	6.5
8/21	122	0-15	46.4	2.2	6.0	5.4	6.9
		30	59.5	5.6	10.9	11.5	14.7
		61	123.7	6.8	52.3	9.5	12.2
		91	155.0	14.3	44.7	13.0	5.9
		122	166.8	22.2	49.6	18.9	9.5
		152	124.3	10.1	34.4	11.2	5.6
	123	0-15	52.1	2.9	6.8	6.4	8.2
		30	55.2	4.6	8.3	9.8	12.5
		61	125.0	8.9	77.9	18.9	24.2
		91				15.9	7.2
		122	115.7	4.8	83.9	15.9	8.0
		152	56.6	3.6	35.4	17.0	8.5
	124	0-15	57.5	2.4	3.8	4.5	7.1
		30	63.6	5.2	7.2	9.2	11.8
		61	100.1	7.6	14.9	8.9	11.4
		91	133.3	16.6	22.9	15.0	6.8
		122	136.8	15.1	29.8	14.1	7.1
		152	126.4	8.8	58.4	11.3	5.7

APPENDIX III continued

Date	Core	Depth cm	Weight Drying	Water Loss	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 82			
4/18	21	0-15	58.5	9.8	3.1	17.7	22.9
		30	64.1	11.6	4.5	19,5	25.3
		61	140.8	21.2	7.8	15.9	20.6
		91	137.7	11.6	21.5	10.0	13.0
		122	145.3	7.9	24.9	6.6	8.1
		152	157.8	8.2	21.0	6.0	7.3
		183	176.8	4.4	17.2	2.8	3.4
	22	0-15	68.2	10.0	2.5	15.2	19.7
		30	67.9	11.2	3.3	17.3	22.4
		61	133.7	22.2	17.5	19.1	24.8
		91	149.7	18.5	15.1	13.7	17.8
		122	179.9	4.6	19.1	2.9	3.6
		152	181.1	4.4	23.7	2.8	3.4
		183	138.3	6.7			
	23	0-15	67.0	10.7	4.1	17.0	22.0
		30	67.4	7.1	2.1	10.9	14.1
		61	128.2	16.7	11.1	14.3	18.5
		91	141.6	16.9	9.1	12.8	16.6
		122	134.0	15.7	10.7	12.7	15.5
		152	199,1	5.9	35.3	3.6	4.4
	24	0-15	62.5	13.0	.4	20.9	27.1
		30	56.9	13.4	2.1	24.5	31.8
		61	121.3	32.5	22.7	33.0	42.8
		91	149.2	15.8	3.3	10.8	14.0
		122	150.8	10.4	17.0	7.8	9.5
		152	137.4	5.9	10.2	4.6	5.6
		183	189.6	7.6	26.5	4.7	5.8
8/13	96	0-15	67.5	2.6	2.4	4.0	5.2
		30	68.7	4.1	3.4	6.3	8.2
		61	128.6	4.5	17.8	4.0	5.2
		91	169.0	6.6	17.1	4.3	5.3
		122	127.7	5.1	13.5	4.5	5.5
		152	196.6	8.0	25.8	4.7	5.8

APPENDIX III continued

Date	Core	Depth cm	Weight Drying	Water Loss	+ 2 mm (g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 82- con't			
8/13	150	0-15	64.6	2.5	1.6	4.0	5.2
		30	62.5	4.6	3.6	7.8	10.1
		61	140.7	5.9	27.7	5.2	6.7
		91	191.3	4.0	31.3	2.5	3.1
		122	165.5	5.2	9.7	3.3	4.1
WETTED SOIL							
		0-15	59.4	9.3	2.1	16.2	21.0
		30	49.5	7.8	2.4	16.6	21.5
		61	143.5	16.9	18.8	13.6	17.6
		91	148.3	6.7	15.0	5.0	6.2
		122	131.0	8.6	13.9	7.3	8.9
		152	136.3	8.3	17.9	7.0	8.6
		183	181.8	10.6			
6/22	72	0-15	56.9	6.6	4.9	12.7	16.5
		30	62.8	8.9	20.4	21.0	27.2
		61	165.7	7.9	31.0	5.9	7.7
		91	146.5	7.1	10.4	5.2	6.8
		122	159.8	8.9	12.9	6.5	8.0
		152	178.9	8.7	10.5	5.2	6.4
		183	116.7	5.4	14.4	5.3	6.5
	73	0-15	63.3	5.7	4.0	9.6	12.4
		30	57.9	10.3	1.4	18.2	23.6
		61	140.1	18.6	10.9	14.4	18.6
		91	171.0	9.0	15.9	5.8	8.4
		122	181.1	6.2	36.3	4.3	5.3
		152	174.3	15.4	20.5	10.0	12.2
		183	175.9	12.3	19.5	7.9	9.7
				CLUSTER 83			
5/20	67	0-15	72.0	11.4	11.6	18.9	18.6
		30	52.4	8.4	6.3	18.2	17.6
		61	143.2	11.4	44.7	11.6	13.3
		91	87.9	6.1	31.5	10.8	12.6
		122	121.9	12.3	24.0	12.6	15.7
		152	147.5	14.0	15.7	10.6	13.3
		183	189.1	13.2	39.1	8.8	11.2

APPENDIX III continued

Date	Core	Depth cm	Weight Drying	Water Loss	2 mm^{+}(g)	Water % Wt. Fine	Water % Vol. Adj. Pit Fines
				CLUSTER 83- con't			
5/20	68	0-15	56.2	8.5	5.8	16.9	16.6
		30	67.0	10.4	11.9	18.8	18.2
		61	90.8	8.1	15.4	12.4	14.3
		91	140.9	15.8	43.0	16.1	18.9
		122	145.3	11.4	51.7	12.2	15.2
		152	148.8	13.5	49.4	13.6	17.4
		183	57.7	2.4	38.0	12.2	15.6
	69	0-15	53.2	8.8	11.4	21.1	21.3
		30	65.5	9.6	12.1	18.0	17.4
		61	144.9	27.2	38.8	25.6	29.4
		91	110.1	12.9	36.1	17.4	20.4
		122	144.9	13.5	38.5	12.7	15.8
		152	80.0	5.9	34.0	12.8	16.3
		183	136.3	8.4	38.0	8.5	10.8
8/25	148	0-15	47.8	2.2	4.9	5.1	5.0
		30	63.9	3.9	3.5	6.5	8.3
		61	132.6	8.2	4.0	6.4	7.4
		91	162.2	7.2	44.3	6.1	7.2
		122	141.0	5.0	73.6	7.4	9.3
		152	185.8	18.0	66.2	15.1	19.3
	149	0-15	48.6	1.1	7.2	2.7	2.6
		30	69.4	3.7	4.9	5.7	7.2
		61	158.4	4.0	41.9	2.4	2.8
		91	35.4	1.1	4.5	3.7	4.4
		122	171.6	3.1	47.4	2.5	3.1
		152	120.4	3.2	40.3	4.0	5.1
	WETTED PROFILE						
8/19	121	0-15	47.8	3.4	15.1	10.4	10.2
		30	57.6	8.3	15.4	19.7	19.0
		61	116.5	14.8	32.9	17.7	20.3
		91	147.5		44.8	12.9	15.1
		122	150.2	9.2	37.3	8.1	10.1
		152	147.7	11.6	14.8	8.7	11.1
		183	103.4	9.8			

APPENDIX III continued

Date	Core	Depth cm	Weight Drying	Water Loss	2 mm$^+$(g)	Water % Wt. Fine	Water % Vol. Standard BD
				CLUSTER 84			
4/22	25	0-15	49.7	9.9		20.0	20.8
		30	49.4	8.8		17.8	22.1
		61	104.3	17.7		17.0	19.4
		91	113.1	10.2		9.0	9.9
		122	133.7	14.9		11.1	12.5
		152	138.7	16.0		11.5	13.0
		183	134.8	17.6		13.1	14.8
	26	0-15	52.9	8.6		16.3	16.9
		30	55.2	8.7		15.8	19.2
		61	100.3	13.6		13.6	15.5
		91	132.1	11.0		8.3	9.1
		122	119.5	18.2		15.2	17.2
		152	123.5	11.8		9.6	10.8
		183	116.8	10.0		8.6	9.7
	27	0-15	48.4	8.9		18.4	19.1
		30	54.8	9.1		16.6	20.6
		61	104.7	14.9		14.2	16.2
		91	125.9	16.4		13.0	14.3
		122	132.5	13.8		10.4	11.7
		152	113.8	10.3		9.1	10.3
		183	133.4	9.7		7.3	8.2
8/13	102	0-15	53.7	3.7		6.9	7.2
		30	87.2	6.5		7.5	9.3
		61	119.6	10.5		8.8	10.0
		91	122.2	12.2		10.0	11.0
		122	128.9	17.3		13.4	15.1
		152	142.0	17.9		12.6	14.2
		183	131.7	16.7		12.7	14.3
	103	0-15	62.0	2.7		4.4	4.6
		30	86.8	3.9		4.5	5.6
		61	126.2	6.3		5.0	5.7
		91	108.1	13.6		12.6	13.9
		122	129.0	15.8		12.2	13.8
		152	126.0	11.0		8.7	9.8
		183	107.0	8.6		8.0	9.0
	104	0-15	61.7	2.3		3.7	3.8
		30	77.8	4.3		5.5	6.8
		61	133.3	7.6		5.7	6.5
		91	127.7	7.3		5.7	6.3
		122	123.5	7.4		6.0	6.8
		152	129.1	6.7		5.2	5.9
		183	110.9	8.6		7.6	8.6

APPENDIX III continued

Date	Core	Depth cm	Weight Drying	Water Loss 2 mm+ (g)	Water % Wt. Fine	Water % Vol. Standard BD
			CLUSTER 84 - con't			
5/25	40	0-15	54.6	12.3	22.5	23.4
		30	64.1	14.4	22.5	27.9
		61	121.0	22.6	18.7	21.3
		91	108.6	14.3	13.2	14.5
		122	130.0	14.1	10.8	12.2
		152	91.1	10.4	11.4	12.9
	41	0-15	61.8	12.2	19.7	20.5
		30	66.9	11.3	16.9	23.6
		61	132.6	20.5	15.5	17.7
		91	118.7	16.7	14.1	15.5
		122	124.2	17.1	13.8	15.6
		152	120.6	11.3	9.4	10.6
		183	108.7	9.1	8.4	9.5
	42	0-15	54.4	10.5	19.3	20.1
		30	55.8	9.5	17.0	21.1
		61	129.6	19.1	14.7	16.8
		91	130.2	17.7	13.6	15.0
		122	110.6	8.2	7.4	8.4
		152	121.6	8.1	6.7	7.6
		183	130.8	12.6	9.6	10.8
7/21	84	0-15	52.6	4.8	9.1	9.5
		30	59.5	6.0	10.1	12.5
		61	116.5	11.0	9.4	10.7
		91	125.3	13.3	10.6	11.7
		122	128.4	13.7	10.7	12.0
		152	140.8	14.9	10.6	12.0
	85	0-15	53.9	1.6	3.0	3.1
		30	78.4	4.0	5.1	6.3
		61	129,6	7.6	5.9	6.7
		91	126.8	11.9	9.4	10.3
		122	125.2	16.8	13.4	15.1
		152	121.1	10.9	9.0	10.2
		183	112.7	9.2	8.2	9.3
	86	0-15	57.7	4.1	7.1	7.4
		30	59.5	4.7	7.9	9.8
		61	112.5	7.7	6.8	7/7
		91	124.8	9.1	7.3	8.0
		122	114.0	10.2	8.9	10.1
		152	146.4	9.2	6.3	7.1
		183	137.3	9.7	7.1	8.0

APPENDIX III

Date	Core	Depth cm	Weight Drying	Water Loss 2 mm+ (g)	Water % Wt. Fine	Water % Vol. Standard BD
			CLUSTER 84- con't			
	WETTED PROFILE					
8/6	70	0-15	49.8	7.8	15.7	16.3
		30	54.7	8.7	15.9	19.7
		61	114,5	15.5	13.5	15.4
		91	127.9	14.3	11.2	12.3
		122	137.8	12.9	9.4	10.6
		152	129.1	8.9	6.9	13.4
		183	130.3	10.9	8.4	9.5
		213	117.0	16.1	13.8	15.6
		244	124.1	14.6	11.8	13.3
		274	130.2	16.4	12.6	14.2
		305	138.2	13.8	10.0	11.3

Date	Core	Depth cm	Weight Drying	Water Loss	2 mm+ (g)	Water % Wt. Fine	Water %. Vol. Standard BD
				CLUSTER 85			
4/8	1	0-15	51.8	9.9		19.1	19.9
		30	52.6	13.6		25.9	31.1
		61	98,0	17.6		18.0	20.5
		91	84.3	9.2		10.9	12.0
		122	138.5	13.8		10.6	11.3
		152	111.5	11.5		10.3	11.6
		183	127.3	13.0		10.2	11.5
	2	0-15	49.3	10.7		21.7	22.6
		30	60.8	11.9		19.6	24.3
		61	120.6	22.8		18.9	21.5
		91	95.5	9.7		10.2	11.2
		122	131.9	13.5		10.2	11.5
		152	124.2	13.2		10.6	11.3
		183	118.6	16.8		14.2	16.0
	3	0-15	59.6	10.8		21.8	22.7
		30	64,4	11,8		18.3	22.7
		61	124.7	20.5		16.4	18.7
		91	89.2	10.2		11.4	12.5
		122	131.3	13.1		10.0	11.3
		152	100.3	12.7		12.7	14.3
		183	114.8	11.2		9.8	11.1
	4	0-15	52.6	8.6		16.3	16.9
		30	63.0	11.7		18.6	23.1
		61	130.0	20.2		15.5	17.7
		91	101.2	12.0		11.9	13.1
		122	102.4	11.3		11.0	12.4
		152	118.4	12.5		10.6	12.0
		183	81.1	7.8		9.6	10.8
8/13	105	0-15	53.8	3.9		7.2	7.5
		30	80.5	6.5		8.1	10.0
		61	132.1	11.0		8.3	9.5
		91	131.3	14.1		10.7	11.8
		122	134.9	17.0		12.6	14.2
		152	140.4	17.3		12.3	13.9
		183	120.6	13.3		11.0	12.4
	196	0-15	67.7	6.2		9.2	9.6
		30	69.5	5.7		8.2	10.2
		61	114.8	12.6		11.0	12.5
		91	118.3	12.7		10.7	11.8
		122	130.8	16.1		12.3	13.9
		152	137.1	16.0		11.7	13.2
		183	105.1	13.0		12.4	14.0

Date	Core	Depth cm	Weight Drying	Water Loss 2 mm$^+$(g)	Water % Wt. Fine	Water % Vol. Standard BD
			CLUSTER 85 - con't			
8/13	107	0-15	53.7	3.8	7.1	7.4
		30	92.1	6.8	7.4	9.2
		61	117.3	8.7	7.4	8.4
		91	99.9	8.6	8.6	9.5
		122	139.9	16.0	11.4	12.9
		152	123.7	14.2	11.5	13.0
		183	121.7	14.8	12.2	13.8
5/25	45	0-15	60.0	15.0	25.0	26.0
		30	66.5	13.1	19.7	24.4
		61	138.8	23.3	18.9	21.5
		91	115.5	17.4	15.1	16.6
		122	129.7	15.2	11.7	13.2
		152	130.0	14.0	10.8	12.2
		183	137.3	14.1	10.3	11.6
	44	0-15	44.5	10.3	23.1	24.0
		30	72.1	14.5	20.1	24.9
		61	106.1	23.9	22.5	25.6
		91	122.1	21.2	17.4	19.1
		122	121.7	13.5	11.1	12.5
		152	125.1	15.6	12.5	14.1
		183	128.2	14.9	11.6	13.1
	43	0-15	47.1	10.8	11.9	23.8
		30	56.1	14.7	26.2	32.5
		61	113.8	23.7	20.8	23.7
		91	117.5	16.6	14.1	15.5
		122	97.1	9.5	9.8	11.0
		152	145.9	13.9	9.5	10.7
		183	133.6	15.6	11.7	13.2
6/23	78	0-15	52.0	6.1	11.7	12.2
		30	57.6	8.2	14.2	17.6
		61	132.9	21.2	16.0	15.7
		91	102.0	16.0	15.7	17.3
		122	146.4	20.3	13.9	15.7
		152	100.3	13.2	13.2	14.9
		183	147.8	16.0	10.8	12.2
	79	0-15	54.3	7.3	13.4	13.9
		30	62.3	9.5	15.2	18.8
		61	109.8	18.9	17.2	19.6
		91	116.7	17.1	14.7	16.2
		122	139.1	17.5	12.6	14.2
		152	118.3	13.5	11.4	12.9
		183	118.3	14.2	12.0	13.6

APPENDIX III continued

Date	Core	Depth cm	Weight Drying	Water Loss 2 mm+ (g)	Water % Wt. Fine	Water % Vol. Standard BD
			CLUSTER 85 - con't			
6/23	80	0-15	53.3	7.0	13.1	13.6
		30	64.1	14.1	22.0	27.3
		61	126.3	21.8	17.3	19.7
		91	128.4	18.3	14.3	15.7
		122	109.8	14.6	13.3	15.0
		152	120.2	12.2	10.1	11.4
		183	104.1	11.6	11.1	12.5
7/21	81	0-15	61.0	4.7	7.7	8.0
		30	86.0	7.4	8.6	10.7
		61	127.8	12.4	9.7	11.0
		91	120.6	14.0	11.6	12.8
		122	142.1	19.8	13.9	15.7
		152	142.9	14.8	10.4	11.7
		183	111.6	16.3	14.7	16.6
	82	0-15	55.7	5.2	9.3	9.7
		30	81.8	7.8	8.9	11.0
		61	125.5	14.3	11.4	13.0
		91	107.7	11.5	10.7	11.8
		122	130.9	8.4	6.5	7.3
		152	130.8	17.9	13.7	15.5
		183	114.1	13.8	12.1	13.7
	83	0-15	52.0	5.0	9.6	10.0
		30	69.4	7.4	10.1	12.5
		61	127.1	14.0	11.0	12.5
		91	118.4	16.5	13.9	15.3
		122	100.8	13.2	13.1	14.9
		152	128.1	19.9	15.5	22.5
		183	132.2	14.6	11.0	16.5
	WETTED PROFILE					
8/13	200	0-15	59.3	10.3	17.4	18.1
		30	41.4	9.0	21.7	16.9
		61	133.5	29.5	22.1	25.2
		91	124.8	19.5	15.6	17.2
		122	103.1	11.6	11.2	12.7
		152	114.9	11.0	9.6	10.8
		183	143.3	14.2	9.9	11.2

APPENDIX III continued

Deate	Core	Depth cm	Weight Drying	Water Loss	2 mm$^+$(g)	Water % Wt. Fine	Water % Vol. Standard BD
				CLUSTER 86			
4/8	5	0-15	46.9	9.4		20.0	20.8
		30	59.9	12.2		20.1	24.9
		61	119.0	22.0		18.5	21.1
		91	124.0	16.1		13.0	14.4
		122	110.5	17.1		15.5	17.5
		152	117.3	13.5		11.5	13.0
		183	112.3	11.3		10.1	11.4
	6	0-15	52.3	10.3		19.7	20.5
		30	55.8	10.0		17.9	22.2
		61	122.3	20.1		16.4	18.7
		91	80.5	12.3		15.3	16.8
		122	115.1	13.6		11.8	13.3
		152	113.1	12.8		11.3	12.8
		183	110.8	11.7		10.6	11.3
	7	0-15	54.1	11.7		21.6	22.5
		30	60.6	12.3		20.3	25.2
		61	70.2	10.6		15.1	17.2
		91	127.0	9.4		7.4	8.1
		122	111.5	12.6		11.3	12.8
		152	112.1	11.3		10.1	11.4
		183	105.0	11.3		10.8	12.2
	8	0-15	51.1	11.0		21.5	22.4
		30	53.0	10.6		20.0	24.8
		61	108.2	17.3		16.0	18.2
		91	140.5	10.4		7.4	8.1
		122	127.7	9.4		7.4	8.4
		152	97.6	11.5		11.8	13.3
		183	87.9	9.6		10.9	12.3
8/13	99	0-15	51.4	3.6		7.0	7.3
		30	67.3	4.4		6.5	8.1
		61	132.6	9.8		7.4	8.4
		91	104.2	9.1		8.0	8.8
		122	115.9	14.5		12.5	14.1
		152	108.5	14.3		13.2	14.9
		183	128.7	12.1		9.4	10.6
	100	0-15	57.2	3.5		6.1	6.3
		30	67.2	4.3		6.5	8.1
		61	127.1	8.2		6.5	7.4
		91	132.6	11.2		8.4	9.2
		122	98.6	8.5		8.6	9.7
		152	100.0	11.7		11.7	13.2
		183	119.3	11.9		10.0	11.3

APPENDIX III continued

Date	Core	Depth cm	Weight Drying	Water Loss	2 mm+ (g)	Water % Wt. Fine	Water % Vol. Standard BD
				CLUSTER 86 - con't			
8/13	101	0-15	39.4	2.5		6.3	6.5
		30	84.5	5.6		6.6	8.2
		61	136.5	8.4		6.2	7.1
		91	129.7	9.7		7.5	8.2
		122	114.9	13.7		11.9	13.4
		152	93.6	11.6		12.4	14.0
		183	114.1	11.4		10.0	11.3
5/25	47	0-15	50.5	11.4		22.6	23.5
		30	69.0	13.9		20.1	24.9
		61	119.9	20.7		17.3	19.7
		91	97.5	14.4		14.8	16.3
		122	115.3	13.9		12.1	13.7
		152	83.8	8.9		10.6	12.0
		183	97.3	10.6		10,9	12.3
	46	0-15	56.2	11.8		21.0	21.8
		30	72.5	14.6		20.1	24.9
		61	128.3	23.5		18.3	20.9
		91	89.2	9.2		10.4	11.4
		122	106.8	15.4		14.4	16.3
		152	114.7	14.3		12.5	14.1
		183	129.2	13.9		10.8	12.2
	48	0-15	50.0	10.8		21.6	22.5
		30	61.4	12.8		20.9	25.9
		61	105.5	18.9		17.9	20.4
		91	131.3	20.2		15.4	16.9
		122	120.6	16.5		13.7	15.5
		152	112.8	10.5		9.3	10.5
		183	92.8	9.1		9.8	11.1

APPENDIX IV

Species* list for 13 clusters at the Red Bluff Ranch and cluster 85 north of Belgrade, Mt.

	CLUSTERS													
	13	20	27	30	50	53	54	56	57	64	65	68	74	85
Perennial Grasses and Sedges														
Agropyron smithii (Bluestem wheatgrass)	x		x	x	x				x					x
Agropyron spicatum (Bluebunch wheatgrass		x	x	x	x	x	x	x	x	x	x	x	x	x
Agropyron subsecundum (Bearded wheatgrass)								x						
Agropyron trachycalum (Slender wheatgrass)								x						
Aristida longiseta (Red threeawn)	x													
Bouteloua gracillis (Blue grama)	x	x	x	x	x	x						x		
Calamagrostis montanensis (Plains reedgrass)	x	x			x									
Carex eleocharis (Needleaf sedge)		x	x	x	x	x	x		x	x	x	x	x	
Carex vallicola								x						
Carex filifolia (Threadleaf sedge)			x		x		x							
Festuca idahoensis (Idaho fescue)				x	x	x	x	x	x	x	x	x	x	
Festuca rubra (Red fescue)						x								

*--Taken from line intercept transects (VanDyne 1960-2) and from intercept transects taken in August 1970 for the Red Bluff Ranch. For cluster 85 species were taken from observations in 1971 by Earl Murray (Ross 1973). Species names are from Forest Service Resource paper PNW-40(Garrison and Poulton 1967)

APPENDIX IV

continued

	CLUSTERS													
	13	20	27	30	50	53	54	56	57	64	65	68	74	85
Perennial Grasses and Sedges continued														
Koeleria cristata (Prairie junegrass)		x	x	x	x	x	x	x	x	x	x	x	x	x
Poa sp. (Bluegrass)										x	x			
Poa pratensis (Kentucky bluegrass)								x						
Poa sandbergii (Sandburg bluegrass)		x	x	x		x	x	x		x	x	x	x	x
Stipa comata (Needleandthread)	x	x		x	x	x	x	x	x	x	x	x	x	x
Stipa vividula (Green needlegrass)														x
Annual Grasses														
Bromus japonicus (Japanese brome)								x						x
Bromus tectorum (Cheatgrass brome)	x	x	x		x			x	x			x	x	
Forbs														
Achillea lanulosa (Yarrow)								x						
Achillea millefolia (Yarrow)														x
Antennaria rosea (Rose pussytoes)			x	x	x	x	x				x	x	x	
Arenaria congesta (Ballhead sandwort)						x	x	x					x	

APPENDIX IV

continued

Forbs--continued	CLUSTERS 13	20	27	30	50	53	54	56	57	64	65	68	74	85
Astragalus miser (Starved milkvetch)				x		x								
Astragalus stenophyllus (Hangingped milkvetch)				x		x						x		
Cerastium brachypodium (Short-stalked chickweed)								x					x	
Chrysopsis villosa (Hairy goldaster)	x					x	x			x	x	x		
Comandra umbellata (Common comandra)					x									x
Erigeron divergens (Spreading fleabane)														x
Geum trifolium (Prairiesmoke ovens)								x						
Geranium viscosissimum								x						
Ligusticum purpureum (Grays licoriceroot)					x			x						
Lupinus sericeus (Silky lupine)		x					x	x			x			
Opuntia polycantha (Plains pricklypear)		x												
Oxytropis sericea (White pointloco)		x										x		
Physaria alpestris (Alpine twinpod)				x						x	x			
Phlox hoodii (Hoods phlox)				x	x	x	x			x				x
Phlox longifolia (Longleaf phlox)													x	x

APPENDIX IV

continued

	CLUSTERS													
	13	20	27	30	50	53	54	56	57	64	65	68	74	85
Forbs--continued														
Prunella vulgaris (Common selfeal)			x						x					
Sphaeralcea coccinea (Red globmellow)		x	x	x										x
Sedum stenopetalum (Wormleaf stonecrop)								x					x	
Tragapogon dubius (Yellow salsify)														x
Shrubs														
Artemesia frigida (Fringed sagebrush)		x		x	x	x	x		x			x	x	x
Artemesia tridentata (Big sagebrush)													x	
Xanthocephalum sarothrae (Broom snakeweed)									x	x				
Other-														
Lichens	x		x	x		x				x	x			
Moss													x	
Selaginella densa (Dense clubmoss)		x	x	x	x	x	x	x	x	x	x	x	x	

APPENDIX V

Habitat Type By Clusters

CLUSTER	HABITAT TYPE*
13	Agropyron spicatum/Agropyron smithii-Agropyron dasystachyum phase
20	Agropyron spicatum/Bouteloua gracilis
27	Agropyron spicatum/Bouteloua gracilis-Liatris punctata phase
30	Festuca idahoensis/Agropyron spicatum
50	" " / " "
53	" " / " "
54	" " / " "
56	" " / " "
57	" " / " "
64	" " / " "
65	" " / " "
68	" " / " "
74	" " / " "
80	Agropyron spicatum/Bouteloua gracilis
81	Agropyron spicatum/Bouteloua gracilis-Liatris punctata phase
82	Agropyron spicatum/Bouteloua gracilis
83	Festuca idahoensis/Agropyron spicatum
84	Agropyron spicatum/Agropyron smithii-Agropyron dasystachyum phase
85	Agropyron spicatum/Agropyron smithii-Agropyron dasystachyum phase
86	Agropyron spicatum/Agropyron smithii-Agropyron dasystachyum phase

* --Personal communication; Bill Stewart, Range Scientist, Intermountain Forest & Range Exp. Sta., Bozeman, Mt..

APPENDIX VI

Soil Family grouping with elevation, aspect and slope for 17 clusters at Red Bluff Ranch and 3 clusters north of Belgrade, Montana.

Cluster	Elevation Meters	Aspect/slope	Soil Classification
74	1860	NW-20%	Argic cryoborolls
56	1820	NW-8%	
68	1780	NE-15%	(fine-loamy)
54	1750	N-5%	
83	1600	N-5%	
30	1580	N-6%	
53	1560	W-12%	
65	1800	E-10%	Typic Cryoborolls
57	1710	E-18%	(sandy)
64	1800	SW-10%	Ustic Torriorthenta
20	1620	SE-10%	(sandy-sketetal, mixed frigid)
82	1670	SE-5%	
80	1540	W-5%	Aridic Argiborolls
81	1540	SW-5%	
27	1540	S-5%	(fine-loamy, mixed)
50	1520	N-6%	
13	1490	SW-5%	
86	1420	W-2%	Aridic Argiborolls
85	1400	SW-2%	(fine-silty)
84	1380	SW-4%	

APPENDIX VII

Consumptive Water Use By Clusters

Appendix VII is a tabulation of the consumptive water use for each period that the soil water was measured. It gives separately the soil water depletion, rainfall, total consumptive use for the period, number of days in each period, and the average consumptive use per day for the period.

Consumptive use for a common growth season (April 18 to August 19, 1970) is also included to facilitate a comparison between clusters which were not sampled at equal time intervals. See text for explanation of estimates used in calculations.

APPENDIX VII

CLUSTER 13

5/4 to 8/21 (109 days)		4/18 to 8/19 (123 days)	
Soil Depletion	9.6 cm	Soil depletion (5/4-8/17)	9.1 cm
Rainfall	17.4 cm	(4/18-5/4)	2.6 cm
Consumptive Use		Rainfall (5/4-8/19)	17.4 cm
Total	27.0 cm	Consumptive Use	
Per day	2.5 mm	Total	29.1 cm
		Per day	2.4 mm

CLUSTER 20

4/22 to 8/19 (119 days)		4/18 to 8/19 (123 days)	
Soil Depletion	11.2 cm	Soil Depletion (11.2 +0.6)	11.8 cm
Rainfall	24.7 cm	Rainfall (4/18-8/19)	24.7 cm
Consumptive Use		Consumptive Use	
Total	35.9 cm	Total	36.5 cm
Per day	3.0 mm	Per day	2.9 mm

CLUSTER 27

4/18 to 8/21 (125 days)		4/18 to 8/19 (123 days)	
Soil Depletion	8.0 cm	Soil Depletion (7.5-0.5)	7.0 cm
Rainfall (4/18-5/4)	4.6 cm	Rainfall (4/18-8/19)	22.0 cm
(5/4-8/21)	17.4 cm	Consumptive Use	
Consumptive Use		Total	29.0 cm
Total	30.0 cm	Per day	2.4 mm
Per day	2.4 mm		

CLUSTER 30

5/20 to 8/10 (82 days)		4/18 to 8/19 (123 days)	
Soil Depletion	17.0 cm	Soil Depletion (5/20-8/19)	19.1 cm
Rainfall	14.5 cm	Soil Depletion (4/18-5/20)	5.2 cm
Consumptive Use		Rainfall (5/20- 8/19)	14.5 cm
Total	31.5 cm	Consumptive Use	
Per day	2.9 mm	Total	38.8 cm
		Per day	3.1 mm

CLUSTER 50

5/20 to 8/25 (97 days)		4/18 to 8/19 (123 days)	
Soil Depletion	15.3 cm	Soil Depletion (5/20-8/19)	14.8 cm
Rainfall	14.5 cm	(4/18-5/20)	5.2 cm
Consumptive Use		Rainfall	14.5 cm
Total	30.1 cm	Consumptive Use	
Per day	3.1 mm	Total	34.5 cm
		Per day	2.8 mm

APPENDIX VII continued

CLUSTER 53

5/20 to 8/25 (97 days)	
Soil Depletion	15.3 cm
Rainfall	14.5 cm
Consumptive Use	
Total	29.8 cm
Per day	3.1 mm

4/18 to 8/19 (123 days)		
Soil Depletion	(5/20-8/19)	14.5 cm
	(4/18-5/20)	5.2 cm
Rainfall		14.5 cm
Consumptive Use		
Total		34.2 cm
Per day		2.8 mm

CLUSTER 54

5/4 to 6/22 (49 days)	
Soil Depletion	10.2 cm
Rainfall	14.7 cm
Consumptive Use	
Total	24.9 cm
Per day	5.1 mm

6/22 to 8/19 (58 days)	
Soil Depletion	5.1 cm
Rainfall	7.9 cm
Consumptive Use	
Total	13.0 cm
Per day	2.2 mm

5/4 to 8/19 (107 days)	
Soil Depletion	15.3 cm
Rainfall	22.6 cm
Consumptive Use	
Total	37.9 cm
Per day	3.5 mm

4/18 to 8/19 (123 days)		
Soil Depletion	(5/4-8/19)	15.3 cm
	(4/18-5/4)	2.6 cm
Rainfall		22.6 cm
Consumptive Use		
Total		40.5 cm
Per day		3.3 mm

CLUSTER 56

5/13 to 8/25 (114 days)	
Soil Depletion	18.1 cm
Rainfall	18.5 cm
Consumptive Use	
Total	36.6 cm
Per day	3.5 mm

4/18 to 8/19 (123 days)		
Soil Depletion	(5/13-8/19)	17.3 cm
	(4/18-5/13)	4.1 cm
Rainfall		18.5 cm
Consumptive Use		
Total		39.9 cm
Per day		3.2 mm

CLUSTER 57

5/6 to 8/13 (99 days)	
Soil Depletion	4.3 cm
Rainfall	21.4 cm
Consumptive Use	
Total	25.7 cm
Per day	2.6 mm

4/18 to 8/19 (123 days)		
Soil Depletion	(5/6-8/19)	5.7 cm
	(4/18-5/6)	2.9 cm
Rainfall		21.4 cm
Consumptive Use		
Total		30.0 cm
Per day		2.4 mm

APPENDIX VII continued

CLUSTER 64

4/18 to 8/14 (118 days)		4/18 to 8/19 (123 days)	
Soil Depletion	5.9 cm	Soil Depletion (+1.2)	7.2 cm
Rainfall	29.0 cm	Rainfall	29.0 cm
Consumptive Use		Consumptive Use	
Total	34.9 cm	Total	36.2 cm
Per Day	3.0 mm	Per day	2.9 mm

CLUSTER 65

5/6 to 6/22 (47 days)		6/22 to 8/19 (58 days)	
Soil Increase	0.8 cm	Soil Depletion	13.2 cm
Rainfall	13.7 cm	Rainfall	7.7 cm
Consumptive Use		Consumptive Use	
Total	12.9 cm	Total	20.9 cm
Per day	2.7 mm	Per day	3.6 mm
5/6 to 8/19 (105 days)		4/18 to 8/19 (123 days)	
Soil Depletion	12.4 cm	Soil Depletion (5/6-8/19)	12.4 cm
		(4/18-5/6)	2.9 cm
Rainfall	21.4 cm	Rainfall	21.4 cm
Consumptive Use		Consumptive Use	
Total	33.8 cm	Total	36.7 cm
Per day	3.2 mm	Per day	3.0 mm

CLUSTER 68

5/20 to 8/23(95 days)		4/18 to 8/19 (123 days)	
Soil Depletion	13.0 cm	Soil Depletion(5/20-8/19)	11.6 cm
		(4/18-5/20)	5.2 cm
Rainfall	18.4 cm	Rainfall	18.4 cm
Consumptive Use		Consumptive Use	
Total	31.4 cm	Total	35.2 cm
Per day	3.3 mm	Per day	2.9 mm

CLUSTER 74

5/20 to 8/23 (95 days)		4/18 to 8/19 (123 days)	
Soil Depletion	19.3 cm	Soil Depletion (5/20-8/19)	17.9 cm
		(4/18-5/20)	5.2 cm
Rainfall	18.4 cm	Rainfall	18.4 cm
Conumptive Use		Consumptive Use	
Total	37.7 cm	Total	41.5 cm
Per day	4.0 mm	Per day	3.4 mm

APPENDIX VII continued

CLUSTER 80

4/18 to 6/22 (65 da ys)	
Soil Increase	-10.1 cm
Rainfall (4/18-5/4)	6.4 cm
(5/4-6/22)	12.5 cm
Consumptive Use	
Total	8.8 cm
Per day	1.3 mm
4/18 to 8/7 (111 days)	
Soil Depletion	6.1 cm
Rainfall Est.(4/18-5/4)	6.4 cm
(5/4-8/7)	18.8 cm
Consumptive Use	
Total	31.3 cm
Per day	2.8 mm

6/22 to 8/7 (46 days)	
Soil Depletion	16.2 cm
Rainfall	6.3 cm
Consumptive Use	
Total	22.5 cm
Per day	2.2 mm
4/18 to 8/19 (123 days)	
Soil Depletion (4/18-8/7)	6.1 cm
(Est. 8/7-8/19)	2.8 cm
Rainfall	25.2 cm
Consumptive Use	
Total	34.1 cm
Per day	2.8 mm

CLUSTER 81

4/18 to 8/21 (125 days)	
Soil Depletion	8.0 cm
Rainfall(4/18-5/4)	4.6 cm
(5/4-8/19)	17.0 cm
Consumptive Use	
Total	29.6 cm
Per day	2.4 mm

4/18 to 8/19 (123 days)	
Soil Depletion	7.5 cm
Rainfall	21.6 cm
Consumptive Use	
Total	29.1 cm
Per day	2.4 mm

CLUSTER 82

4/22 to 6/22 (61 days)	
Soil Depletion	7.5 cm
Rainfall (Est. 4/22-5/4)	6.4 cm
(5/4-6/22)	11.3 cm
Consumptive Use	
Total	25.2 cm
Per day	4.1 mm
4/22 to 8/13 (113 days)	
Soil Depletion	13.6 cm
Rainfall	24.3 cm
Consumptive Use	
Total	37.9 cm
Per day	3.3 mm

6/22 to 8/13(52 days)	
Soil Depletion	6.1 cm
Rainfall	6.6 cm
Consumptive Use	
Total	12.7 cm
Per day	2.4 mm
4/18 to 8/19 (123 days)	
Soil Depletion (4/18-4/22)	+.5 cm
(4/18-8/13)	13.6 cm
(8/13-8/19)	1.4 cm
Rainfall	24.3 cm
Consumptive Use	
Total	39.8 cm
Per day	5.2 mm

APPENDIX VII continued

CLUSTER 83

5/20 to 8/25 (97 days)	
Soil Depletion	13.6 cm
Rainfall	14.5 cm
Consumptive Use	
Total	28.1 cm
Per day	2.9 mm

4/18 to 8/19 (123 days)	
Soil Depletion (5/20-8/19)	12.2 cm
(4/18-5/20)	5.2 cm
Rainfall	14.5 cm
Consumptive Use	
Total	31.9 cm
Per day	2.6 mm

CLUSTER 84

4/22 to 5/25 (33 days)	
Soil Increase	- 1.5 cm
Rainfall(4/22-5/4)	1.9 cm
(5/4-5/25)	5.0 cm
Consumptive Use	
Total	5.4 cm
Per day	1.6 mm

7/21 to 8/13 (23 days)	
Soil Depletion	0.3 cm
Rainfall	3.9 cm
Consumptive Use	
Total	4.2 cm
Per day	1,8 mm

4/18 to 8/19 (123 days)	
Soil Depletion	
(4/18-4/22)	0.7 cm
(4/22-8/13)	8.7 cm
(8/13-8/19)	1.4 cm
Rainfall	21.4 cm
Consumptive Use	
Total	32.2 cm
Per day	2.6 mm

5/25 to 7/21 (57 days)	
Soil Depletion	9.9 cm
Rainfall	10.6 cm
Consumptive Use	
Total	20.5 cm
Per day	3.6 mm

4/22 to 8/13 (113 days)	
Soil Depletion	8.7 cm
Rainfall	21.4 cm
Consumptive Use	
Total	30.1 cm
Per day	2.7 mm

CLUSTER 85

4/8 to 5/25 (47 days)	
Soil Increase	- 3.6 cm
Rainfall	8.1 cm
Consumptive Use	
Total	4.5 cm
Per day	0.1 mm

5/25 to 6/23 (29 days)	
Soil Depletion	4.2 cm
Rainfall	6.9 cm
Consumptive Use	
Total	11.2 cm
Per day	3.8 mm

APPENDIX VII continued

CLUSTER 85 continued

6/23 to 7/21 (28 days)		7/21 to 8/13 (24 days)	
Soil Depletion	3.6 cm	Soil Depletion	2.5 cm
Rainfall	3.8 cm	Rainfall	3.9 cm
Consumptive Use		Consumptive Use	
Total	7.4 cm	Total	6.4 cm
Per day	2.6 mm	Per day	2.8 mm
4/8 to 8/13 (127 days)		4/18 to 8/19 (123 days)	
Soil Depletion	6.7 cm	Soil Depletion (4/8-4/18)	1.0 cm
		(4/8-8/13)	6.7 cm
		(4/18-8/13)	5.7 cm
		(8/13-8/19)	1.4 cm
Rainfall	22.6 cm	Rainfall	21.4 cm
Consumptive Use		Consumptive Use	
Total	29.3 cm	Total	28.5 cm
Per day	2.3 mm	Per day	2.3 mm

CLUSTER 86

4/8 to 5/25 (47 days)		5/25 to 8/13 (80 days)	
Soil Increase	- 2.3 cm	Soil Depletion	11.9 cm
Rainfall	8.1 cm	Rainfall	14.5 cm
Consumptive Use		Consumptive Use	
Total	5.8 cm	Total	26.4 cm
Per day	1.2 mm	Per day	3.3 mm
4/8 to 8/13 (127 days)		4/18 to 8/19 (123 days)	
Soil Depletion	9.6 cm	Soil Depletion (4/8-4/18)	1.2 cm
		(4/8-8/13)	9.6 cm
		(4/18-8/13)	8.4 cm
		(8/13-8/19)	1.4 cm
Rainfall	22.6 cm	Rainfall	21.4 cm
Consumptive Use		Consumptive Use	
Total	32.2 cm	Total	31.2 cm
Per day	2.5 mm	Per day	2.5 mm

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