



Plant phenology in the western United States using the ERTS-1 satellite
by Charles Moncur Jones

A thesis submitted in partial fulfillment of the requirements for the degree of DOCTOR OF
PHILOSOPHY in Crop and Soil Science
Montana State University
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Abstract:

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Algorithms were developed to use the ERTS-1 data in specifying , greenness, foliage height or biomass, and species for certain crops (especially irrigated alfalfa, dryland winter wheat, and nonirrigated rangeland) in the test plots. Methods are presented to indicate feasibility of computer-assisted crop identification and inventory over broad areas by using satellite data.

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by

CHARLES MONCUR JONES

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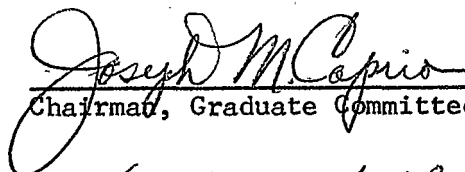
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ABSTRACT

Methods are described for the detection of phenological events in Western United States (especially vegetation development - green wave, and vegetation senescence - brown wave) for certain crops using ERTS-1 data during 1972 and 1973. Multispectral scanner satellite data were used in conjunction with ground data collected at more than 30 test areas consisting of 3 subsites at each of the 10 main test sites.

Algorithms were developed to use the ERTS-1 data in specifying greenness, foliage height or biomass, and species for certain crops (especially irrigated alfalfa, dryland winter wheat, and nonirrigated rangeland) in the test plots. Methods are presented to indicate feasibility of computer-assisted crop identification and inventory over broad areas by using satellite data.

INTRODUCTION

As we continue to place greater demands on the earth's resources, it becomes increasingly important to inventory and understand the available plant resources. This investigation is mainly concerned with the productive cycle and time-distribution of plant life in the Western United States. However, the techniques described herein are readily adaptable for investigation of other earth resources.

The Earth Resources Technology Satellite (ERTS-1) data and some of the ground data for this investigation were collected in conjunction with the NASA-funded Phenology Satellite Experiment. Under contract number NAS5-21781, NASA funded the experiment to investigate the timing of the green wave's northward movement across the United States in springtime and the brown wave's southward movement in autumn. Also, techniques to monitor the general phenological status of the earth's surface on a broad scale were to be developed if possible.

A coordinated network of 24 ground observations sites was established to collect appropriate ground-truth data for comparison with the satellite data. Fourteen of these sites were in two "corridors" in the Eastern United States and ten sites (each having 3 sub-sites) were in two corridors in the Western United States.

Most of the information contained herein is related to the investigations in Western United States where information was collected for irrigated alfalfa, nonirrigated winter wheat, and nonirrigated rangeland. A few test plots also covered spring planted barley,

conifer forests, and an irrigated range plot, but due to insufficient replication of these test plots the data were not analyzed as were the data from alfalfa, wheat, and range plots. The eastern corridors provided information mostly on deciduous forests.

As funded by NASA, the Phenology Satellite Experiment was a temporal study of plant properties and their associated spectral emissions. The broad aim of this investigation was to observe the temporal and geographical progression of the plant life cycle during the annual seasons in the United States by using ERTS-1 data.

Also reported herein are the efforts and results of attempts to use satellite data for the computer-assisted identification of crop species, inventory of crops by area, and determination of plant height or biomass.

REVIEW OF LITERATURE

Charles Morren, a Belgian botanist, appears to be one of the first to use the term "phenology". In 1853 he applied the term to that branch of science which studies the periodic phenomena in the plant and animal world insofar as they depend upon the climate of any locality. A complete definition of phenology may be hard to find, but W. P. Lowry (1972) calls it "the study of the time patterns associated with the developmental sequences of organisms". Daubenmire (1959) says "phenology embraces all studies of the relationships between climatic factors and periodic phenomena in organisms".

Phenological studies seemed to be popular in Europe before they became popular in the United States. Pioneering work in phenology was done by the Swedish naturalist, Carolus Linnaeus. His famous book Philosophia Botanica (Linnaeus 1751) suggested local phenological calendars and phenological networks in Sweden. F. Schnelle (1948) studied phenological records from a network located in Germany from 1936 to 1939 using rye as the principal indicator species.

One of the most notorious early American phenologists was A. D. Hopkins who published his famous Bioclimatic Law in 1918 and extended it in 1938 (Hopkins 1918, 1938). By the mid-1950's, J. M. Caprio had established an extensive phenological network in Western United States (Caprio 1966) which provided the impetus for new and expanded networks in the western, northcentral, and northeastern regions using clonally propagated plant material. These networks now

cover 40 states and 5 Canadian Provinces with several thousand observation sites (Detheir, 1974, page 5).

In recent years the study of plant related phenological events has been done from several types of aircraft. By far the most popular means of recording these data has been by photographic methods. The most used forms have progressed through black and white film, color film, black and white infrared film, and color infrared film. Now the practice of recording these data via a multispectral scanner (MSS) has become popular and useful. Baumgardner (1970) explains the operation of multispectral scanners (MSS) from aircraft and spacecraft.

A four-channel multispectral recording system is described by Johnson, et. al. (1969) using four cameras, sensitive to blue, red, green, and infrared light. This instrumentation is roughly equivalent to a MSS system and is relatively inexpensive. For the cameras operating in the visible spectrum, a simple filter over the lens specifies the band of wavelengths being recorded.

More complicated and powerful MSS systems using various types of electronic and color enhancement on digitally recorded data are presented in Purdue University Research Bulletin 873 (Anonymous 1970). This publication also describes evaluations of data and computerized analysis techniques.

It has been difficult for many people to realize that MSS can

provide information within the visible spectrum which the human eye can not detect. This stems from the separation of that spectrum into several discrete bands by MSS. In general, the more bands, the more information that can be detected. This approaches the principles of analytical spectroscopy.

The Phenology Satellite Experiment (sponsored by NASA) using ERTS-1 data was probably the first significant attempt at monitoring earth's plant phenology from a satellite (Dethier 1974). However, tremendous amounts of remote sensing data were available to indicate feasibility of the experiment before the satellite was launched.

Immediately prior to the time ERTS-1 data became available for phenological studies and research, a comprehensive compilation of state-of-the-art remote sensing techniques was published in conjunction with a symposium presented by Forestry Remote Sensing Laboratory personnel from the University of California, Berkeley (Anonymous 1972a). Within this publication are "Basic Considerations of Remote Sensing" by R. N. Colwell, "Agricultural Land Use, Stereoscopy, and Manual Image Interpretation Techniques" by D. T. Lauer, and discussions of crop inventory, vigor, and yield analysis by W. C. Draeger. Colwell's paper (pages 17 and 19) suggests the use of multispectral tone signatures on photographic film for monitoring crop features:

Two-Band Signatures

Crop	Pan-25A Film (.58 to .72 microns)	IR-89B Film (.72 to .89 microns)
Hardwood trees	Dark	Light
Conifers	Dark	Dark

Four-Band Signatures

Crop	Pan-47B Film (.40 to .48)	Pan-61 Film (.47 to .61)	Pan-25A Film (.58 to .72)	IR-89B Film (.72 to .89)
Alfalfa:				
Healthy	Dark	Dark	Dark	Light
Unhealthy	Dark	Light	Very Light	Dark

Haas and Watson (1971) indicate applications of color IR for distinguishing species of woody plants. Their data were taken by aircraft flying at 4000 feet.

Prior to launch of the ERTS-1 from Lompoc, California on July 23, 1972, extensive plans were made for agricultural studies using satellite data (Anonymous 1972). Applegate (1972) indicates that some of the studies planned were the use of the satellite data to determine kinds of vegetables (by C. L. Wiegand, Weslaco, Texas) and yields of corn, milo, alfalfa and wheat (by V. I. Meyers, Remote Sensing Institute, Brookings, South Dakota).

Unfortunately, the three-channel "TV system" malfunctioned and only four bands of the multispectral scanner system were available for research.

Before the ERTS-1 was launched, about the only opportunity to

remotely study the earth's surface from spacecraft was with data from weather satellites. Ormsby and Dethier (1970) published a bibliography mainly concerned with interpretation of clouds, but most of the satellite data and associated research done prior to 1970 are referenced therein.

Now that data from ERTS-1, ERTS-2, and Skylab are available, much agricultural research is being conducted with satellite data and related ground truth information. Some recent ground based investigations have provided information which should be valuable in making use of satellite data. Kanemasu (1974) agrees with Bowers and Hanks (1965) that longer wavelengths are more strongly reflected from green foliage. Kanemasu further reports % cover equations developed from his studies of reflectance at a height of 1.5 to 2 meters above a wheat test plot:

$$\begin{array}{rcl} \% \text{ Cover} & = & 109.88 \times (\text{ratio}) - 63.71 \quad \frac{R}{.87} \\ \% \text{ Cover} & = & 2.85 \times (\text{NIR}) - 19.24 \quad .72 \end{array}$$

where (ratio) is approximately equivalent to the ratio of ERTS-1 Band 4 and (NIR) represents near infrared reflectance. R is the correlation coefficient. He concluded that "reflectance ratio alone does not discriminate between crop species, but should be a valuable parameter when used with other recognition processes".

Gausman, Allen, Cardenas, and Richardson (1973) found that "increasing leaf age of corn within four growth stages had little effect on near infrared (.75 to 1.35 microns) reflectance whereas

mature leaves of cotton had higher near IR light reflectance than young leaves".

Caprio (1973) published a preliminary model of the green wave timing for the world by using meteorological data and his Solar Thermal Unit Theory. This and his other worldwide maps (Caprio 1974) should be valuable in correlating specific satellite phenology studies with good truth for use on a worldwide basis.

Since ERTS-1 data have become available, several publications have appeared which actually make satellite data useful for phenological observations. The most comprehensive of these is the Phenology Satellite Experiment Final Report (Dethier 1974) which includes studies in Eastern and Western United States. Carlson and Fenton (1975) have shown how ERTS-1 data have been useful in determining Iowa's agricultural resources. Carnegie, Degloria, and Colwell (1974) have indicated usefulness of ERTS-1 and aircraft data to monitor California's pasturelands. Wiegand, Richardson, Gerbermann, Gausman, and Cuellar (1975) have developed a reflectance model relating reflectance to proportions of ground area covered by vegetation, exposed to sun, and occupied by plant shadows, for use with ERTS data.

Some of the studies referenced above have described how ERTS data can provide practical information. Hopefully, this study will make a significant contribution to encourage practical applications of phenology using satellite data.

MATERIALS AND DATA ACQUISITION

Satellite Data

The ERTS-1 satellite data available for use in accomplishing the objectives stated previously were as follows:

Four discrete bands of electromagnetic radiation within the visible and near infrared spectrum were collected by the satellite's multispectral scanner (MSS) and relayed via the data distribution system to various users (Anonymous 1971).

Band 4: .5 to .6 microns wavelength - covers most greens and all yellows

Band 5: .6 to .7 microns wavelength - covers most oranges, all reds, and some very near infrareds

Band 6: .7 to .8 microns wavelength - covers near infrareds

Band 7: .8 to 1.1 microns wavelength - covers near infrareds

(Bands coded 1, 2, and 3 were assigned to a system which malfunctioned on ERTS-1).

The data from the four bands is first recorded in digital form (discrete steps) on a magnetic tape aboard the satellite. At appropriate intervals the data are then transmitted to earth stations and recorded on computer compatible tapes (still in digital form) for

distribution to users.

Each of the sensors for the four bands provides a maximum of 128 voltage levels to represent the full range of reflected energy in each band. Therefore, users of the data cannot expect to receive smooth (analog) transitions from one intensity level to another, such as the eye or a photograph might simulate. However, the discrete intensity levels are displayed and distributed in a simulated analog system as photo transparencies.

This simulated photographic image is created by causing a computer to provide the appropriate intensity levels to a cathode ray tube (like a black and white television tube) as its control circuits scanned rapidly across the face of the tube. (This method of display might be called "digital TV".) A photograph is taken of each displayed image for distribution to users. Figures 1, 2, 3, and 4 are prints of typical transparencies from bands 4, 5, 6, and 7 of the satellite, respectively.

Thus, all data recorded by the satellite multispectral scanner (MSS) are available from NASA as either magnetic tape recorded digital data or as photo transparencies of those data displayed to form an "apparent" photo-image. Each transparency (available in 70 mm or 9.5 inch size) of the data from a single MSS sensor covers an earth area approximately 100 nautical miles square. In addition to the above output products, the NASA Data Processing Facility (NDPF) also



Fig. 1 Print of a Transparency from ERTS-1 Band 4



Fig. 2 Print of a Transparency from ERTS-1 Band 5



Fig. 3 Print of a Transparency from ERTS-1 Band 6

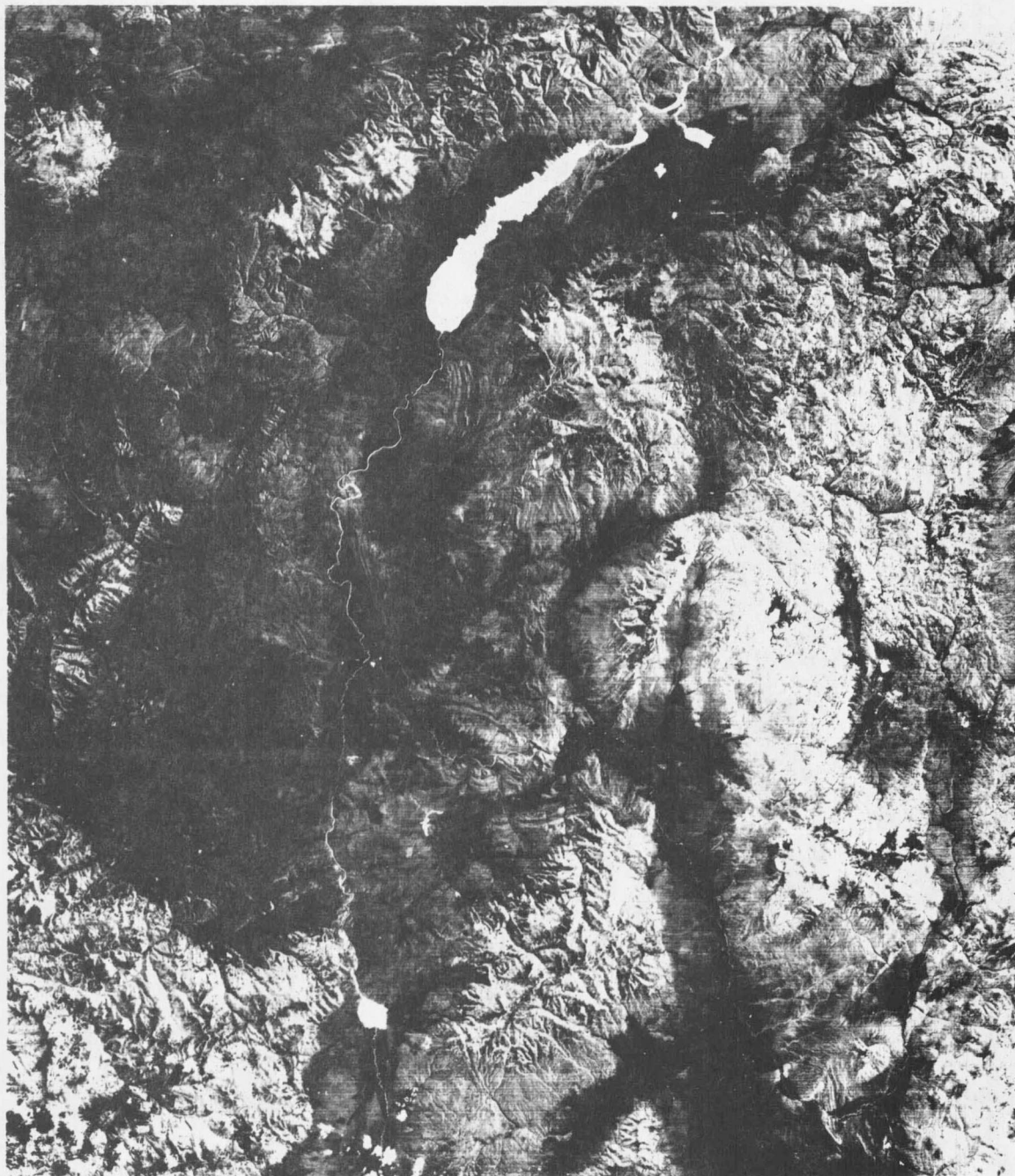


Fig. 4 Print of a Transparency from ERTS-1 Band 7

provides color transparencies and color prints by assigning a unique "false color" to each of the bands. Superimposed and printed, these create a "false color composite" for a particular image. Further details on the types of output data available from NDPF and correction processes (to preserve preciseness of the data) are outlined in section 3 of the ERTS Data Users Handbook (Anonymous 1971).

Ground Truth Data

Ground truth data were taken at 10 main locations throughout the western states. At each of the sites, three or more test plots were specified. These test sites (established for the NASA contract by Dr. J. M. Caprio with the assistance of cooperators in the several western states) were arranged in two "corridors".

The first corridor, named the "Rocky Mountain Corridor" begins near Browning, Montana and runs approximately southward through Idaho, Utah, and Northern Arizona. Its sites are at an approximate altitude of 4800 feet.

The other corridor, called the "Columbia Valley Corridor" begins near Havre, Montana, and runs westward through Idaho to Bickleton, Washington. Its sites are at an approximate altitude of 3000 feet. Appendix 1 gives more detailed location and altitude information for all the sites.

Two items of ground data were taken at each plot within each site on 6-day intervals: Crop height and color photographs to indicate

fraction green or stage of plant development. These 6-day intervals were synchronized with the 18-day "repeating orbit" interval of the satellite to collect ground data, as nearly as possible, at the same time the satellite data were taken. Approximate yields for small grains and alfalfa production at each cutting were recorded at harvest time.

In using the available satellite data, the most desirable ground information is the comprehensive status of plant conditions at the time of the overpass. It also is desirable to record the reflected radiation near the ground in exactly the same way it is recorded on the satellite to indicate anomalies in the data due to atmospheric or other causes.

Acquisition of Satellite Data for Analyses

In this study, ground data (plant height, fraction green ground cover, and crop species) are compared directly to the satellite data. The satellite data were corrected for sun angle and distortion by NASA and the Texas A and M Remote Sensing Center (RSC).

Satellite data for this study were available in simulated-photograph form direct from NASA or as a computer output in statistical summary form. The statistical summaries of requested areas were available from RSC in the form of a "Site Processing Report" such as shown in Figures 5, 6, and 7. Pages 163 through 503 of the Phenology Satellite Experiment Report (Dethier 1974) include all of the processing

```
*****
*
*           ERTS-1           *
*
*  SITE PROCESSING REPORT  *
*****
```

```
SITE DESIGNATOR:  RM 6  A      CELLS  2377 TO  2382
IMAGE IDENTIFIER:  1411-17422  LINES  1763 TO  1768
DATE ACQUIRED:     07SEP73     TOTAL  POINTS   36
```

CORRECTED FOR SUN ELEVATION 49 DEGREES

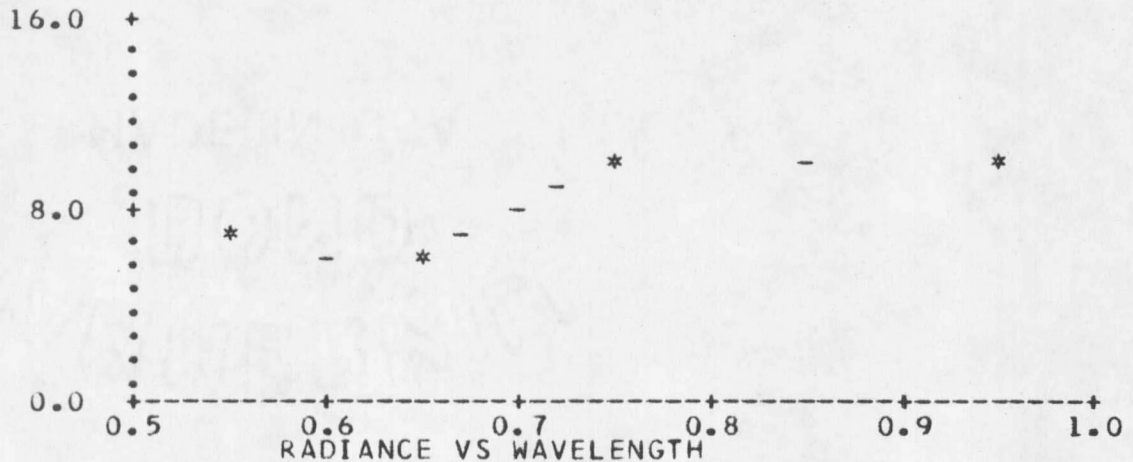
RADIANCE(MWATTS/SQCM-STR-MICROMETER)

	MEAN	STANDARD DEVIATION	WAVELENGTH (MICROMETERS)
BAND 4	7.22	0.71	.5 - .6
BAND 5	5.55	1.12	.6 - .7
BAND 6	9.78	0.80	.7 - .8
BAND 7	10.07	1.27	.8 - 1.1

NORMALIZED COVARIANCES

	BAND 4	BAND 5	BAND 6	BAND 7
BAND 4	1.000	0.921	-0.133	-0.289
BAND 5	0.921	1.000	-0.360	-0.547
BAND 6	-0.133	-0.360	1.000	0.912
BAND 7	-0.289	-0.547	0.912	1.000

BAND RATIO PARAMETER 0.289
TRANSFORMED PARAMETER 0.888



PREPARED BY: TEXAS A&M UNIVERSITY, REMOTE SENSING CENTER
DATA ANALYSIS LABORATORY 02JAN74

Fig. 5 A Typical Processing Report for Alfalfa

```

*****
*
*           ERTS-1           *
*
* SITE PROCESSING REPORT *
*****

```

```

SITE DESIGNATOR:  CV 7  W      CELLS  2631 TO  2634
IMAGE IDENTIFIER: 1232-17463   LINES  1534 TO  1541
DATE ACQUIRED:    12MAR73      TOTAL  PCINTS   32

```

CORRECTED FOR SUN ELEVATION 33 DEGREES

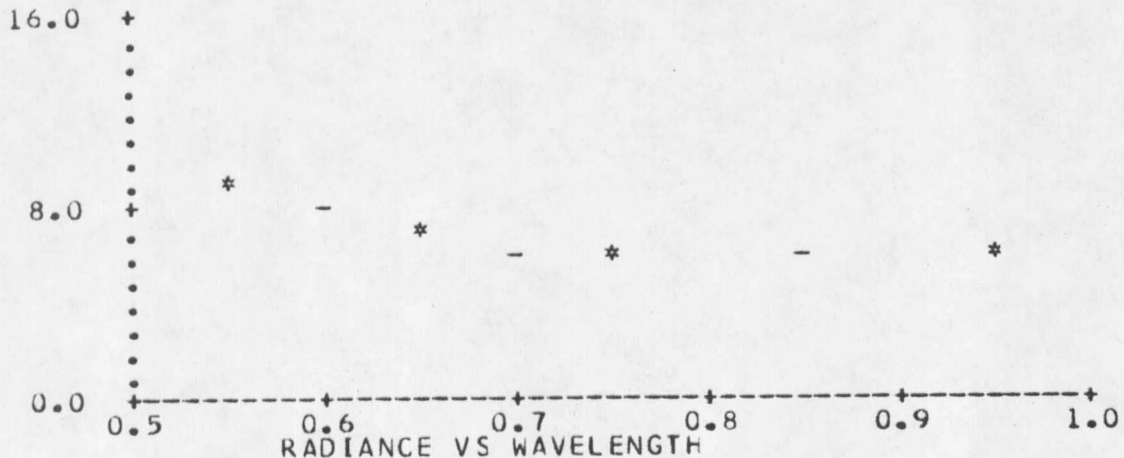
RADIANCE(MWATTS/SQCM-STR-MICROMETER)

	MEAN	STANDARD DEVIATION	WAVELENGTH (MICROMETERS)
BAND 4	9.24	0.43	.5 - .6
BAND 5	7.12	0.46	.6 - .7
BAND 6	6.29	0.45	.7 - .8
BAND 7	5.55	0.47	.8 -1.1

NORMALIZED COVARIANCES

	BAND 4	BAND 5	BAND 6	BAND 7
BAND 4	1.000	0.622	0.703	0.715
BAND 5	0.622	1.000	0.685	0.660
BAND 6	0.703	0.685	1.000	0.778
BAND 7	0.715	0.660	0.778	1.000

BAND RATIO PARAMETER -0.124
TRANSFORMED PARAMETER 0.613



PREPARED BY: TEXAS A&M UNIVERSITY, REMOTE SENSING CENTER
DATA ANALYSIS LABORATORY 26SEP73

Fig. 6 A Typical Processing Report for Wheat

 * ERTS-1 *
 * SITE PROCESSING REPORT *

SITE DESIGNATOR: CV 7 R CELLS 2433 TO 2440
 IMAGE IDENTIFIER: 1052-17452 LINES 1422 TO 1430
 DATE ACQUIRED: 13SEP72 TOTAL POINTS 72

CORRECTED FOR SUN ELEVATION 40 DEGREES

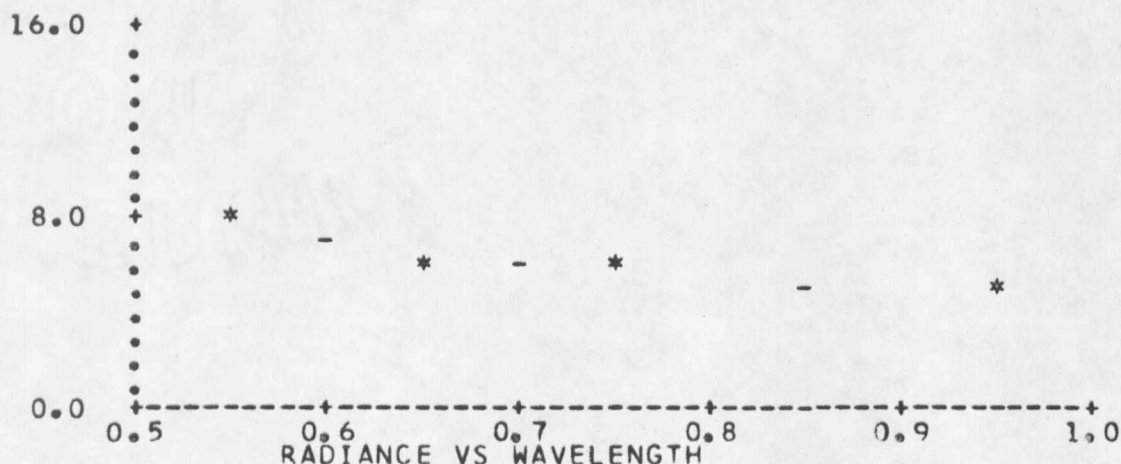
RADIANCE(MWATTS/SQCM-STR-MICROMETER)

	MEAN	STANDARD DEVIATION	WAVELENGTH (MICROMETERS)
BAND 4	8.13	0.37	.5 - .6
BAND 5	5.74	0.37	.6 - .7
BAND 6	5.69	0.35	.7 - .8
BAND 7	4.83	0.44	.8 - 1.1

NORMALIZED COVARIANCES

	BAND 4	BAND 5	BAND 6	BAND 7
BAND 4	1.000	0.605	0.028	-0.078
BAND 5	0.605	1.000	-0.041	-0.203
BAND 6	0.028	-0.041	1.000	0.610
BAND 7	-0.078	-0.203	0.610	1.000

BAND RATIO PARAMETER -0.086
 TRANSFORMED PARAMETER 0.643



PREPARED BY: TEXAS A&M UNIVERSITY, REMOTE SENSING CENTER
 DATA ANALYSIS LABORATORY 23JUL73

Fig. 7 A Typical Processing Report for Range

reports.

It was necessary to specify the exact location of each test plot so RSC could program their computer to process only those digital data lying within the test plot boundaries. This proved to be a very difficult task. Figure 8 is an example of a gray-scale map produced by the RSC computer, on which test plot locations were manually marked. In order to determine the correct places to mark, the gray-scale maps for every plot (more than 30) were compared with:

1. Available maps of the area including county maps, road maps, aviation maps, topographical maps, etc.
2. Available aerial photographs of the area including U-2 aircraft overflights, Agricultural Stabilization and Conservation Service crop photos, etc.
3. Descriptions of the appropriate areas by workers at each of the sites.

If necessary, on-site comparisons of the land features with the gray-scale maps were made.

Once the initial location of each test plot had been marked on a gray-scale map as specified above, future locating procedures for each overpass were simplified. The magnetic tapes (from NDFF) used at RSC gave the approximate latitude and longitude of each data group (covering approximately 10,000 square nautical miles). An acetate overlay made from a precious overflight image was then used to accurately locate the test plots on a new gray-scale map. As long as successive overflight images were useful, (those with no clouds, haze, or snow) the changes in each ensuing gray-scale map were not



Figure 8. A Typical Gray-Scale Map from Computer Output
for "Locating" the Test Plots

drastic enough to cause serious location problems. However, only about 39% of the images for the 1973 growing season were useful. Appendix 2 indicates the usefulness of the images during the test period.

After the processing report for each test plot was produced at RSC, the reports were sent to Montana State University for analysis. Gray-scale maps (accompanying the processing reports) were examined to assure that the correct data had been extracted by the computer at RSC.

Acquisition of Ground Data for Analyses

Use was made of 35 mm Ektachrome slides taken from a height of four feet above the ground, at an angle of 30 degrees down from the horizontal (Dethier 1974, pages 108-126) to determine how much of the ground was covered by green foliage at each of the 10 sites (30 sub-sites) in the Rocky Mountain and Columbia Valley corridors. A panel of seven individuals observed the slide projections on a screen and each person judged the fraction of the ground covered with green foliage. The most suitable series of photographs were used for each subsite, and in each case the same photographic scene was observed simultaneously by the seven panel members. Thus, while four different 30 degree photographic views at each rangeland site were available (one in each compass direction), only a single directional view typical of the area was considered and viewed by the panel. For alfalfa and

wheat the most suitable of the two available 30 degree photographs taken was selected in each case. Judgments of fraction green were not modified to adjust for possible bias related to the fact that photographs were not taken perpendicularly to the ground.

The lowest and highest judgments of ground covered with green foliage were dropped and a mean was computed from the remaining five judgments. Figures 9 through 28 give plots of the mean for the fraction green judgments. Fraction green is plotted as ordinate and time (from October 1972 through November 1973) as abscissa. Since photographs were normally made every six days, date points are usually six days apart. There are some gaps in the 14-month time period, especially during the winter of 1972-73 when most stations were not operative because of snow cover.

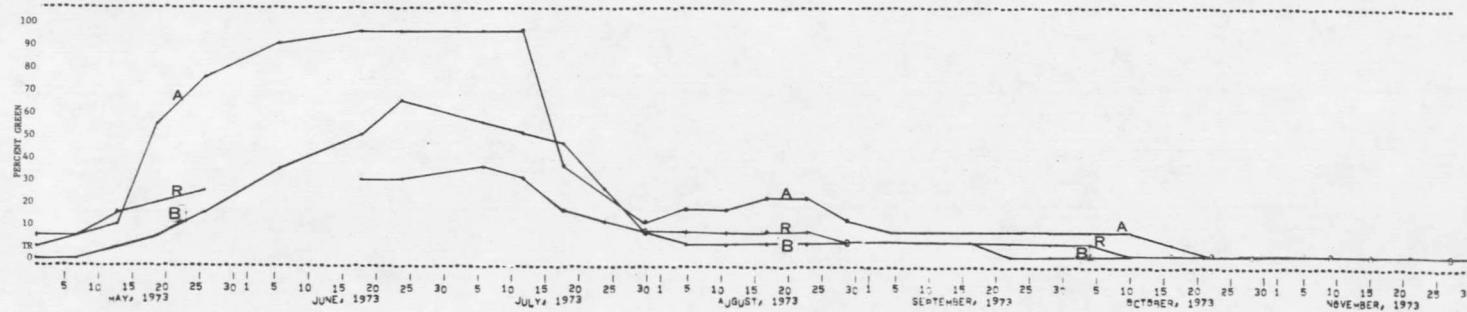
There are two figures for each of the sites. The first figure gives mean percent green over time for each of the three subsites. Thus, there are three lines on the graph for each site. The second figure gives the average fraction green for the site throughout the observation period based on the means of fraction green for alfalfa, wheat, and range.

Tables in Appendix 3 list the judgments made by the panel of fraction green ground cover created by the foliage.

Ground data for range plots used in the analyses are taken from sites where only one range test plot was originally specified for

LEGEND: A-ALFALFA; B-BARLEY; R-RANGE

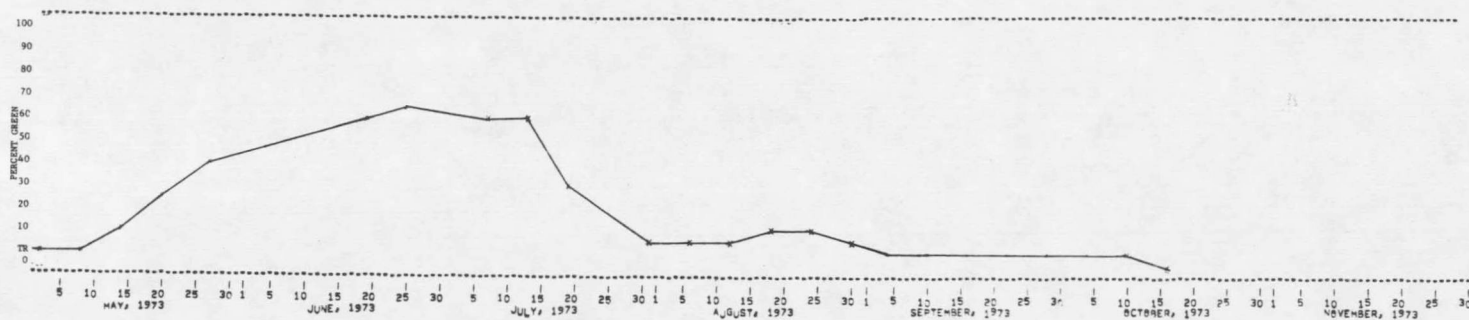
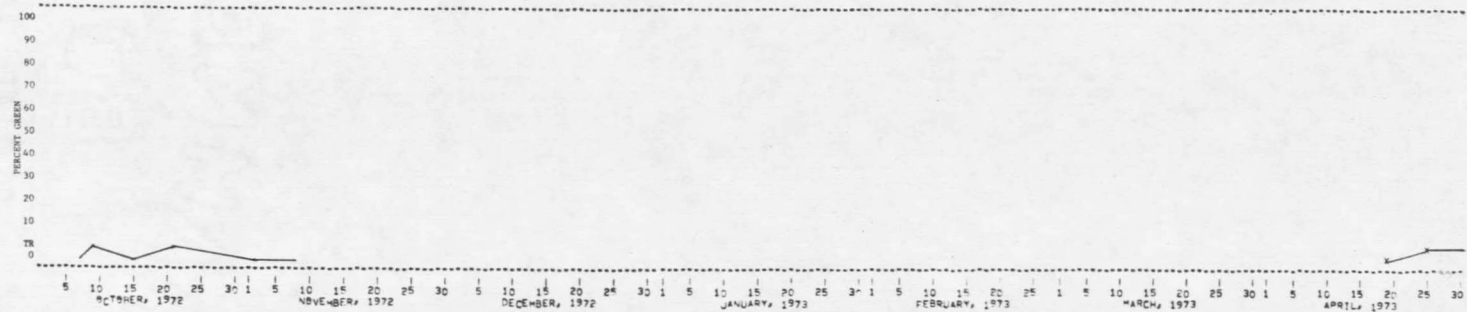
Date	Percent Green (O)	Percent Green (Δ)
5 Oct 1972	10	10
10 Oct 1972	10	10
15 Oct 1972	10	10
20 Oct 1972	10	10
25 Oct 1972	10	10
30 Oct 1972	10	10
5 Nov 1972	10	10
10 Nov 1972	10	10
15 Nov 1972	10	10
20 Nov 1972	10	10
25 Nov 1972	10	10
30 Nov 1972	10	10
5 Dec 1972	10	10
10 Dec 1972	10	10
15 Dec 1972	10	10
20 Dec 1972	10	10
25 Dec 1972	10	10
30 Dec 1972	10	10
5 Jan 1973	10	10
10 Jan 1973	10	10
15 Jan 1973	10	10
20 Jan 1973	10	10
25 Jan 1973	10	10
30 Jan 1973	10	10
5 Feb 1973	10	10
10 Feb 1973	10	10
15 Feb 1973	10	10
20 Feb 1973	10	10
25 Feb 1973	10	10
30 Feb 1973	10	10
5 Mar 1973	10	10
10 Mar 1973	10	10
15 Mar 1973	10	10
20 Mar 1973	10	10
25 Mar 1973	10	10
30 Mar 1973	10	10
5 Apr 1973	10	10
10 Apr 1973	10	10
15 Apr 1973	10	10
20 Apr 1973	10	10
25 Apr 1973	10	10
30 Apr 1973	10	10



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Fig. 9 Percent of Ground Covered With Green Foliage At Site RM-1 From October 1972 to November 1973 for Alfalfa, Barley and Range.

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE
AVERAGE OF ALFALFA, BARLEY, RANGE
SITE RM-1



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Fig. 10 Percent of Ground Covered With Green Foliage At Site RM-1 From October 1972 to November 1973 (Average of Alfalfa, Barley and Range).

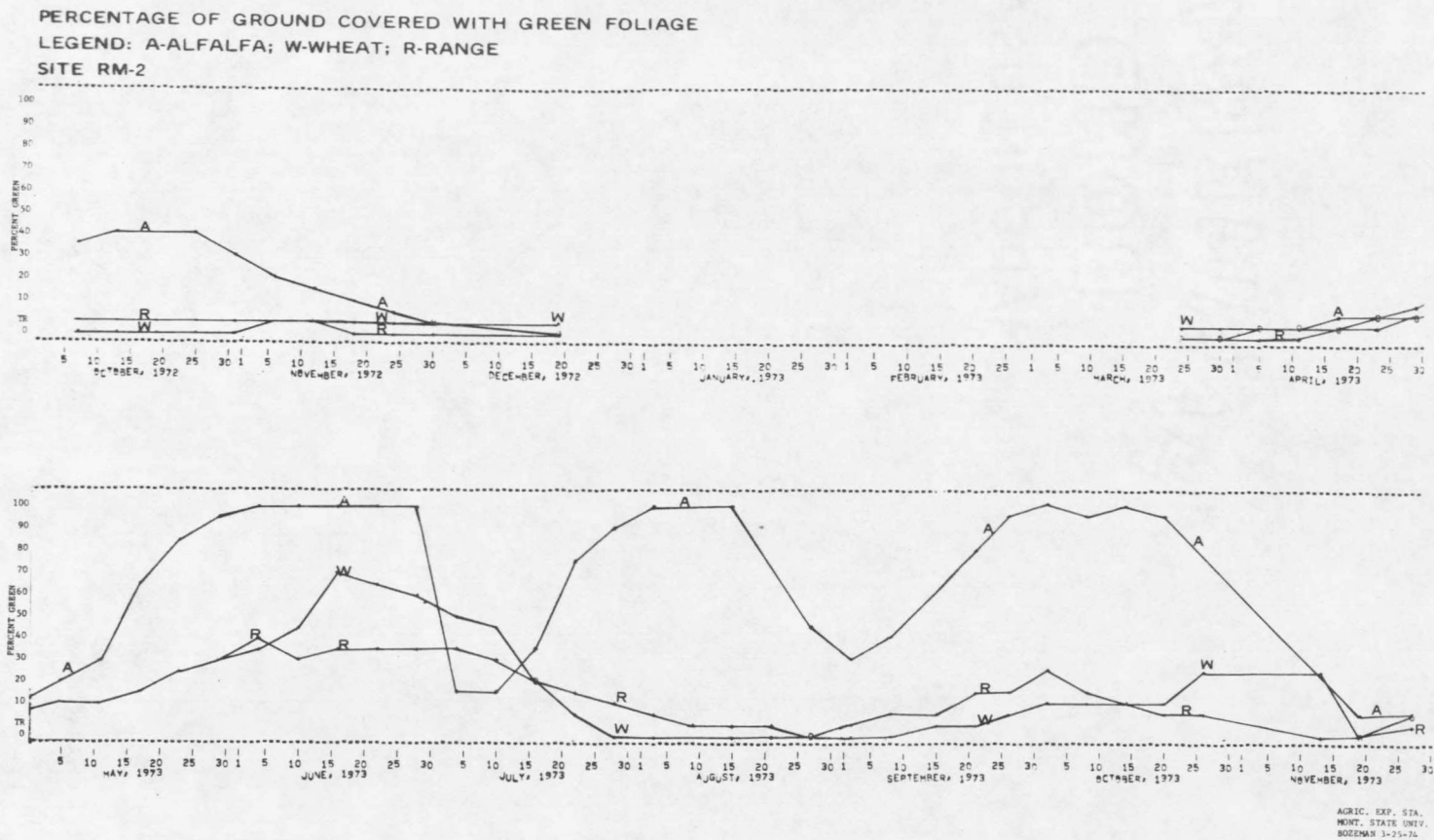


Fig. 11 Percent of Ground Covered With Green Foliage At Site RM-2 From October 1972 to November 1973 for Alfalfa, Wheat and Range.

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE

LEGEND: A-ALFALFA; W-WHEAT; R-RANGE

SITE RM-3

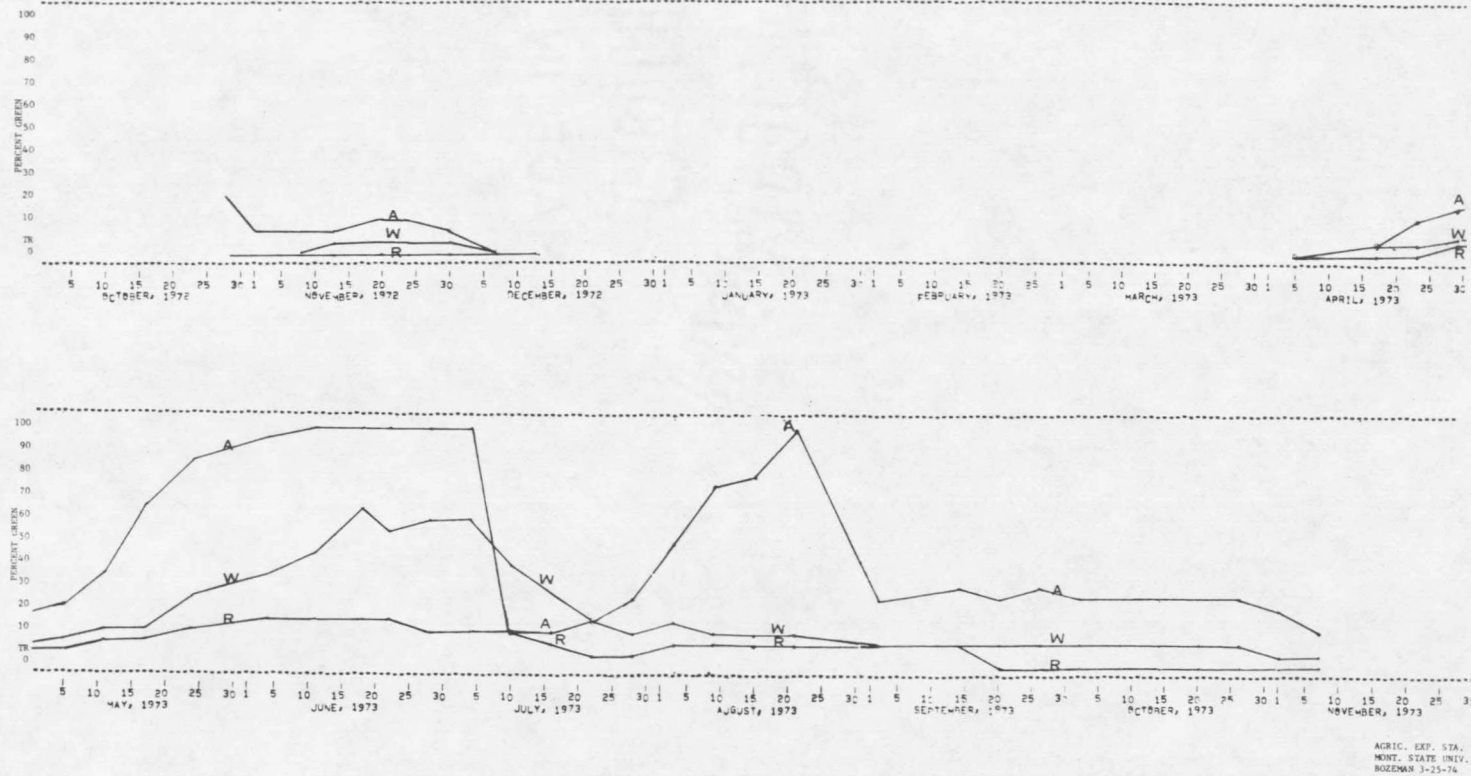


Fig. 13 Percent of Ground Covered With Green Foliage At Site RM-3 From October 1972 to November 1973 for Alfalfa, Wheat and Range.

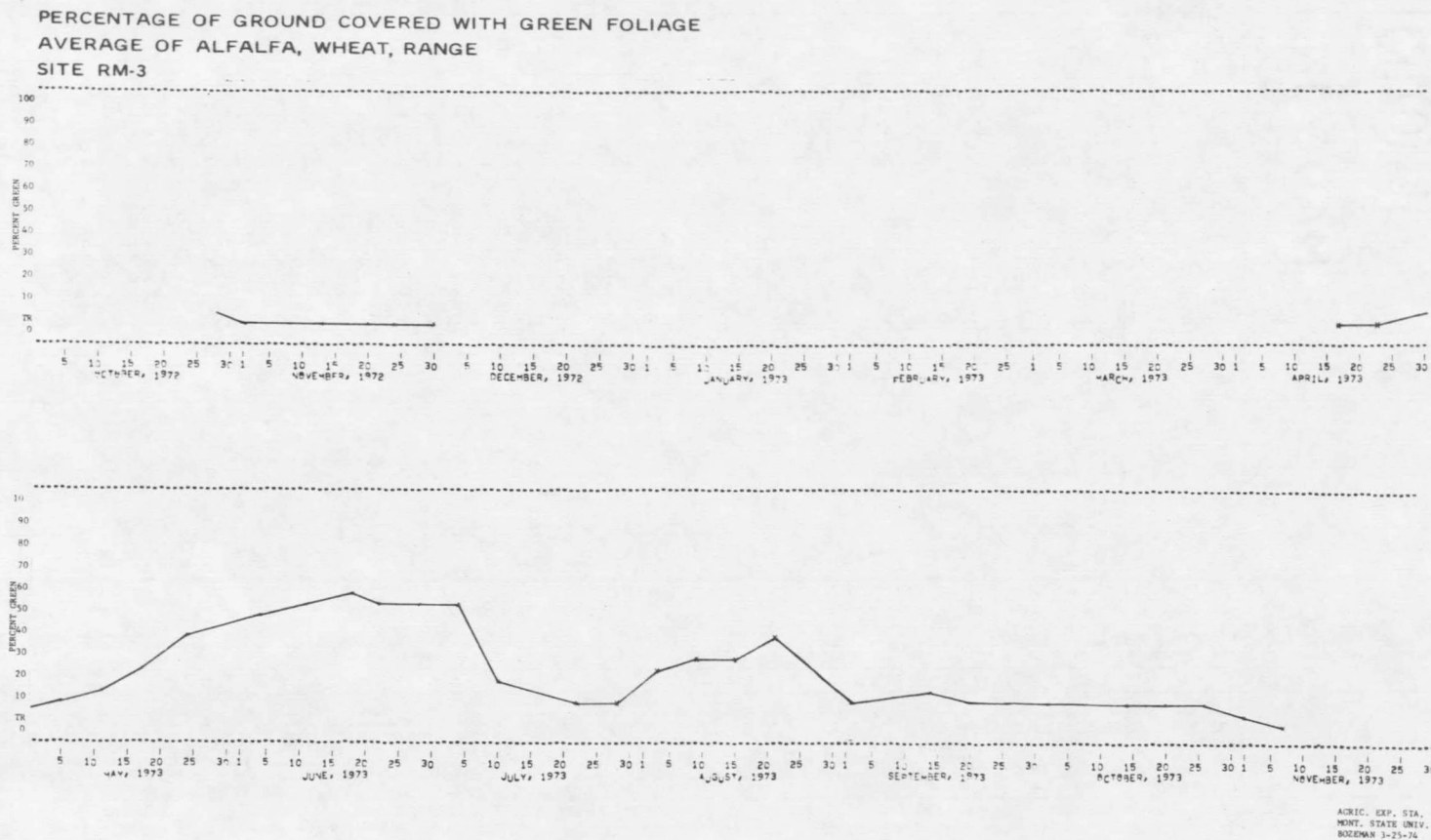


Fig. 14 Percent of Ground Covered With Green Foliage At Site RM-3 From October 1972 to November 1973 (Average of Alfalfa, Wheat and Range).

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE
 LEGEND: A-ALFALFA; W-WHEAT; R-RANGE
 SITE RM-4

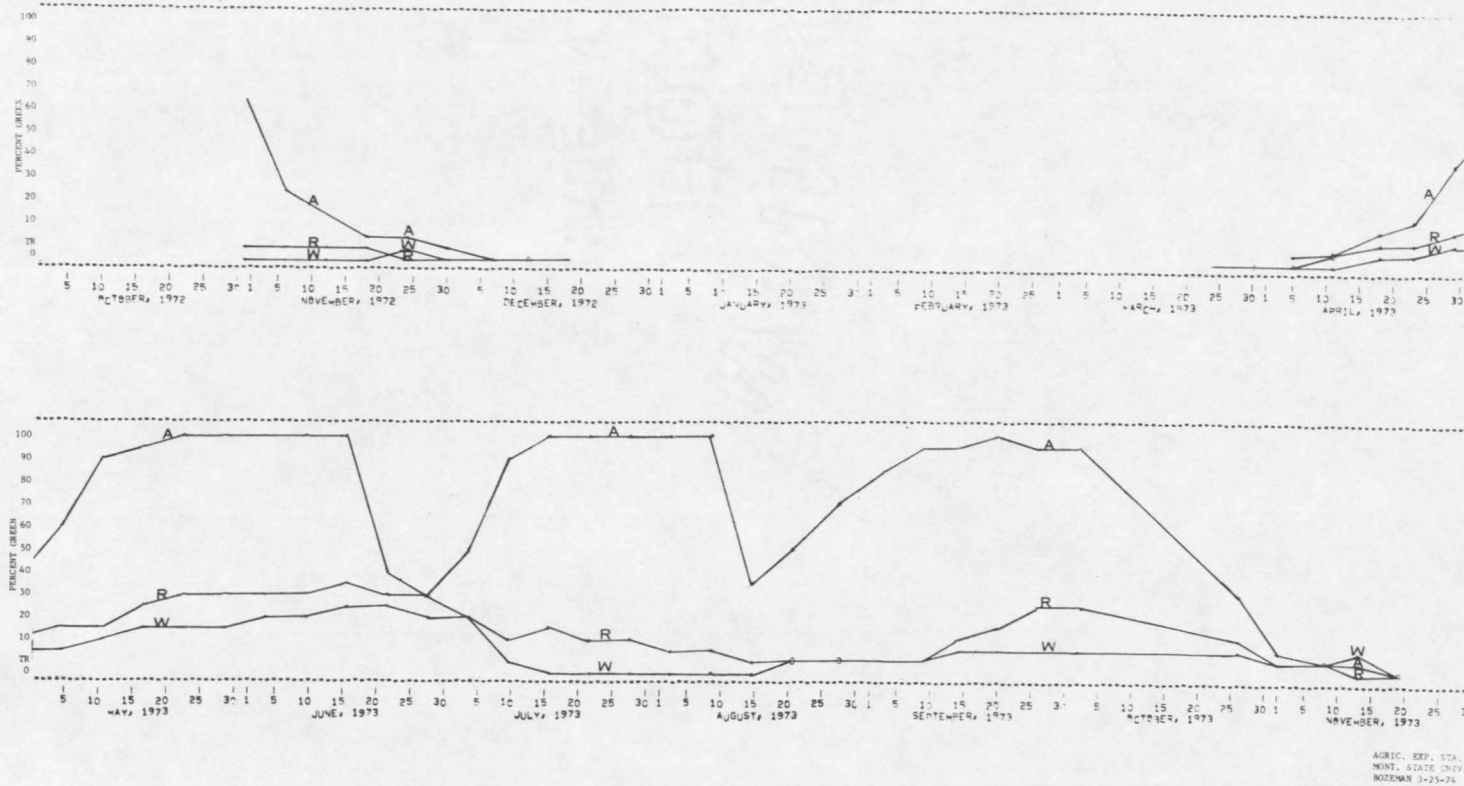


Fig. 15 Percent of Ground Covered With Green Foliage At Site RM-4 From October 1972 to November 1973 for Alfalfa, Wheat and Range.

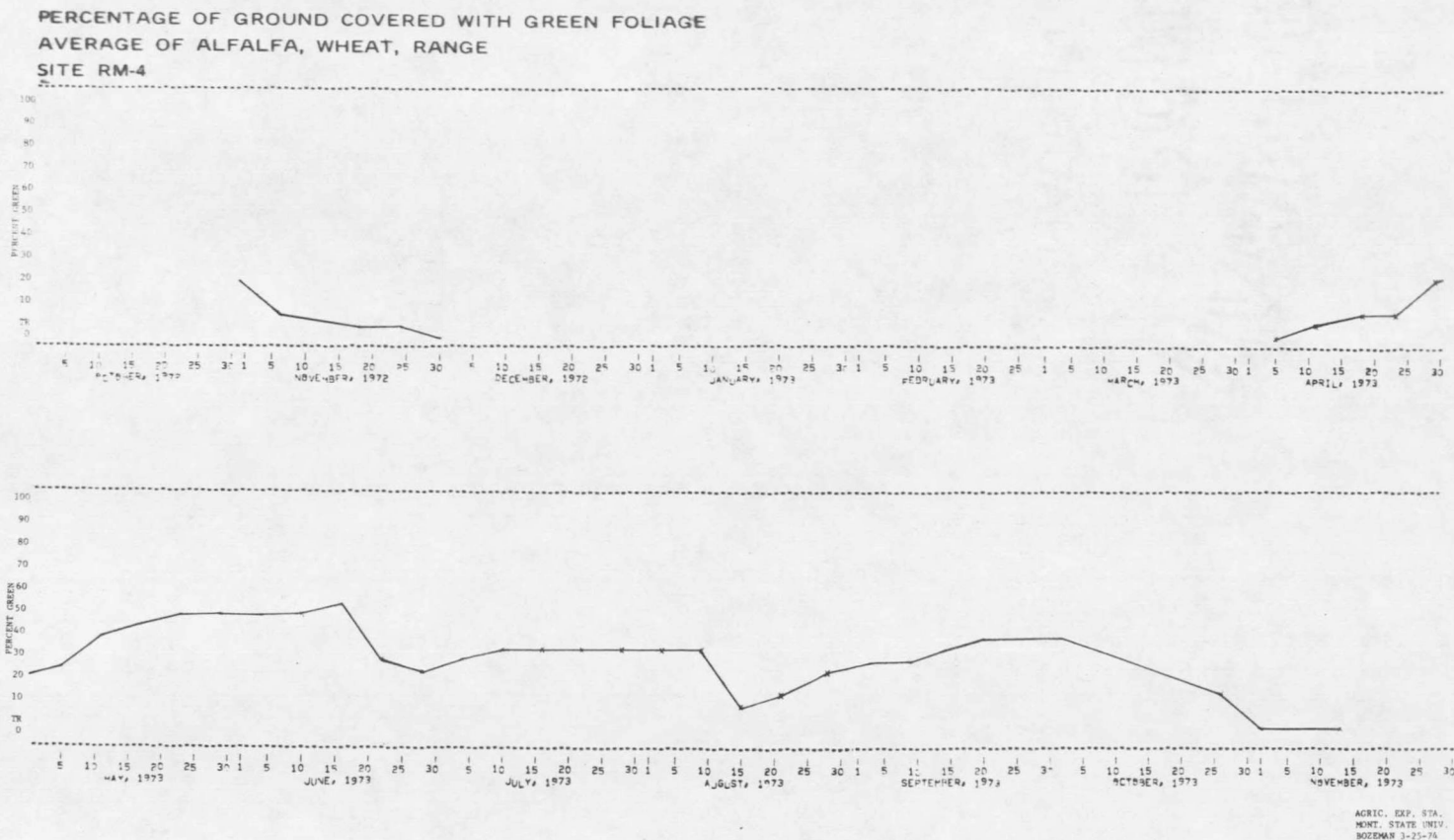


Fig. 16 Percent of Ground Covered With Green Foliage At Site RM-4 From October 1972 to November 1973 (Average of Alfalfa, Wheat and Range).

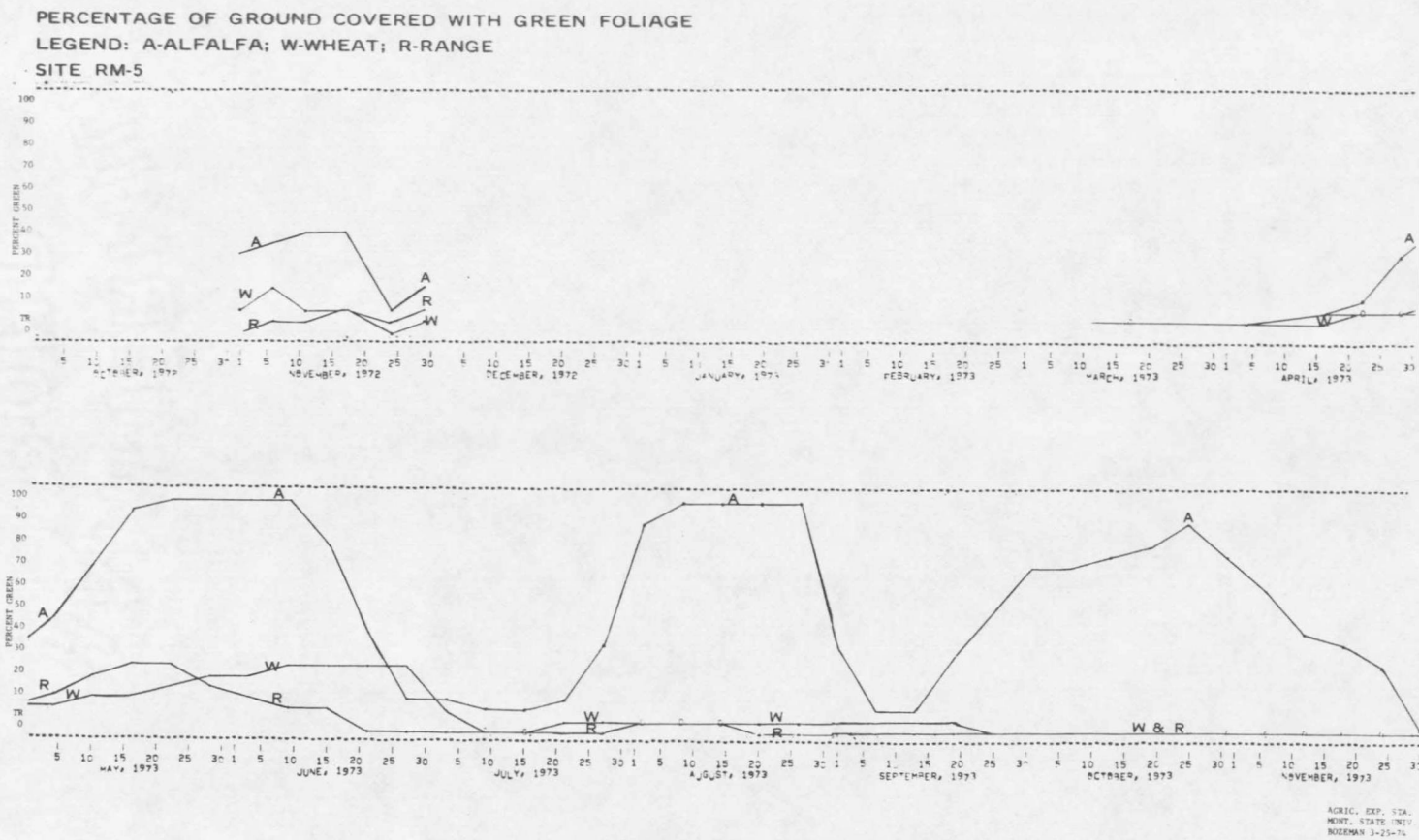
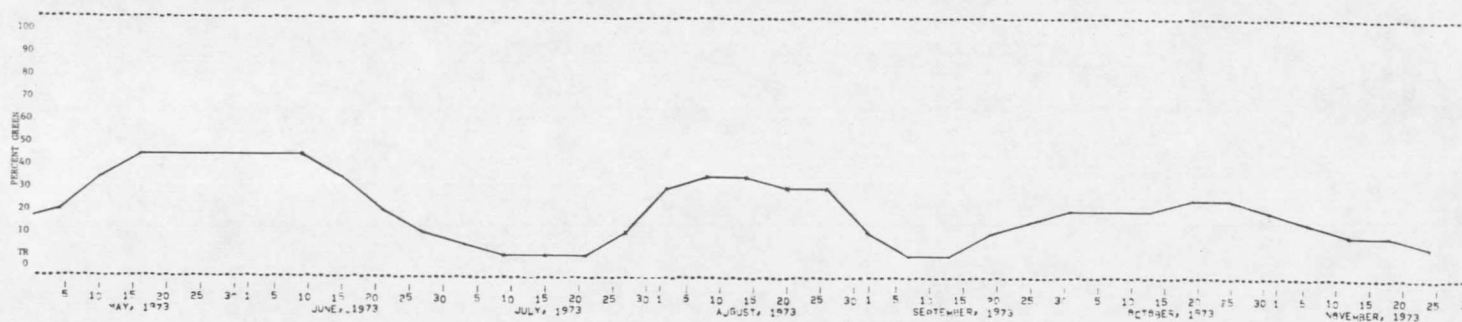
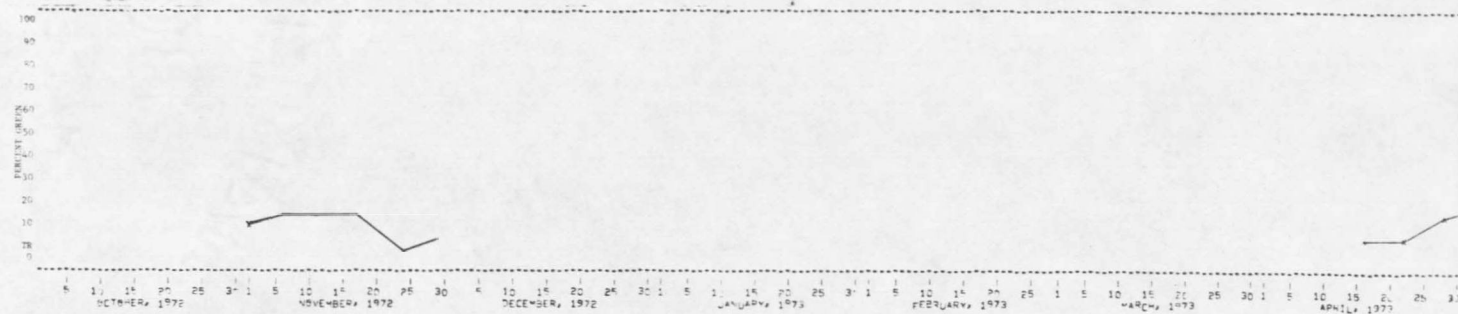


Fig. 17 Percent of Ground Covered With Green Foliage At Site RM-5 From November 1972 to November 1973 for Alfalfa, Wheat and Range.

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE
AVERAGE OF ALFALFA, WHEAT, RANGE
SITE RM-5



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Fig. 18 Percent of Ground Covered With Green Foliage At Site RM-5 From November 1972 to November 1973 (Average of Alfalfa, Wheat and Range).

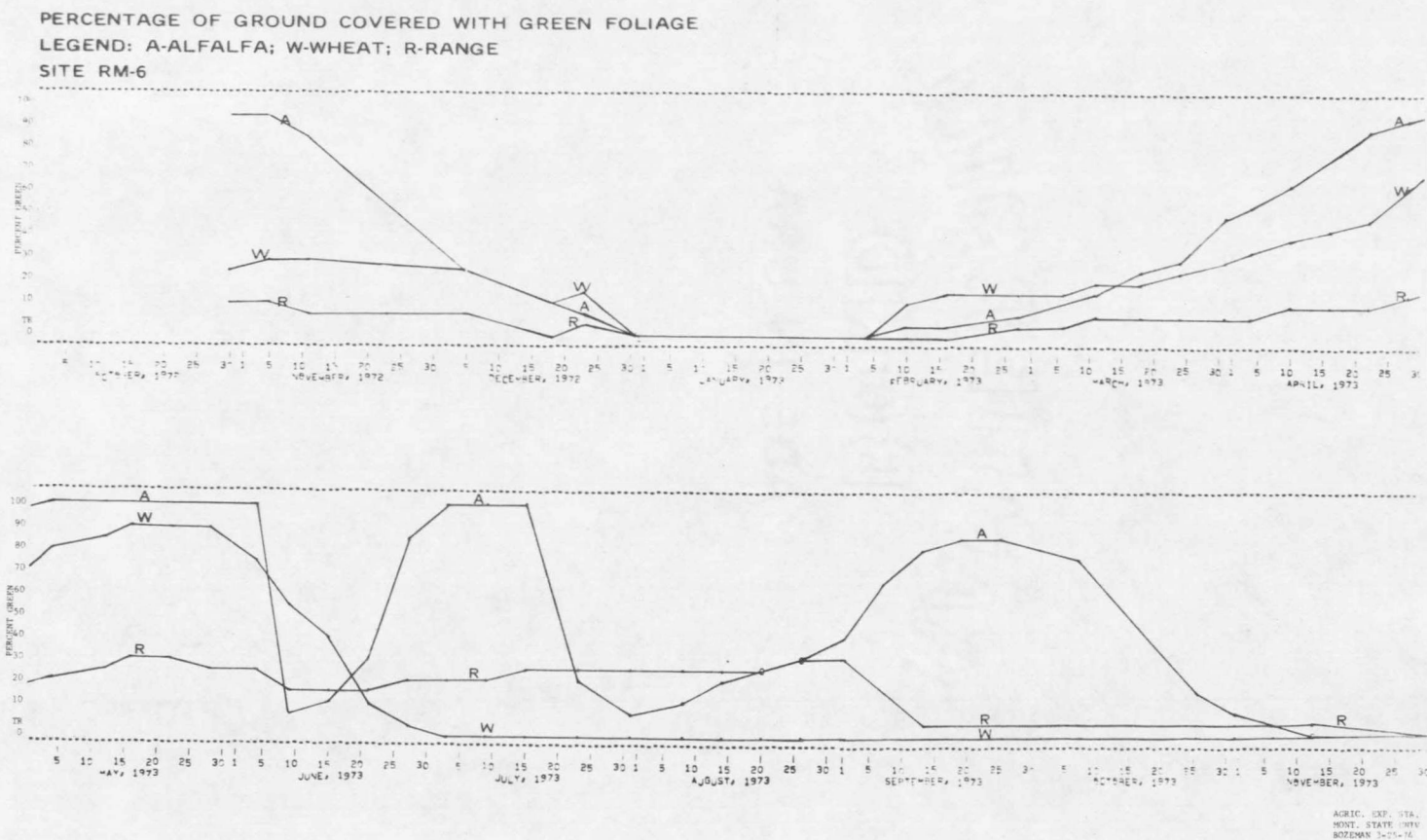


Fig. 19 Percent of Ground Covered With Green Foliage At Site RM-6 From October 1972 to November 1973 for Alfalfa, Wheat and Range.

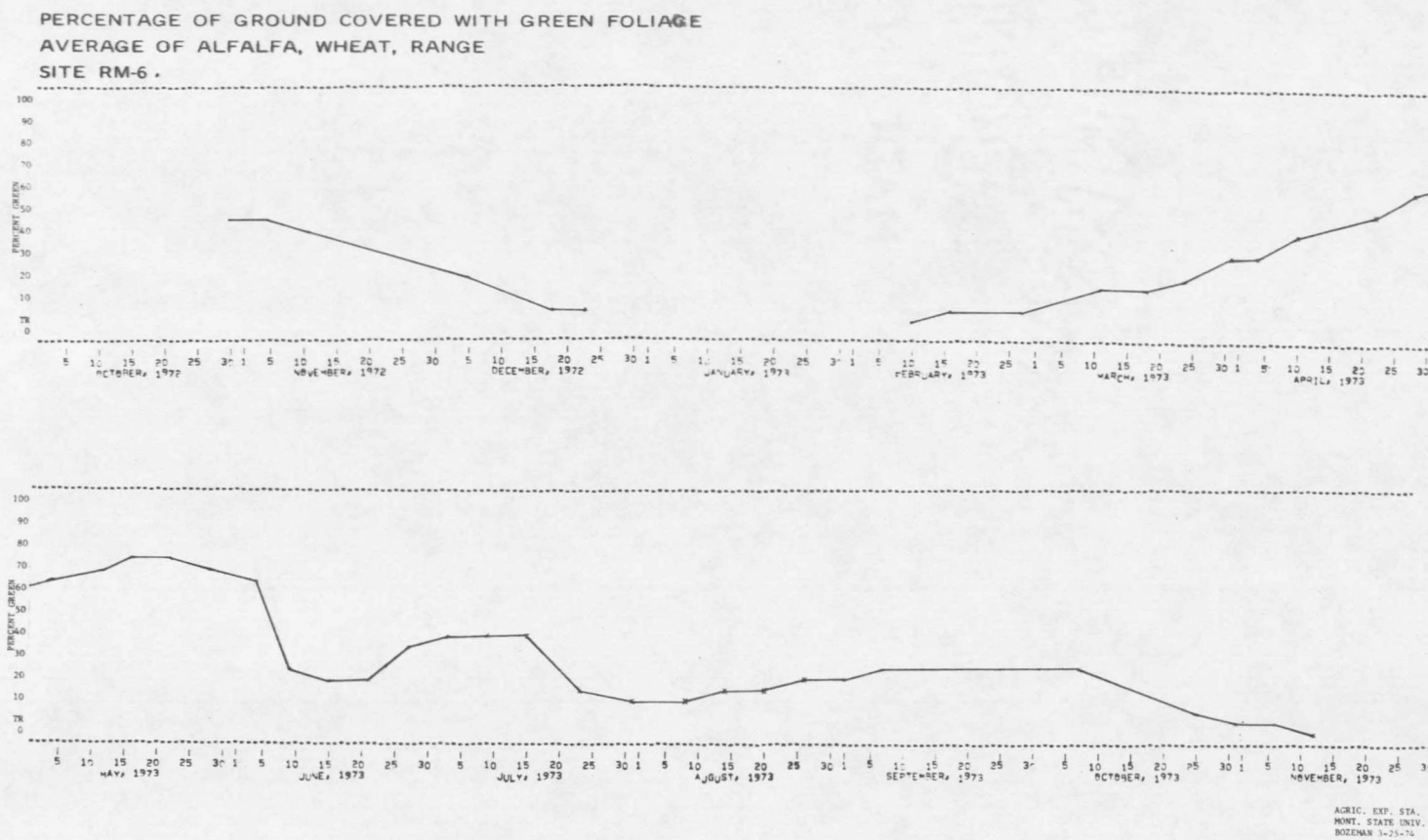


Fig. 20 Percent of Ground Covered With Green Foliage At Site RM-6 From October 1972 to November 1973 (Average of Alfalfa, Wheat and Range).

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE
 LEGEND: A-ALFALFA; W-WHEAT; R-RANGE
 SITE CV-7

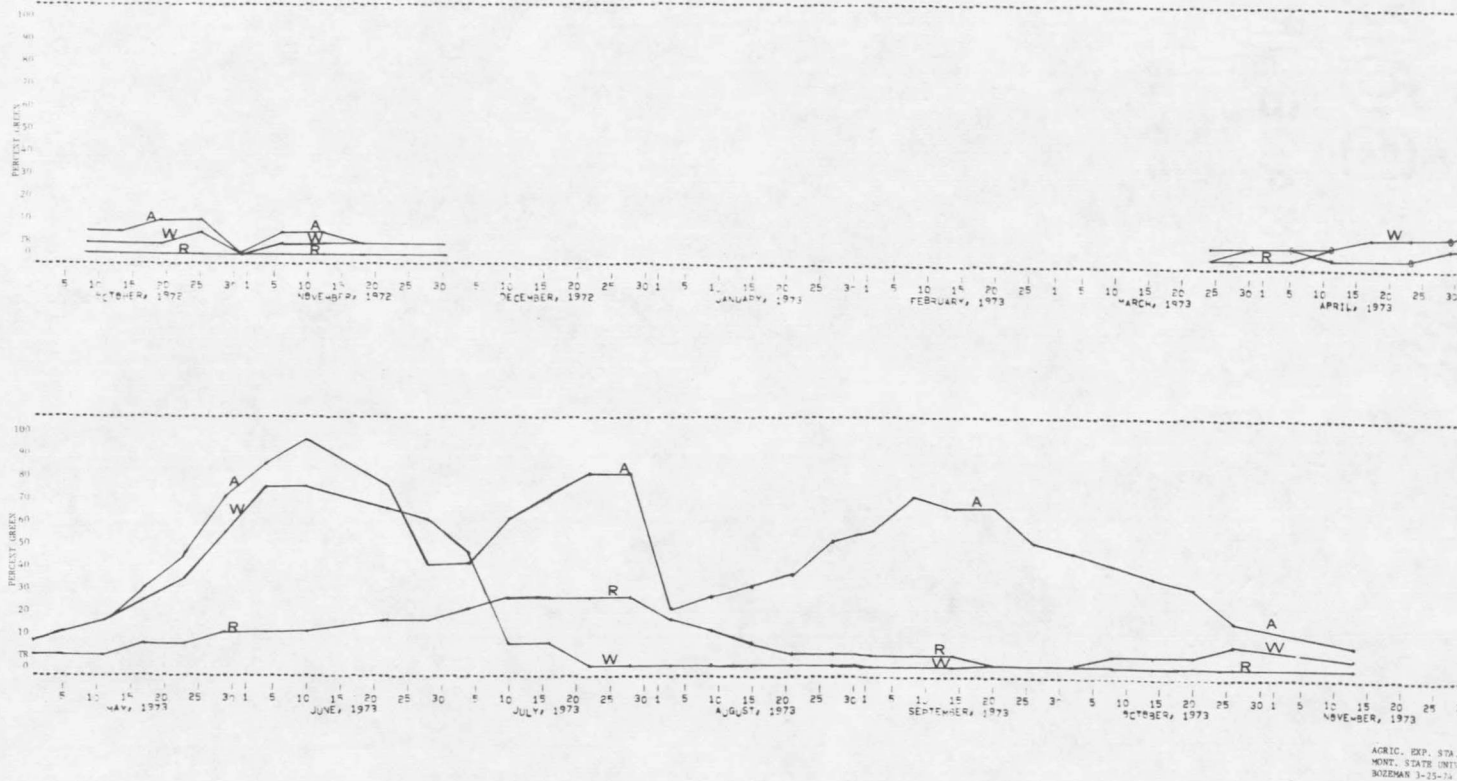


Fig. 21 Percent of Ground Covered With Green Foliage At Site CV-7 From October 1972 to November 1973 for Alfalfa, Wheat and Range.

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE
AVERAGE OF ALFALFA, WHEAT, RANGE
SITE CV-7

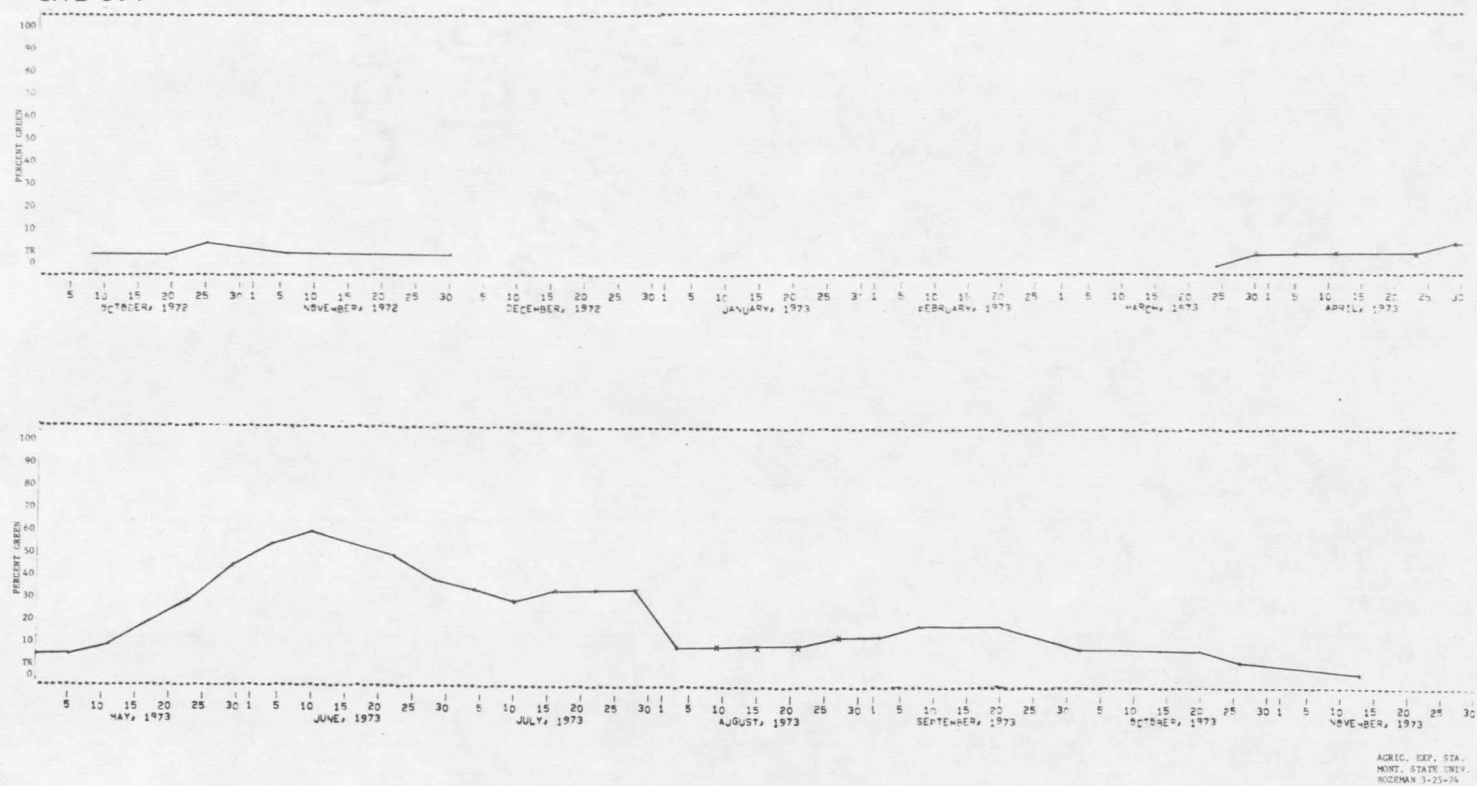
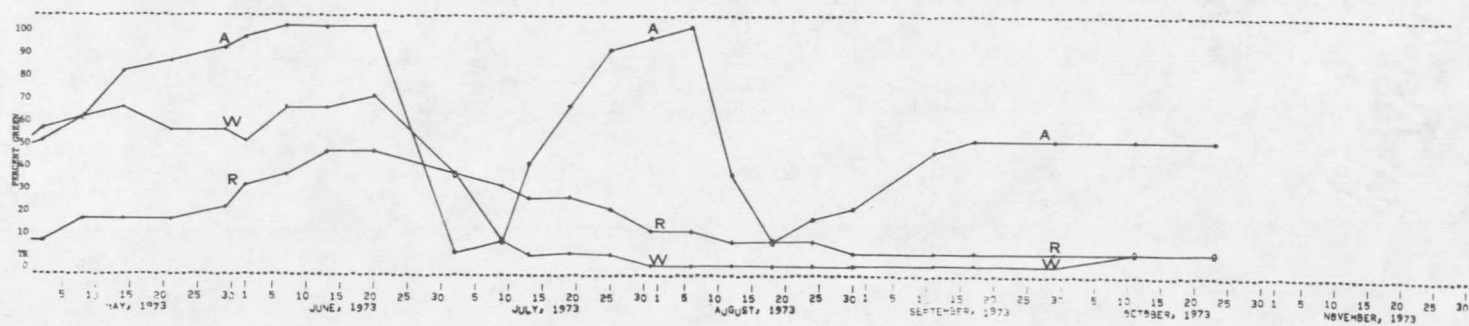
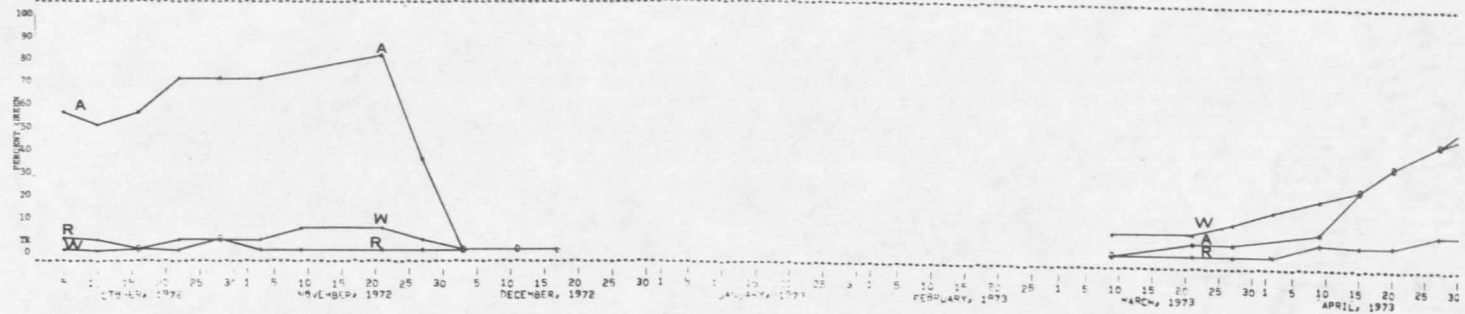


Fig. 22 Percent of Ground Covered With Green Foliage At Site CV-7 From October 1972 to November 1973 (Average of Alfalfa, Wheat and Range).

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE

LEGEND: A-ALFALFA; W-WHEAT; R-RANGE

SITE CV-8



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Fig. 23 Percent of Ground Covered With Green Foliage At Site CV-8 From October 1972 to October 1973 for Alfalfa, Wheat and Range.

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE
AVERAGE OF ALFALFA, WHEAT, RANGE
SITE CV-8

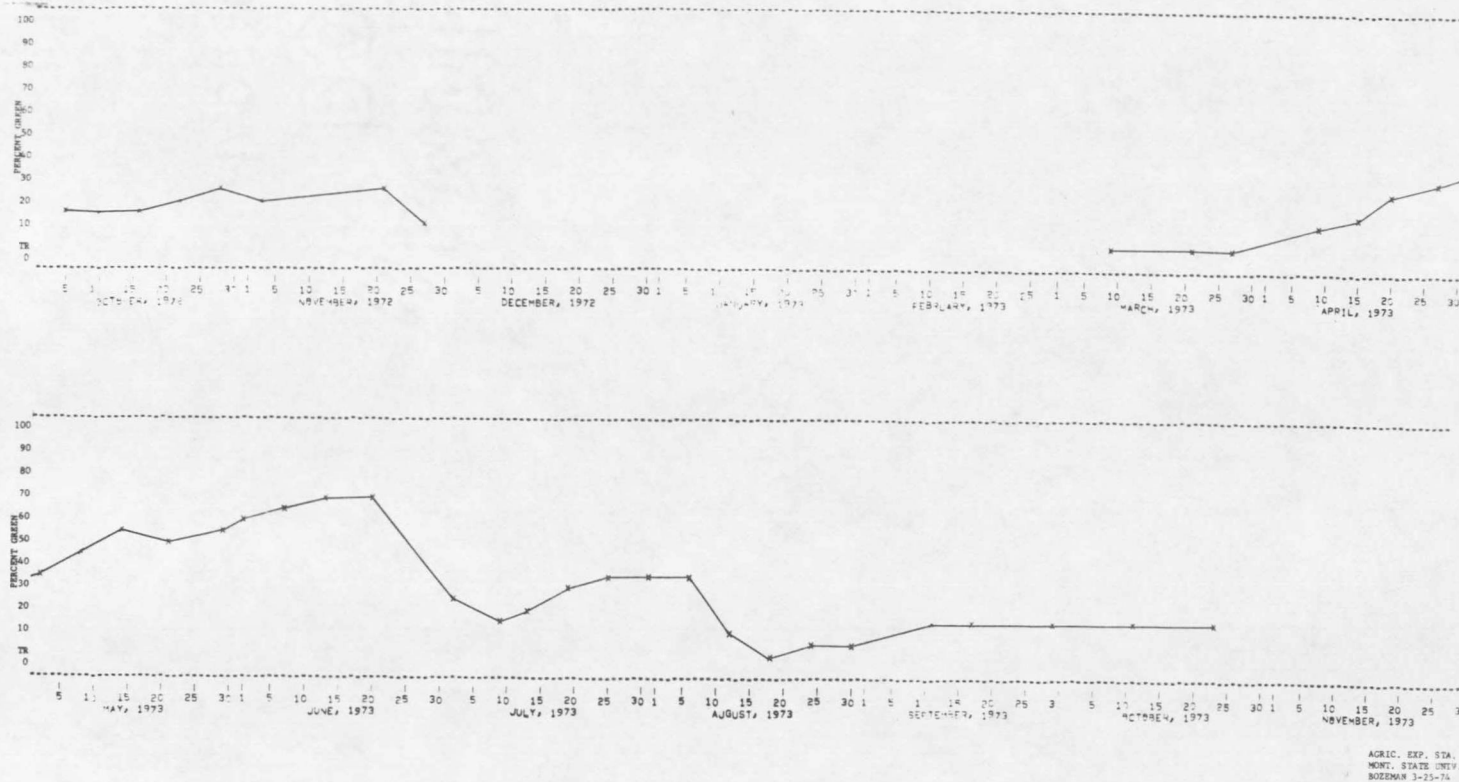


Fig. 24 Percent of Ground Covered With Green Foliage At Site CV-8 From October 1972 to November 1973 (Average of Alfalfa, Wheat and Range).

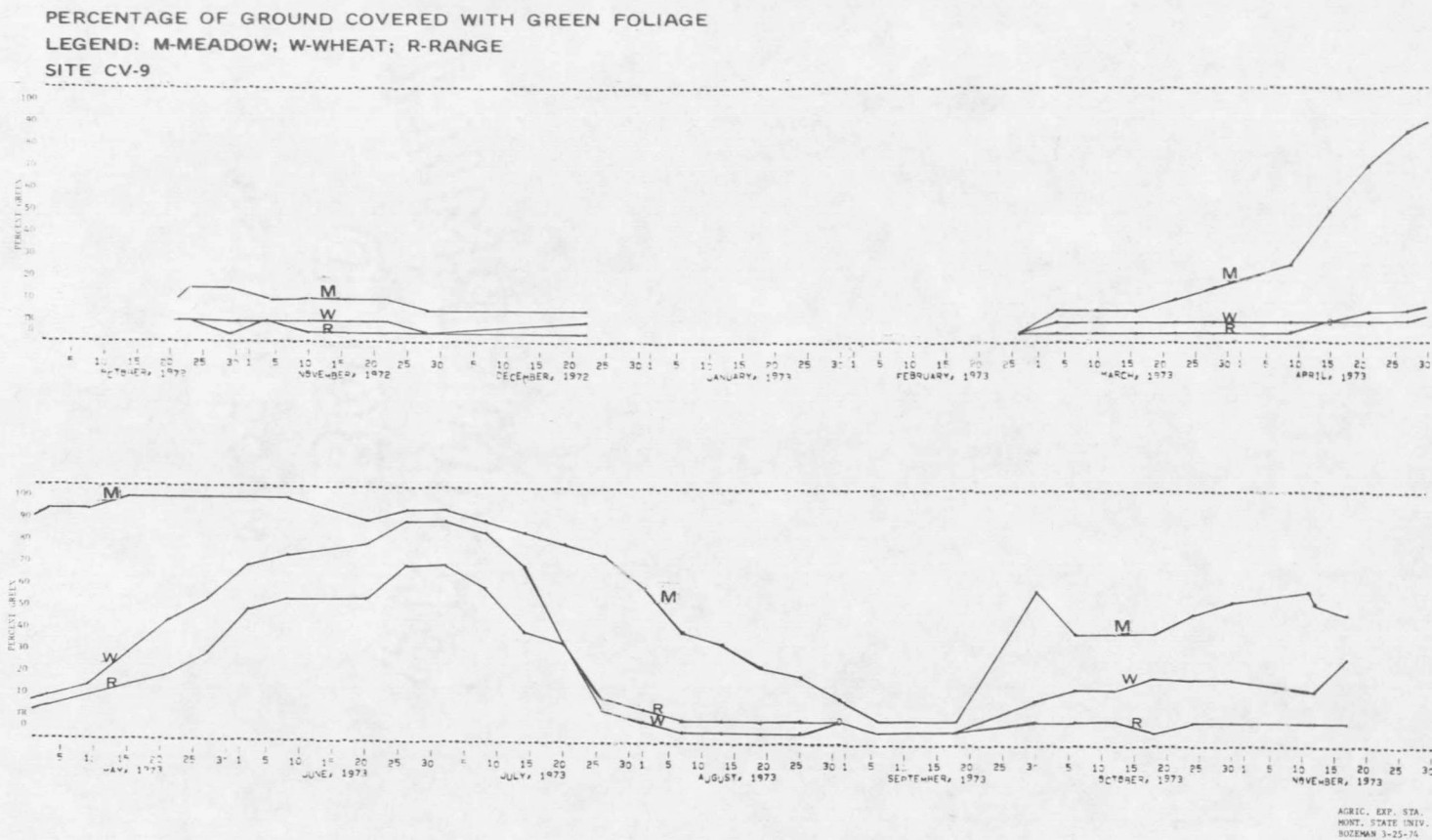


Fig. 25 Percent of Ground Covered With Green Foliage At Site CV-9 From October 1972 to November 1973 for Meadow, Wheat and Range.

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE
AVERAGE OF MEADOW, WHEAT, RANGE
SITE CV-9

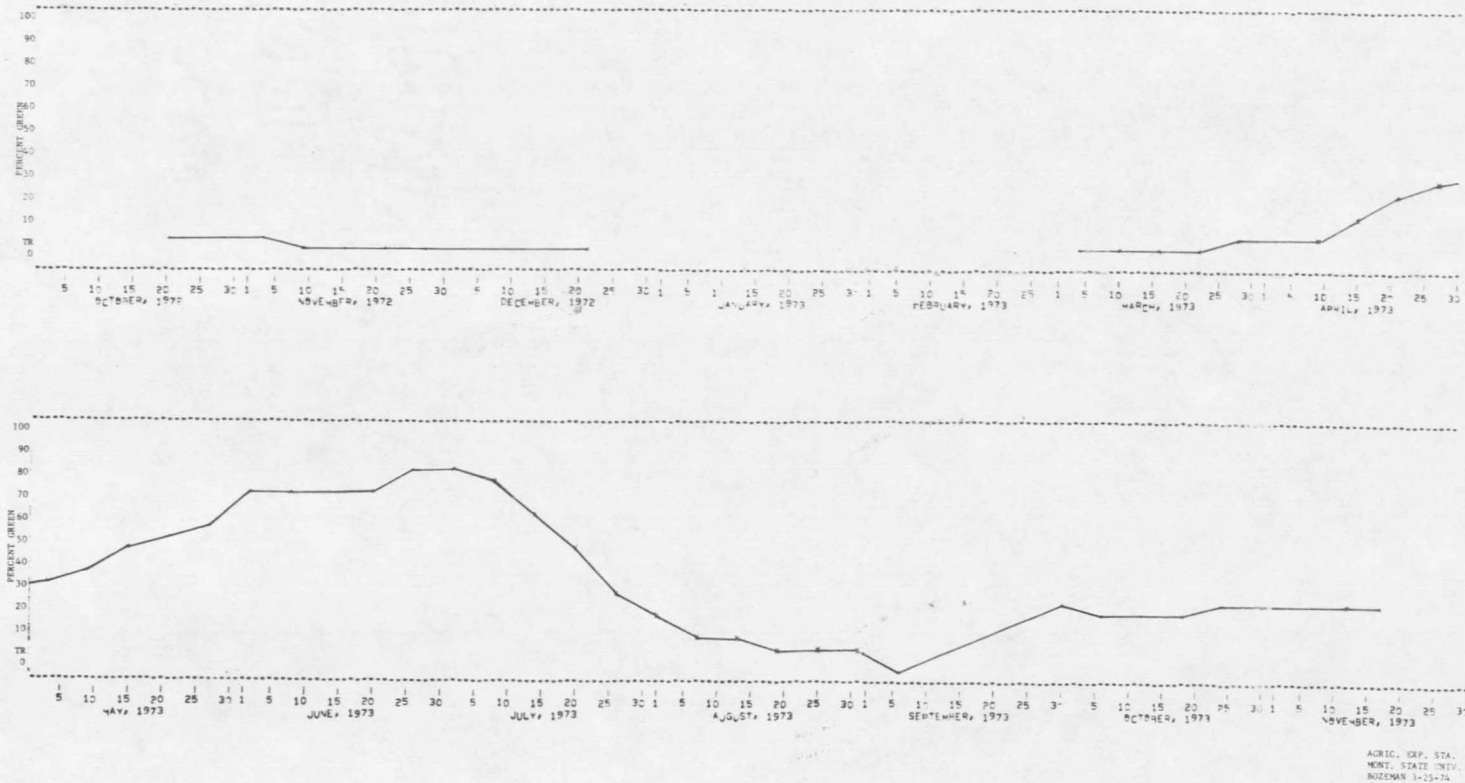
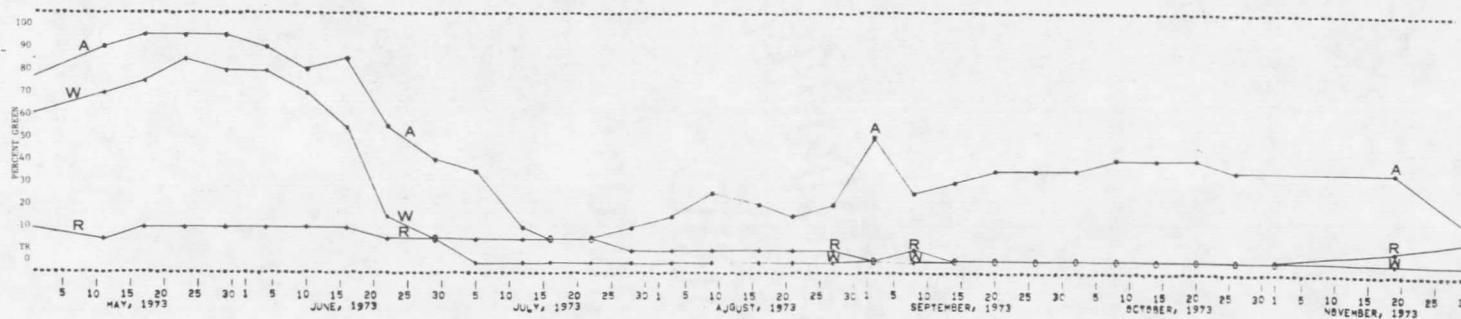
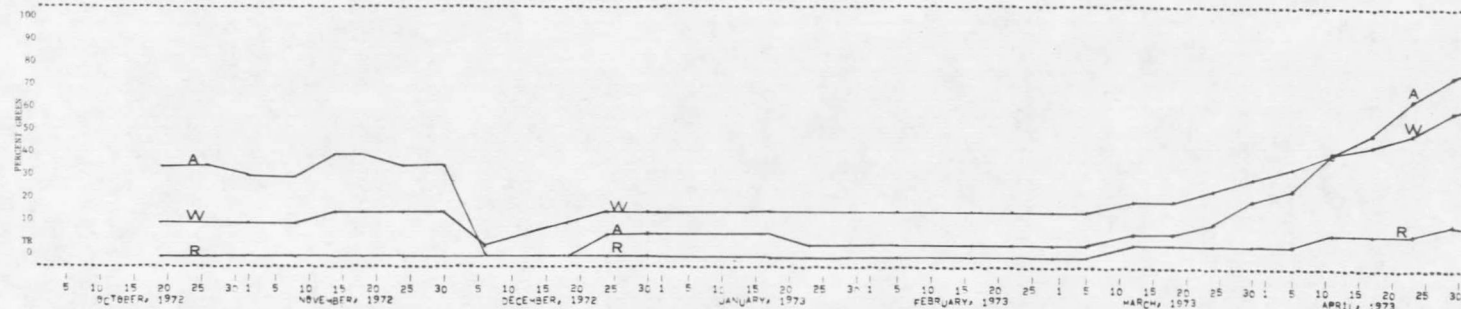


Fig. 26 Percent of Ground Covered With Green Foliage At Site CV-9 From October 1972 to November 1973 (Average of Meadow, Wheat and Range).

PERCENTAGE OF GROUND COVERED WITH GREEN FOLIAGE

LEGEND: A-ALFALFA; W-WHEAT; R-RANGE

SITE CV-10



AGRIC. EXP. STA.
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Fig. 27 Percent of Ground Covered With Green Foliage At Site CV-10 From October 1972 to November 1973 for Alfalfa, Wheat and Range.

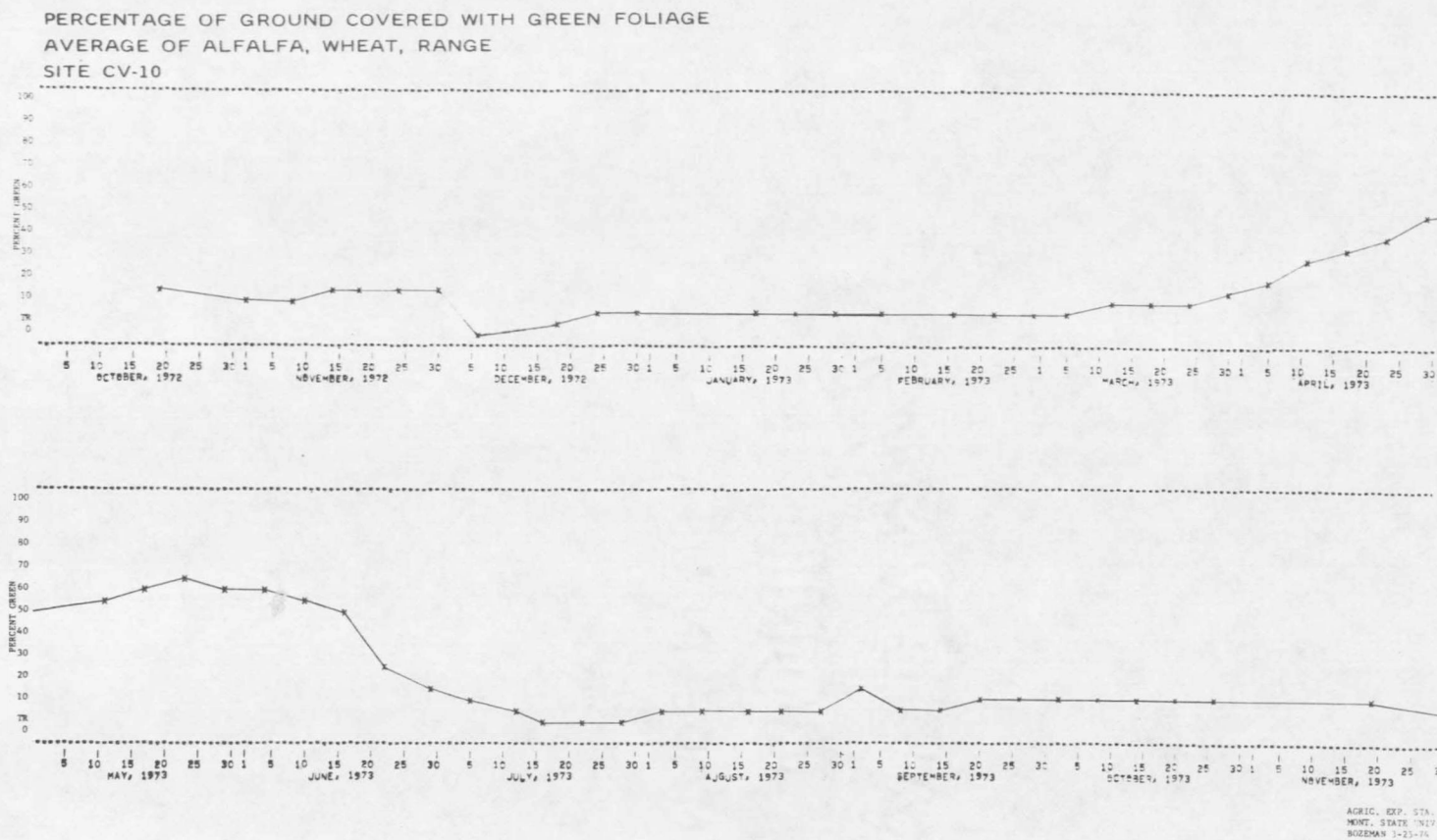


Fig. 28 Percent of Ground Covered With Green Foliage At Site CV-10 From October 1972 to November 1973 (Average of Alfalfa, Wheat and Range).

analysis. Thus, range data from sites RM-5 and CV-10 (Appendix 1 specifies site locations) were not used because multiple test plots and conifer test plots were observed. Data from "extra" range plots at site CV-9 were not included because ground observation and verification of the crop type were not available.

Exceptions to using alfalfa and wheat data from all ten test sites were:

1. No alfalfa data were available from the CV-7 and CV-9 sites.

The crops there were mostly grass with sparse patches of alfalfa and irrigated meadow grass forage, respectively.

2. No wheat data were available from RM-1 site since the farmer replanted barley after the late-planted wheat winter-killed.

However, these data were included with the wheat data since only two satellite samples (on 4 August and 10 September 1973) of .01 and .006 fraction green were involved.

Other ground truth data recorded in the field such as crop type and plant height, were used directly (without any judgments required) in making appropriate correlations with satellite data.

ANALYSES AND RESULTS

In order to develop an appropriate method for data analysis, several analytical procedures were attempted. The method selected to accomplish the objectives, (green and brown wave, crop identity, biomass, etc.) was the incorporation of all available data from the ground and satellite in a computerized analytical procedure. However, some of the other useful methods attempted (not using all satellite data) are also reported below with their results, limitations, and advantages.

Criteria (or ground observation characteristics) available to develop or judge the algorithms include:

1. Indication of fraction green for the test plots. This relates to the overall progress of the green or brown waves which can be considered on an individual crop basis or on a more general basis including all plant species.
2. Indication of a particular crop or plant type. These data might be used in studies to identify or inventory certain crops or plant species.
3. Indication of foliage height. These data can be applied to estimate total amounts of biomass available or crop yields.

In general, the simpler methods were attempted first and the results were used to develop an improved method.

Visual Examination of Transparencies

The four black-and-white transparencies for each satellite

observation were examined under magnification to determine that:

- A. no cloud, haze, or smoke was obscuring the ground test site and that
- B. no malfunction had occurred to cause erroneous or missing data in the test site area.

All four of the transparencies were simultaneously examined and compared to the appropriate ground data to look for correlations that might lead to the objectives.

Limitations and Advantages of Visual Examination

The 9 by 9 inch transparencies could not be sufficiently magnified to accurately locate the test plots at some of the sites. The most useful magnification was about 7 or 8 power. This magnification cannot (under most conditions) isolate a 10 acre field out of the transparency which covers more than 6,400,000 acres. However, even for the larger test plots (up to 40 acres) which could be identified, the objectives of this study could not be fully satisfied by correlation between the ground data and the transparencies. This method is useful in that it indicates general conditions of the area and the presence of reasonable satellite data. Thus, this "preliminary analysis" should be performed before proceeding to other analyses.

Color Enhancement

Color enhancement to obtain more information from the black and white transparencies was performed by several methods, two of these

are described below.

Simultaneous projection was made of two or more (of the four) transparencies using a different colored light in each projector. The projected images were superimposed so that combination of the colors could enhance certain objects. The colored light for each projector is easily obtained by using a colored band pass filter next to the transparency or in front of the lens.

In a similar manner, each black and white transparency can be copied (by the Diazo process) to make a "color transparency". These can then be "stacked" to produce color enhancement of certain objects.

Limitations and Advantages of Color Enhancement

Although three or more transparencies could be projected simultaneously, usually two is the maximum useful number. Likewise, three transparencies is about the limit in stacking the colored transparencies. Thus, color enhancement is feasible and useful when combining two or three transparencies, but if more channels of data are useful, some other means of combining them is appropriate. This method can be usefully adapted to detect percent green cover by combining two channels (such as bands 5 and 7) but precise measurements are difficult. Light sources can be combined to produce a white color (such as three projectors emitting red, blue, and green) while stacked colored filters (or transparencies) in appropriate combinations (such as red, blue,

and yellow) produce black.

These methods of color enhancement could indicate where green foliage exists, but it is estimated that measurements of green cover would be no better than ± 30 percent. Color enhancement would appear to be useful for synoptic studies indicating large areas of dense vegetation.

Color composite prints are examined in a manner similar to that described for transparencies. Three of the four channels (usually numbers 4, 5, and 7) are assigned a false color and are combined to produce a single print. The colors used are approximately red, blue, and yellow. This method is good for a coarse look at a large area, but does not lend itself to easy enlargement or accurate densitometer analysis on each of the data channels. It would be a simple method for detection of the green and brown waves if the land were flat and good cloud-free imagery could be obtained during the relatively short time it takes for the green wave to travel about 100 miles. Since these conditions generally do not occur, this method is only good for detecting the green wave associated with a few precise crops at test plots of equal altitude located in an area of approximately 10,000 square nautical miles.

Use of Densitometer on Transparencies

The four black and white transparencies are examined with a densitometer to determine the "exact" shade of gray at the location of

of the test plot. Thus, it is not necessary to depend on human judgment to determine the value of the reflected energy from the test plot.

Limitations and Advantages of Densitometer Use

This method requires a densitometer with an unusually small aperture. Ashley and Rea (1973) describe methods for performing this measurement. An obvious advantage of this method is that no computer or magnetic tape reader is required to process the data. However, the data is not as precisely presented in a transparency because all 128 levels of the digital data cannot be indicated in a photograph of a cathode ray tube which is displaying the digital data. Furthermore, test plots must be larger than about 20 acres. A serious problem would occur where this method must be used on many test plots. The time required for each measurement would be prohibitive.

Use of BRP, TVP, 5'/7', and 6'/7' Parameters

The band ratio parameter (Rouse 1973) is defined as:

$$BRP = \frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}$$

The transformed vegetation parameter is $TVP = (BRP + 0.5)^{\frac{1}{2}}$

According to the June 1973 Progress Report on the Phenology Satellite Experiment from Texas A and M's Remote Sensing Center (Rouse 1973), the full utility of these parameters has not been determined, however they have correlated well with green biomass measurements

in other studies". Since it has been used before, BRP was one of the first parameters investigated for use in relating satellite data to fraction green cover of the ground.

In choosing an algorithm that will indicate passage of the green wave or brown wave over all foliage in general, it is desirable to select a single equation which, when applied to the satellite data, will show about the same statistical results for all types of foliage. The equation must provide reasonable correlation between satellite data and fraction green. Thus, it is desirable to have an equation which is not crop specific. It would appear that equations containing very few of the bands or band ratios are more likely to fill these requirements.

Table 1 is a partial listing of regression equations and their statistical indicators that were calculated on a computer to relate satellite MSS information to ground data. The first column gives the equation code. The first letter in columns 1 and 2 of the table indicates the type of ground parameter (the "calibration standard" or dependent variable) against which the MSS data were regressed to develop the linear algorithms tabulated. The standards are fraction green (G), plant height (H), and fraction green times plant height (GH). Abbreviations used in each of the three parts of the code are explained on the second page of the table. The second column lists the regression equations. The third column specifies crop type. Columns 4 through 6 contain

pertinent statistical information on the regression equations.

Of all the regression equations developed and listed in Table 1, it appears that an equation which relates BRP to fraction green could meet the criteria specified above. Equations G-A-BRP, G-W-BRP, and G-R-BRP in Table 1 for alfalfa, wheat, and range, respectively, have about the same response for lower values of fraction green. These equations are:

$$\text{Equation G-A-BRP: } G = 1.128 \text{ BRP} + .2817 \text{ (alfalfa)}$$

$$\text{Equation G-W-BRP: } G = 1.190 \text{ BRP} + .2679 \text{ (wheat)}$$

$$\text{Equation G-R-BRP: } G = 0.665 \text{ BRP} + .1758 \text{ (range)}$$

where: G = fraction green as established by ground photography and

$$\text{BRP} = \frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}$$

Figure 29, showing the relation between BRP and fraction green according to these equations, indicates that the three equations could be closely approximated by just one equation, at least in the part of the graph where fraction green values are low.

J. M. Caprio (1974a) has determined that visual field observations of time of "predominant greenness" on the landscape in the spring correspond to the time when about 10 percent of the ground is covered with green foliage as recorded by the ground photography used in this study. The value of BRP at "green wave occurrence" was thus determined by solving the appropriate BRP equation when fraction green equals 0.1. This procedure yields a value for BRP of -.114 for rangeland at the

Table 1

Equations and Statistical Indicators Relating Ground Observations to Satellite MSS Data

Equation Code	Regression Equation	Crop Type	Statistical Indicators		
			R ²	F	N
G-A-BRP	G = 1.128 (BRP) + .2817	Alfalfa	.483	34.6***	39
G-A-TVP	G = 1.680 (TVP) - .8745	Alfalfa	.447	29.9***	39
G-A-ABIO	G = .5270 (ABIO) + .1892	Alfalfa	.337	18.3***	38
G-A-12R	G = f ₁ (12 Band Ratios) + 1.382	Alfalfa	.703	4.93***	38
G-W-BRP	G = 1.190 (BRP) + .2679	Wheat	.359	25.2***	47
G-W-TVP	G = 1.646 (TVP) - .8839	Wheat	.363	25.7***	47
G-W-ABIO	G = .4931 (ABIO) + .1296	Wheat	.197	10.8***	46
G-W-12R	G = f ₂ (12 Band Ratios) + .4516	Wheat	.518	2.95**	46
G-R-BRP	G = .6651 (BRP) + .1758	Range	.212	8.90**	35
G-R-TVP	G = .9117 (TVP) - .4661	Range	.223	9.48***	35
G-R-ABIO	G = -.0089 (ABIO) + .1316	Range	.000	0.43 NS	35
G-R-12R	G = f ₃ (12 Band Ratios) + 19.12	Range	.665	3.48**	35
G-R-12RA	G = f ₄ (12 Band Ratios) + 4.198	Range	.517	4.37***	62
G-R-12RN	G = f ₅ (12 Band Ratios) + 9.756	Range	.540	3.23***	46
G-R-ABION	G = .003 (ABIO) + .1090	Range	.004	0.19 NS	46
GH-A-BRP	GH = 2082 (BRP) + 175.4	Alfalfa	.363	20.5***	38
GH-A-TVP	GH = 3023 (TVP) - 1893	Alfalfa	.321	17.0***	38
GH-A-ABIO	GH = 715.6 (ABIO) + 80.57	Alfalfa	.385	22.6***	38
H-A-ABIO	H = 7.185 (ABIO) + 3.409	Alfalfa	.391	23.1***	38
H-W-ABIO	H = -6.301 (ABIO) + 9.579	Wheat	.030	0.68 NS	24
H-R-ABION	H = 9.743 (ABIO) + 12.55	Range	.038	1.74 NS	46
H-R-12R	H = f ₆ (12 Band Ratios) + 1105	Range	.755	2.82*	24
H-W-12R	H = f ₇ (12 Band Ratios) + 336.2	Wheat	.524	3.03**	46
H-A-12R	H = f ₈ (12 Band Ratios) + 717.1	Alfalfa	.556	2.61*	38

Table 1 is continued on the next page.

Table 1 continued:

Dependent Variables (Ground Truth)

G = Fraction Green

H = Plant Height

GH = Fraction Green x Plant Height

Other Symbols

A represents Alfalfa (crop type)

W represents Wheat (crop type)

R represents Rangeland (crop type)

f_x = multiple regression coefficients with Band Ratios tabulated
in Table 2

Independent Variables (Satellite Data)

$$BRP = \frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}$$

$$TVP = (BRP + .5)^{\frac{1}{2}}$$

$$ABIO = (0.5 + (.964 - 6'/7')) + (.567 - 5'/4')) 6'/5'$$

12R = a function of all 12 Band Ratios

Statistical Indicators

R^2 = Square of the regression coefficient

(Multiple regression coefficients for equations using 12 Band Ratios and simple regression coefficients for all other equations)

F = Test of statistical significance

* indicates better than 5% confidence level

** indicates better than 1% confidence level

*** indicated better than .5% confidence level

NS indicates not significant

n = Number of ground truth samples used in the regression

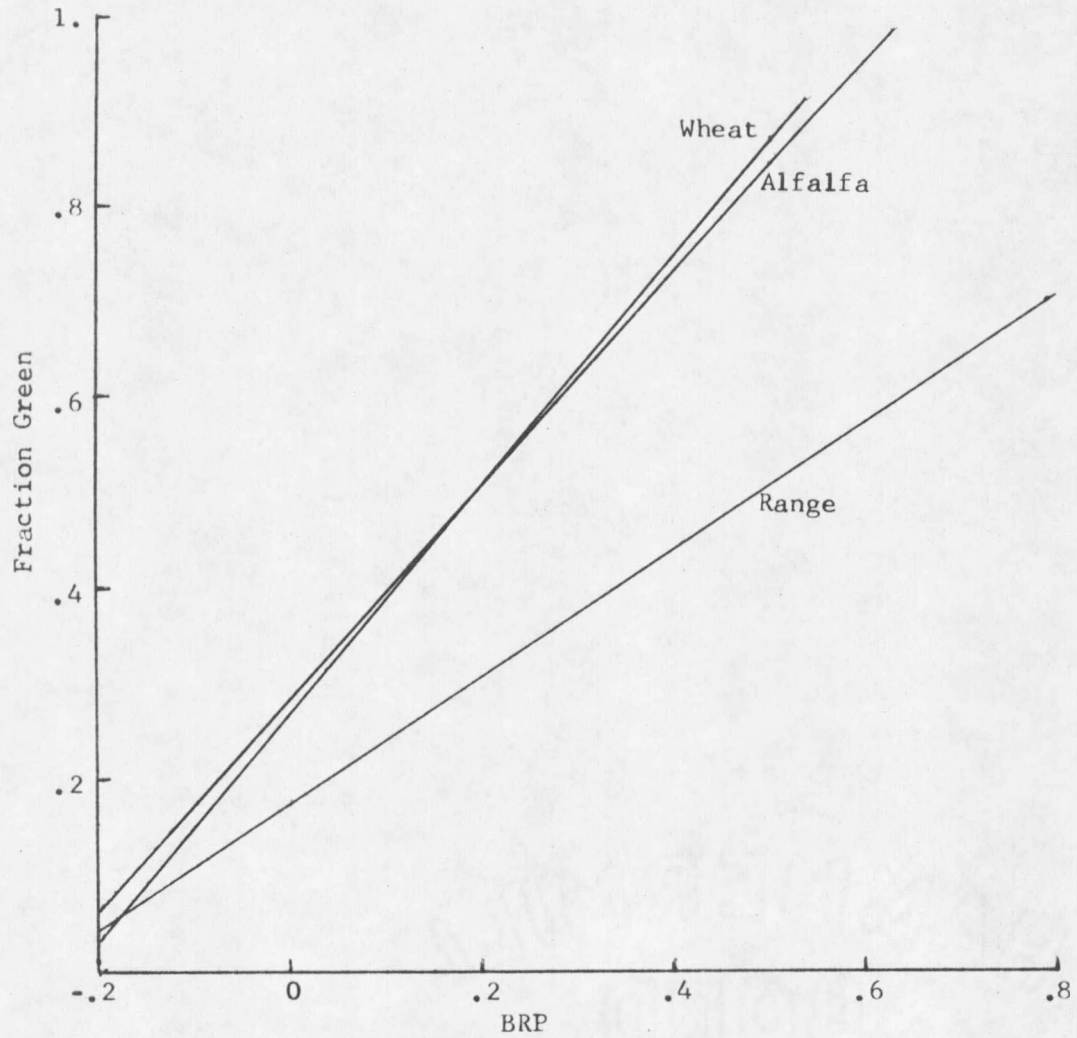


Figure 29. Relationship of BRP to Fraction Green

occurrence of the green wave. Similar processing of G-A-BRP for alfalfa and G-W-BRP for wheat gives BRP values of -.161 and -.141, respectively, at the time of green wave occurrence. The computations are:

$$G-R-BRP = .1 = .665 \text{ BRP} + .1758 \text{ or}$$

$$\text{BRP at Green Wave} = \frac{-.0758}{.665} = -.114 \text{ for range}$$

$$G-W-BRP = .1 = 1.19 + .2679$$

$$\text{BRP}_{\text{GW}} = \frac{-.1679}{1.19} = -.141 \text{ for wheat}$$

$$G-A-BRP = .1 = 1.128 \text{ BRP} + .2817$$

$$\text{BRP}_{\text{GW}} = \frac{-.1817}{1.128} = -.161 \text{ for alfalfa}$$

Since the value of the BRP parameter at green wave occurrence for wheat is about midway between the values of BRP for range and alfalfa, it is probably best to use the value of BRP = -.141 as the general green wave indicator. In some areas like Montana where two-thirds of the area is rangeland, it may be appropriate to use the value of BRP = -.114 from the range equation. (Wheat and alfalfa generally become green before range.) However, the R^2 (square of the regression coefficient) value of .21 for the range equation is much lower than the R^2 value of .36 for the wheat equation (as indicated in Table 1). The relatively low value of R^2 for range may be somewhat misleading since the range equation is based on sites having a multitude of plant species. Appendix 4 lists the plant species within each test plot. The large number of plant species involved in the range-

land green wave, lends added support for utilizing the G-R-BRP equation in spite of the relatively low R^2 value.

The total deviation in the BRP parameter for the three crops is 29 percent at fraction green equals 0.1. (G equals .114 for range and .161 for alfalfa). If the G-W-BRP algorithm (for wheat) is chosen for the general green wave indicator, the error in the BRP is 12 percent and 19 percent for alfalfa and range, respectively.

TVP is a nonlinear equation which uses the BRP parameter:
 $TVP = (BRP + 0.5)^{\frac{1}{2}}$. Neither TVP nor BRP can satisfactorily be used by itself as a fraction green indicator, but TVP is more suitable. BRP and TVP in the equations within Table 1 can be useful as green wave indicators.

Since TVP equations are the only ones listed in Table 1 that are nonlinear, it is appropriate to make a comparison to determine their usefulness. The comparison may be made by examining the following equations extracted from Table 1:

<u>Identifier</u>	<u>Equation</u>	<u>R²</u>	<u>F</u>
G-A-BRP (Alfalfa)	$G = 1.13 \text{ BRP} + .28$	.48	34.6***
G-A-TVP (Alfalfa)	$G = 1.68 \text{ TVP} - .87$	.45	29.9***
G-W-BRP (Wheat)	$G = 1.19 \text{ BRP} + .27$	.36	25.2***
G-W-TVP (Wheat)	$G = 1.65 \text{ TVP} - .88$	.36	25.7***
G-R-BRP (Range)	$G = .67 \text{ BRP} + .18$	.21	8.90**
G-R-TVP (Range)	$G = .91 \text{ TVP} - .47$	.22	9.48***

Comparison of the statistical indicators, R^2 and F, for the three pairs of equations listed above indicates that the use of TVP has no significant advantage over use of BRP in the equations. However, the value of R^2 and other statistical indicators fluctuated excessively when ground truth data near the limits of the data range were included or excluded while making the regressions. Since the relationship of fraction green to BRP might be quite nonlinear near the extremes of the data range, an equation using squared and cubed terms of the BRP factor was developed:

$$\text{G-A-(BRP)}^3 \text{ (Alfalfa): } G = .656 (\text{BRP})^3 + .205 (\text{BRP})^2 + .950 (\text{BRP}) + .259 \text{ where } R^2 = .53 \text{ and } F = 13.4^{***}$$

As noted above, the statistical indicators for the G-A-BRP (Alfalfa) equation are almost as good:

$$R^2 = .48 \text{ and } F = 34.6^{***}$$

Therefore, the nonlinear terms do not offer enough improvement to make the more complicated equation, G-A-BRP^3 , useful.

Equations developed using the parameters $\frac{\text{Band 5}}{\text{Band 7}}$ and $\frac{\text{Band 6}}{\text{Band 7}}$ are listed below with the G-R-BRP equation for comparison. The statistical indicators are similar, but the less complicated equations appear slightly more suitable for fraction green detection on rangeland than the equation using the BRP parameter.

<u>Identifier</u> ^{1/}	<u>Equation</u>	<u>R²</u>	<u>F</u>	<u>N</u>
G-R-5'/7' (Range)	$G = -.312 \text{ 5'/7'} + .491$	.23	10.05***	35
G-R-5'/6' (Range)	$G = -.453 \text{ 5'/6'} + .577$	.23	9.80***	35
G-R-BRP (Range)	$G = .67(\text{BRP}) + .18$	.21	8.90**	35

For areas having mostly rangeland, the most suitable equation (of the three listed above) for detecting the green wave occurrence is the G-R- 5'/7' equation.

$$\text{Thus: } G\text{-R-5'/7'} = .1 = .31 \frac{\text{Band 5}}{\text{Band 7}} + .18$$

$$\text{or: } \frac{\text{Band 5}}{\text{Band 7}} \text{ at Green Wave} = \frac{.1 - .18}{.31} = -.258 \text{ for range.}$$

BRP and TVP were also tested for use in determining fraction green times height as an indicator relating to biomass for alfalfa. The resulting equations, extracted from Table 1, are listed below:

<u>Identifier</u>	<u>Equation</u>	<u>R²</u>	<u>F</u>
GH-A-BRP (Alfalfa)	$GH = 2082 \text{ BRP} + 175$	.36	20.5***
GH-A-TVP(Alfalfa)	$GH = 3023 \text{ TVP} - 1893$	.32	17.0***

The TVP equation listed above offers no particular advantage and is not recommended for use. Another "GH" equation using ABIO reported hereinafter is preferable to both of the above equations.

Limitations and Advantages of BRP, TVP, 5'/7', and 6'/7' Parameters

TVP offers no advantage over BRP unless an attempt is made to

^{1/} 5'/7' is equivalent to Band 5/Band 7. All primed numbers are band numbers and the appropriate data should be inserted in their places.

use the parameters themselves to indicate fraction green. This would yield unsatisfactory results.

BRP used in the G-W-BRP equation offers a relatively simple method of determining fraction green over general areas from only two channels of satellite data. It is not very crop specific. Thus, the recommended value of BRP as an indicator of the general green wave occurrence is:

$$BRP_{GW} = -.141 = \frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}$$

The most suitable indicator for determination of green wave occurrence over rangeland is:

$$\frac{\text{Band 5}}{\text{Band 7}} = -.258$$

The BRP parameter is useful for determining fraction green times height for alfalfa. However, another equation reported in the next section offers greater precision with a slightly more complicated equation incorporating data from all four satellite channels.

Development and Use of the ABIO Algorithm

At the bottom of each processing report, such as in Figure 5, is a graph of the mean radiance value for each of the four channels representing all pixels (smallest increments of data recorded on the satellite) examined by the computer on a particular satellite image. If transparent copies of each graph were made for a particular crop in various phenological conditions, some clues to the correlation between the data and the crop may appear by superimposing or "stacking" the trans-

parent graphs. This procedure was followed for alfalfa, wheat, and range. Typical "average" graphs which resulted from stacking are illustrated in Figures 30, 31, and 32, (see Jones 1975).

Comparison of the spectral graphs representing data recorded by the satellite on two successive days indicates that the spectral graphs retain their shape but are often shifted up or down. Thus, a bias or level-shift of the data from one day to the next is evident. However, careful examination of the ratio of data from each channel to data from every other channel will show that a crop in the same condition gives about the same ratios each time, even though a bias or level-shift in the data may have occurred.

It is not the purpose of this investigation to explain the bias or level-shift. However, the use of band ratios proved to be far superior to use of absolute values of data from each channel to establish correlations with ground data.

Visual comparison of all the graphs from the processing reports with the appropriate ground data indicated that the following situations exist:

1. Bands 6 and 7 (near IR) have approximately the same value over green crops. Alfalfa is an especially good reflector of near infrared radiation.
2. The ratio of data values from band 6 to band 5 is especially related to biomass and fraction green.

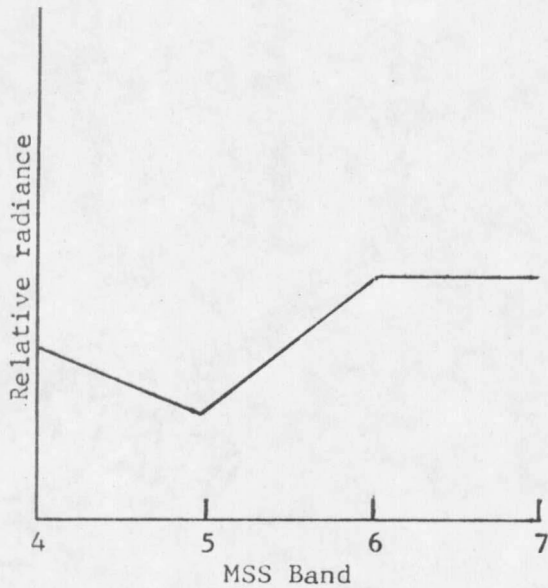


Figure 30. Typical response curve from an alfalfa field

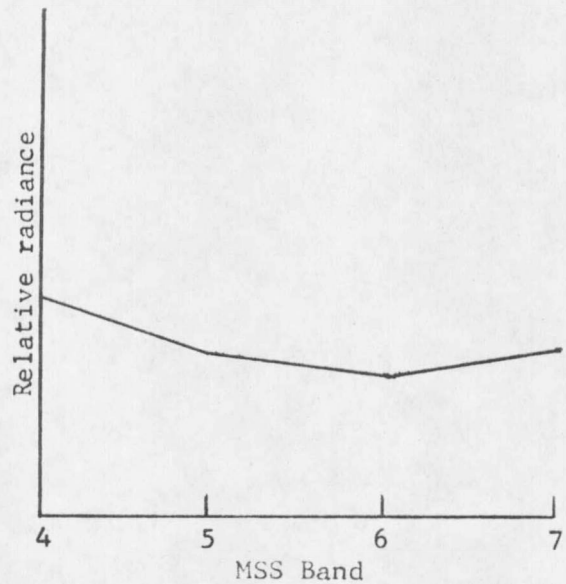


Figure 31. Typical response curve from a wheatfield

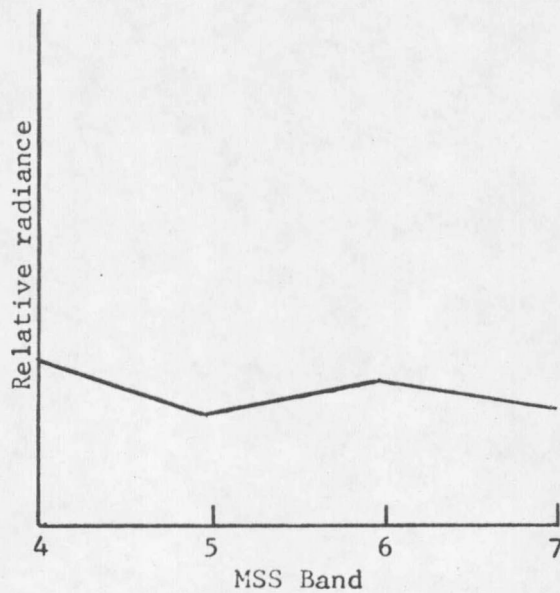


Figure 32. Typical response curve from a range grass field

After Jones, 1975

3. For predominantly green crops, band 4 is greater than band 5.

The factor called "ABIO" was developed for use in identification of alfalfa and estimation of biomass, along with plant height and fraction green. This factor is the result of an attempt to obtain a crop-specific linear algorithm using only a few ratios of relative radiance data (ratios of one band value to another within the same observation). Several "good" alfalfa crops from various sites were selected to provide the "standard" for building the equation. Test plot locations were carefully checked on computer print-out gray-scale maps (to assure analysis of the correct data) to select test plots having more than 0.95 fraction green.

Graphs of these data were compared with each other, with data from less-green alfalfa and with data from nonalfalfa samples (including haze, snow, bare ground, etc.). One sample included data from a test plot where the uncut alfalfa had retained much of its biomass but had lost most of its green color. The ratio, $\frac{\text{band 6}}{\text{band 5}}$ remained relatively high even though the fraction green (ground truth) was significantly decreased.

The twelve band ratios were "culled" to retain only those which consistently (in spite of noise factors mentioned above) vary directly with fraction green and biomass of alfalfa crops only. The ratio,

Band 6, was found to vary most with fraction green or biomass and was, Band 5 therefore, made a multiplicative factor. Two other ratios, 6'/7' and 5'/4' were found to always be within a certain fairly narrow range of values and were inversely proportional to fraction green. These two ratios were used as "enabling" factors in the equation by subtracting them from their minimum values which were found to occur at a fraction green of approximately 1.0. A bias constant of 0.5 was chosen to adjust the range of resultant values. Those resultant values greater than 1.0 are used only in biomass determinations, but are limited to 1.0 maximum for fraction green indication. The resultant algorithm is:

$$ABIO = (0.5 + (.964 - 6'/7') + (.567 - 5'/4')) 6'/5' \frac{1}{2}$$

As a partial test of the ability of "ABIO" to reject crops other than alfalfa, regression equations G-W-ABIO and G-R-ABIO (in Table 1) were run for wheat and range, respectively, to compare with a similar "identity" test for alfalfa (equation G-A-ABIO). Statistical indicators and the regression equations extracted from Table 1 using ABIO as the independent variable are as follows:

<u>Identifier</u>	<u>Equation</u>	<u>R²</u>	<u>F</u>	<u>n</u>
G-A-ABIO (Alfalfa)	G = + .527 (ABIO) + .189	.337	18.3***	38
G-W-ABIO (Wheat)	G = + .493 (ABIO) + .130	.197	10.8***	46
G-R-ABIO (Range)	G = -.0089 (ABIO) + .132	.000	N.S.	35

^{1/} 5'/7' is equivalent to Band 5/Band 7. All primed numbers are band numbers and the appropriate data should be inserted in their places.

Since R^2 and F for wheat and range are much lower than for alfalfa in the ABIO regressions above, the G-A-ABIO equation might serve as an indicator to distinguish alfalfa from wheat and range. If the G-A-ABIO equation (alfalfa) had been used on the wheat and range crops instead of the best-fit ABIO equations, G-W-ABIO and G-R-ABIO, the rejection of nonalfalfa sites would be more dramatic since the values for R^2 and F would be even lower than those listed above for the nonalfalfa crops. Thus, equation G-A-ABIO is a possible identifier for alfalfa, especially where snow, bare ground or unclear atmospheric conditions exist.

As a further test of the ABIO factor to detect fraction green for alfalfa, a regression was computed using only alfalfa ground truth data in which there were no noise factors such as snow or haze. Further, only data from dense and pure stands of alfalfa were used. The resulting equation using ABIO was:

$$\text{G-A-ABIOS (Alfalfa)} \quad G = .9826(\text{ABIO}) - .0061$$

$$\text{where } R^2 = .926 \text{ and } F = 212.7*** \text{ with } n = 19$$

Under special conditions this equation would be excellent for use in view of the exceptional values for R^2 and F . Since the coefficient and intercept in the above equation are close to 1.0 and zero, respectively, the ABIO factor can be used by itself to identify fraction green for pure alfalfa. Thus: $G = \text{ABIO}$ for alfalfa. (G is limited to a maximum value of 1.0).

An effort was made to test the ABIO equation in a crop identi-

fication procedure for alfalfa. Figure 33 is an averaged ground truth of the percent green and plant height for alfalfa, wheat, and range. Appendix 5 gives the complete data graphs which contributed to Figure 33. The percent green ground cover for alfalfa rises rapidly as plant height increases. By the time the alfalfa is about 12 inches high, the percent green is nearly 100 percent. Therefore, a computer assisted method to identify the alfalfa crop area is to take satellite data on a date in the spring when the crop should be showing about 100 percent green. These data could then be used in the G-A-ABIO equation to indicate fraction green of the entire area under study. If the computer output indicated a fraction green near 1.0, the crop could be considered to be alfalfa. If the fraction green indicated for any pixel was significantly less than 1.0, the crop would not be alfalfa. (A pixel covers approximately one acre.) The above procedure is adapted to computer operation for inventory of the total acreage of alfalfa in a given area having a somewhat homogeneous climate. The procedure would be improved by specifying each pixel accepted as alfalfa must be adjacent to another pixel accepted as alfalfa. (Farmers generally do not plant alfalfa in isolated one acre plots.)

The ABIO factor was developed to be crop-specific for alfalfa and is therefore, not useful with other crops except to reject them as non-alfalfa crops. The equations listed below from Table 1 are for plant

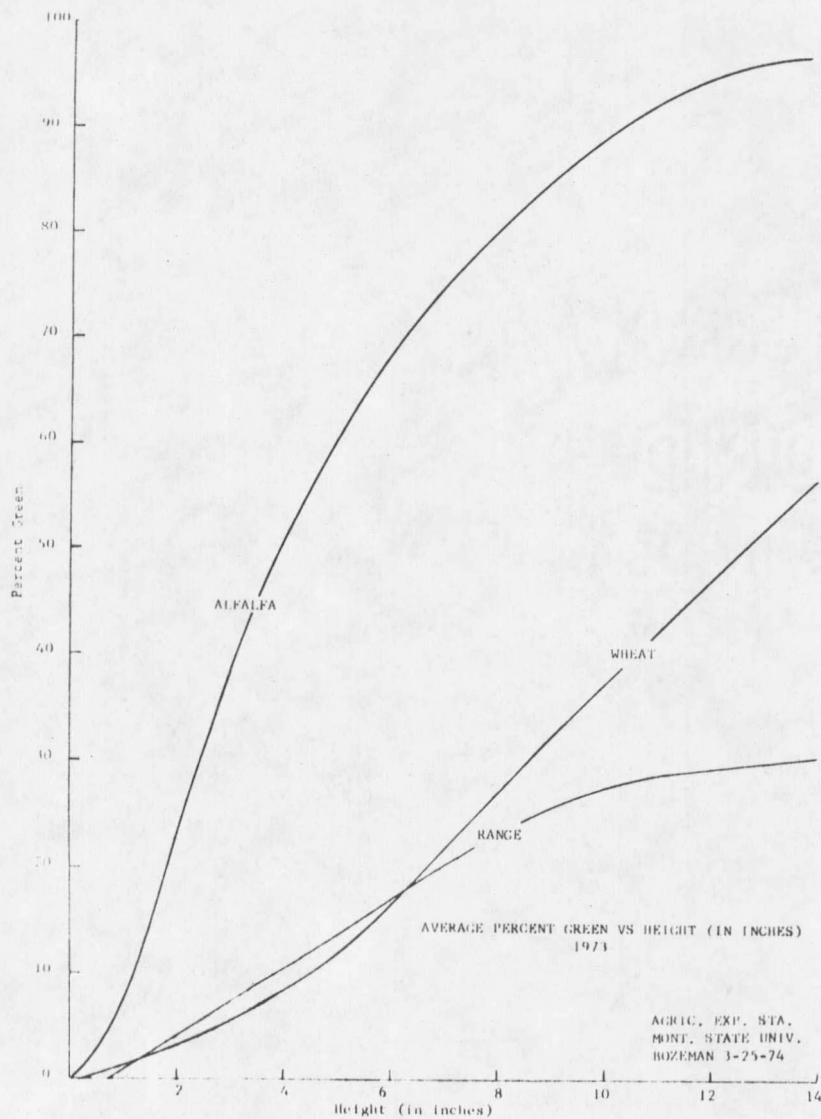


Fig. 33 Average Relations Between Heights of Alfalfa, Range-land Vegetation and Wheat and Percent Green Foliage Covering the Ground For Columbia Valley and Rocky Mountain Corridors.

height and fraction green times plant height.

$$\text{H-A-ABIO: } H = 7.18 (\text{ABIO}) + 3.41$$

$$\text{where } R^2 = .39 \text{ and } F = 23.1^{***}$$

$$\text{GH-A-ABIO: } G \times H = 7.16 (\text{ABIO}) + 80.6$$

$$\text{where } R^2 = .38 \text{ and } F = 22.6^{***}$$

The H-A-ABIO is perhaps preferable in view of its slightly higher values for R^2 and F . The ability of these equations to indicate plant height is strictly limited to alfalfa as shown by the values of R^2 and F for wheat and range crops indicated below (from Table 1):

$$\text{H-W-ABIO: } H = -6.3 (\text{ABIO}) + 9.6$$

$$\text{where } R^2 = .03 \text{ and } F = .68 \text{ NS}$$

$$\text{H-R-ABION: } H = 9.7 (\text{ABIO}) + 12.5$$

$$\text{where } R^2 = .04 \text{ and } F = 1.74 \text{ NS}$$

The ABIO factor performs as intended for alfalfa by indicating biomass and fraction green. Its ability to perform these functions should continue quite well even under "difficult" conditions such as partial snow cover and haze, etc., since that kind of "noisy" data was used in the development of the ABIO factor.

Limitations and Advantages of ABIO Algorithm

Complete testing of the ability of the H-A-ABIO equation to indicate biomass for alfalfa has not been accomplished. However, the equation has a fairly high R^2 value of .39 and an exceptionally high F value of 23.1^{***}. This F value is even more significant than the F value for the H-A-12R equation using all possible ratios as reported

in the next section. The biomass of alfalfa crops is desirable information, but most of the earth's biomass would remain unknown since alfalfa represents only a very meager portion of the earth's total biomass.

Perhaps the most important potential of the ABIO factor is its ability to identify alfalfa through snow, haze, and other noise factors. Use of the ABIO factor in this way needs further testing to determine actual reliability.

For good (pure) stands of alfalfa the fraction green is perhaps best indicated by $G \approx ABIO$. For mixed stands of alfalfa the $G-A-ABIO$ equation is possibly more applicable.

Development of Algorithms Using 12 Band Ratios

It would seem reasonable that all 12 ratios of data from the satellite would correlate with changes in the observed crops. Multiple linear regression equations using the 12 ratios (12R) were calculated on a computer and are tabulated in Tables 1 and 2. Pertinent statistical information for these equations is listed in Table 3. The relative importance of each of the 12 possible band ratios, for indicating fraction green cover or plant height on each of the three test plots, is indicated by the order of magnitude of the t-tests in Table 3. The tabulation below is determined from information given in Table 3 for

Table 2

Regression Coefficients for 12 Band Ratio Equations (Tabulated in Table 1)

Equation Code	Regression Coefficients with Band Ratios			
G-A-12R	$f_1(12R)$	$= 6.723 (4'/5') + 1.292 (5'/7') + 11.02 (7'/4')$	$-4.576 (4'/6') + 1.820 (6'/7') - .1151 (6'/5')$	$-3.289 (4'/7') + 8.978 (5'/6') - 7.644 (5'/4') - 4.416 (6'/4')$
G-W-12R	$f_2(12R)$	$= 5.451 (4'/5') + 3.246 (5'/7') + 1.674 (7'/4')$	$-3.302 (4'/6') - 2.327 (6'/7') - 4.956 (6'/5')$	$-1.151 (4'/7') + 3.063 (5'/6') - 9.793 (5'/4') + 9.881 (6'/4')$
G-R-12R	$f_3(12R)$	$= -2.934 (4'/5') + 1.273 (5'/7') - 4.762 (7'/4')$	$+1.763 (4'/6') - 7.407 (6'/7') - 2.758 (6'/5')$	$+6.279 (4'/7') - 5.287 (5'/6') + 4.759 (6'/4') - 6.925 (7'/6')$
G-R-12RA	$f_4(12R)$	$= -.5185 (4'/5') + .9494 (5'/7') - .9519 (7'/4')$	$+ .2067 (4'/6') - 1.427 (6'/7') - .8348 (6'/5')$	$- .03596 (4'/7') - 1.928 (5'/6') + 1.771 (6'/4') - .5731 (7'/6')$
G-R-12RN	$f_5(12R)$	$= .8209 (4'/5') + 4.058 (5'/7') + 1.098 (7'/4')$	$+ .6421 (4'/6') - 3.355 (6'/7') - 3.661 (6'/5')$	$- 1.679 (4'/7') - 3.603 (5'/6') + 2.508 (6'/4') - 3.745 (7'/6')$
H-R-12R	$f_6(12R)$	$= -105.3 (4'/5') - 12.62 (5'/7') - 230.9 (7'/4')$	$+ 209.0 (4'/6') - 77.18 (6'/7') - 587.5 (6'/5')$	$- 117.9 (4'/7') - 174.4 (5'/6') + 244.5 (6'/4') - 781.6 (7'/6')$
H-W-12R	$f_7(12R)$	$= 353.1 (4'/5') - 448.5 (5'/7') + 749.8 (7'/4')$	$- 773.4 (4'/6') + 286.3 (6'/7') - 206.1 (6'/5')$	$+ 178.5 (4'/7') - 356.3 (6'/4') - 168.7 (7'/5') - 406.2 (7'/6')$
H-A-12R	$f_8(12R)$	$= -263.2 (4'/5') + 97.65 (5'/7') - 337.1 (7'/4')$	$- 81.72 (4'/6') - 270.8 (6'/7') + 5.654 (6'/5')$	$+ 110.2 (4'/7') - 183.2 (5'/6') + 178.1 (6'/4') + 124.6 (7'/6')$

Table 3 Regression Coefficients, t-Values and Ratio Means for Equations Having All 12 Band Ratios as Independent Variables

	Equation	Band Ratios											
	Code	4/5	4/6	4/7	5/6	5/7	6/7	5/4	6/4	7/4	6/5	7/5	7/6
Coefficients	G-A-12R	+6.723	-4.576	-3.289	+8.978	+1.292	+1.820	-7.644	-4.416	+11.02	-.1151	-4.223	-6.798
	G-W-12R	+5.451	-3.302	-1.151	+3.063	+3.246	-2.327	-9.793	+9.881	+1.674	-4.956	-2.510	+4.960
	G-R-12R	-2.934	+1.763	+6.279	-5.287	+1.273	-7.407	-.5252	+4.759	-4.762	-2.758	+2.893	-6.925
	G-R-12RA	-.5185	+2.067	-.03596	-1.928	+9.494	-1.427	-1.161	+1.771	-.9519	-.8348	+3.549	-.5731
	G-R-12RN	+3.3209	+6.421	-1.679	-3.603	+4.058	-3.355	-3.906	+2.508	+1.098	-3.661	+1.081	-3.745
	H-R-12R	-105.3	+209.0	-117.9	-174.4	-12.62	-77.18	-60.11	+244.5	-230.9	-587.5	+569.0	-781.6
	H-W-12R	+353.1	-773.4	+178.5	+1037	-448.5	+286.3	-546.0	-356.3	+749.8	-206.1	-168.7	-406.2
	H-A-12R	-263.2	-81.72	+110.2	-183.2	+97.65	-270.8	-209.6	+178.1	-337.1	+5.654	+97.09	-124.6
t-values	G-A-12R	+1.323	-.5453	-.4551	+1.006	+2.133	+2.440	-1.186	-.4357	+1.306	-.01724	-.8496	-1.289
	G-W-12R	+1.029	-.5895	-.2914	+3.986	+5.906	-.2793	-1.885	+1.446	+2.248	-.9536	-.4797	-.0525
	G-R-12R	-.9536	+3.923	+2.073	-.9939	+3.962	-1.184	-.1430	+1.447	-1.177	-.9594	+82.2	-1.237
	G-R-12RA	-.2343	-.09702	-.02268	-.6728	+4.595	-.6892	-.4536	+6.663	-.3065	-.3924	+1.367	-.1983
	G-R-12RN	+3.3161	+2.713	-.9239	-1.044	+1.374	-1.297	-1.217	-.8365	+3.244	-1.357	+3.055	-1.097
	H-R-12R	-.5725	+8543	-.6690	-.6194	-.05609	-.2342	-.2584	+1.302	-.9763	-3.576	+2.516	-2.312
	H-W-12R	+1.490	-3.086	+1.010	+3.016	-1.824	+7.683	-2.349	-1.166	+2.251	-.8865	-.7206	-1.144
	H-A-12R	-2.021	-.3799	+5.949	-.8007	+6.289	-1.416	-1.268	+6.854	-1.559	+0.03305	+7.621	-.9214
Ratio Means	G-A-12R	1.398	.8729	.9413	.6526	.7124	1.044	.7237	1.232	1.228	1.791	1.805	.9697
	G-W-12R	1.157	1.148	1.368	1.003	1.197	1.177	.8728	.8822	.7548	1.026	.8815	.8459
	G-R-12R	1.214	1.195	1.401	.9851	1.156	1.165	.8286	.8466	.7269	1.023	.8791	.9520
	G-R-12RA	1.169	1.143	1.370	.9340	1.187	1.194	.8655	.8832	.7476	1.028	.8734	.8417
	G-R-12RN	1.168	1.140	1.365	.9817	1.184	1.192	.8661	.8857	.7535	1.028	.8798	.8448
	H-R-12R	1.239	1.199	1.400	.9679	1.130	1.159	.8108	.8450	.7300	1.041	.9004	.8558
	H-W-12R	1.157	1.148	1.368	1.003	1.197	1.177	.8728	.8822	.7548	1.026	.8815	.8459
	H-A-12R	1.398	.8729	.9413	.6526	.7124	1.044	.7237	1.232	1.228	1.791	1.805	.9697

the 12 ratios: ^{1/}

For alfalfa fraction green, the most important band ratios are 4'/5', 7'/4', 7'/6', 5'/4', 5'/6'.

For wheat fraction green, the most important band ratios are 5'/4', 6'/4', 4'/5'.

For range fraction green, the most important band ratios are 6'/4', 7'/6', 6'/7', 7'/4'.

It is interesting to note that band ratio 5'/6' is most important (has the highest t-test value) only in the alfalfa equation. Ratio 6'/7' is likewise most important only in the range equation. Ratios 5'/4' and 6'/4' are more important in the wheat equation than are any of the other ratios in their respective equations. The above information derived from the t-tests indicates a strong possibility for unique equations using some or all of the 12 ratios to specify fraction green for alfalfa, wheat, and range.

Simple linear equations that do not depend on absolute magnitudes or calibration of the satellite instrumentation are desirable. Therefore, all possible ratios of the satellite data were retained for use in the equations.

Except for equation G-R-12RN (the "N" in the equation code means

^{1/} 5'/7' is equivalent to Band 5/Band 7. All primed numbers are band numbers and the appropriate data should be inserted in their places..

"no clouds" in the site area) all equations listed in Table 1 were developed by regression of MSS data against ground data for dates when cloud cover was "nonexistent" or "probably thin". The similar equation G-R-12RA was developed from "all" data which included data where clouds were near the site and some thin haze or cloud cover might exist over the site even though it was not detected by visual examination of the associated imagery. Apparently there was some "undetectable" haze or cloud cover with nearby clouds affecting the data since the R^2 value of .52 for equation G-R-12RA was lower than the value of .54 for R^2 with the G-R-12RN equation as tabulated in Table 1. Equation G-R-12R had an even higher value of $R^2 = .67$ because the "no cloud" data were further screened to delete data which were not taken exactly centered over the test site.

Fraction Green Using Band Ratios

Results presented in Table 1 indicate that relative data values in a linear algorithm can give reasonably high correlation and highly significant F values (at better than .5 percent confidence levels) for indicating fraction green on alfalfa, wheat and range. Three of the equations for indicating fraction green, identified in Table 1 by codes G-A-12R, G-W-12R and G-R-12R are as follows:

Equation G-A-12R:

$$G = + 6.72 (4'/5') - 4.58 (4'/6') - 3.29 (4'/7') + 8.98 (5'/6') \\ + 1.29 (5'/7') + 1.82 (6'/7') - 7.64 (5'/4') - 4.42 (6'/4')$$

$$+ 11.02 (7'/4') - .11 (6'/5') - 4.22 (7'/5') - 6.08 (7'/6') \\ + 1.382 \text{ with } R^2 = .70 \text{ and } F = 4.93^{***} \text{ for } n = 38.$$

Equation G-W-12R:

$$G = + 5.45 (4'/5') - 3.30 (4'/6') - 1.15 (4'/7') + 3.06 (5'/6') \\ + 3.25 (5'/7') - 2.33 (6'/7') - 9.79 (5'/4') + 9.88 (6'/4') \\ + 1.67 (7'/4') - 4.96 (6'/5') - 2.51 (7'/5') + .50 (7'/6') \\ + .4516 \text{ with } R^2 = .52 \text{ and } F = 2.95^{**} \text{ for } n = 46.$$

Equation G-R-12R:

$$G = - 2.93 (4'/5') + 1.76 (4'/6') + .63 (4'/7') - 5.24 (5'/6') \\ + 1.27 (5'/7') - 7.41 (6'/7') - .53 (5'/4') + 4.76 (6'/4') \\ - 4.76 (7'/4') - 2.76 (6'/5') + 2.89 (7'/5') - 6.93 (7'/6') \\ + 19.12 \text{ with } R^2 = .67 \text{ and } F = 3.48^{**} \text{ for } n = 35.$$

Note: Primed numbers are band numbers and values to be entered are mean radiance values for the bands.

The true test of the usefulness of any of these equations is the closeness (correlation) of the ground observation data to the algorithm results using satellite data. Of the 15 fraction green equations listed in Table 1, the three equations referenced above will correlate most closely to the fraction green (ground data) as indicated by the higher R^2 and F values for these three equations.

Since these three algorithms are all quite different from each other, they might be used for crop identification or inventory. An example of this procedure for alfalfa is presented above with the ABIO

algorithm. The G-A-12R equation could be used in place of the ABIO algorithm.

An attempt was made to discard one or more of the least important band ratios according to the computed t-tests (Table 3) for each regression coefficient in the 12 ratio equations. The resulting R^2 value dropped dramatically. An example for alfalfa, wheat, and range is listed below. Listed for comparison, prior to each equation which was developed using less than 12 band ratios, is an equation which was developed from the same selected data for all 12 band ratios:

G-A-12RS (Alfalfa):

$$\begin{aligned} G_a = & 17.00 (4'/5') - 20.00 (4'/6') + 3.814 (4'/7') + 24.25 (5'/6') \\ & - 4.181 (5'/7') - .01863 (6'/7') - 9.409 (5'/4') - 1.206 (6'/4') \\ & + 14.95 (7'/4') - 4.951 (6'/5') - 5.167 (7'/5') - 7.653 (7'/6') \\ & - 6.801 \text{ with } R^2 = .874, F = 13.3^{***}, n = 36. \end{aligned}$$

G-A-6RS (Alfalfa):

$$\begin{aligned} G_a = & 3.088 (4'/5') - 3.029 (4'/6') + 1.739 (5'/6') - 1.476 (6'/5') \\ & + .5572 (7'/5') - .7139 (7'/6') - .0750 \text{ with } R^2 = .615, F = 7.73^{***}, \\ & n = 36. \end{aligned}$$

With the above equations, reduction of the ratios used, from 12 to 6, caused R^2 to drop from .874 to .615.

A similar procedure in selecting ratios based on computed t values gave the following:

G-W-12RS (Wheat): $G_W = 3.137 (4'/5') - .7106 (4'/6') - 1.379 (4'/7')$
 $+ 1.444 (5'/6') + 2.521 (5'/7') - 1.459 (6'/7')$
 $- 8.404 (5'/4') + 8.572 (6'/4') + 1.529 (7'/4')$
 $- 4.528 (6'/5') - 1.276 (7'/5') - 1.093 (7'/6')$
 $+ 1.816$ with $R^2 = .447$, $F = 2.42^*$, $n = 49$.

G-W-5RS (Wheat): $G_W = -.05798 (5'/6') + .5587 (5'/7') + .7956 (6'/7')$
 $- .1128 (5'/4') + .3700 (6'/4') - .2553$
 with $R^2 = .355$, $F = 4.738^{***}$, $n = 49$.

With the above pair of equations, reduction of the ratios used, from 12 to 5, caused R^2 to drop from .447 to .355.

The computed t values for selective reduction of the number of band ratios (used to specify fraction green) for rangeland gave the following results:

G-R-12RS (Range): $G_R = -.2345 (4'/5') - 1.754 (4'/6') + 1.410 (4'/7')$
 $- 1.116 (5'/6') + .3459 (5'/7') - 2.368 (6'/7')$
 $- .4991 (5'/4') + 3.775 (6'/4') - 3.965 (7'/4')$
 $- 1.457 (6'/5') + 1.361 (7'/5') + 1.176 (7'/6')$
 $+ 3.375$ with $R^2 = .504$, $F = 3.73^{***}$, $n = 57$.

G-R-3RSS (Range): $G_R = - 1.609 (4'/6') + 1.027 (4'/7') + 1.995 (7'/6')$
 $- 1.072$ with $R^2 = .395$, $F = 5.658^{***}$, $n = 30$.

With the above pair of equations, not all data used to develop the twelve ratio equation were used to develop the three ratio equation. The reduction in R^2 was so great that some of the questionable range

data were omitted to improve the R^2 value. The improvement was still not enough to make the three ratio equation useable.

In general, the computed t test for each coefficient in the twelve ratio equations can be used to cull out a few of the twelve ratios. However, for all three crops, the value for R^2 become so much worse that the effort to leave out some of the ratios is not justified. The 6, 5 and 3 ratio equations are not recommended for use. They were obtained by using specially selected data and are included only to indicate the desirability of including all 12 ratios in the equations.

Plant Height and Biomass Using Band Ratios

Regression equations were computed comparing satellite data to plant height and fraction green times height. These height equations (in inches) listed below for alfalfa are extracted from Table 1.

$$\begin{aligned} \text{H-A-12R (Alfalfa): } H = & - 263.2 (4'/5') - 81.72 (4'/6') + 110.2 (4'/7') \\ & - 183.2 (5'/6') + 97.65 (5'/7') - 270.8 (6'/7') - 209.6 \\ & (5'/4') + 178.1 (6'/4') - 337.1 (7'/4') + 5.654 (6'/5') \\ & + 97.09 (7'/5') + 124.6 (7'/6') + 717.1 \end{aligned}$$

where $R^2 = .556$, $F = 2.61^*$, $n = 38$.

$$\begin{aligned} \text{H-W-12R (Wheat): } H = & 353.1 (4'/5') - 773.4 (4'/6') + 178.5 (4'/7') \\ & + 1037 (5'/6') - 448.5 (5'/7') + 286.3 (6'/7') - 546.0 \\ & (5'/4') - 356.3 (6'/4') + 749.8 (7'/4') - 206.1 (6'/5') \\ & - 168.7 (7'/5') - 406.2 (7'/6') \text{ where } R^2 = .524, F = \end{aligned}$$

3.03**, and $n = 46$.

H-R-12R (Range): $H = -105.3 (4'/5') + 209.0 (4'/6') - 117.9 (4'/7')$
 $- 174.4 (5'/6') - 12.62 (5'/7') - 77.18 (6'/7') - 60.11$
 $(5'/4') + 244.5 (6'/4') - 230.9 (7'/4') - 587.5 (6'/5')$
 $+ 569.0 (7'/5') - 781.6 (7'/6') + 1105$ where $R^2 = .755$,
 $F = 2.82^*$, and $n = 24$.

Limitations and Advantages of 12 Ratio Equations

Of all the ratios listed in Table 1, the 12 ratio equations gave the highest R^2 values. The only equation specified previously which gave a greater R^2 was the G-A-ABIOS equation which gave an R^2 of .926 on selected stands of relatively "pure" alfalfa.

Equations G-A-12R, G-W-12R, and G-R-12R are good for detecting the fraction green for alfalfa, winter wheat, and range, respectively. This is also true for the height equations H-A-12R, H-W-12R and H-R-12R. These equations are crop specific and should not be expected to work well on all crops, but they could be used as green and brown wave indicators for their respective crops.

The exact relation of biomass to plant height or fraction green times height is not specified here. Further study would be required to specify the exact relation for each crop. However, plant height or fraction green times height should be expected to give a relative indication of biomass.

Although the 12 ratio equations are slightly more complicated

than some of the other equations, they give consistently good results. The height and fraction green equations could be used in a computerized crop identification and inventory system proposed in the summary which follows. In general, the 12 ratio equations maintain higher R^2 values for data near the limits of the data range.

SUMMARY AND CONCLUSIONS

Several algorithms were developed utilizing satellite data from the four ERTS-1 bands (data channels) to determine fraction green, plant height and fraction green times plant height. The equations were developed by using as many ground truth samples as possible from all sites in the Rocky Mountain and Columbia Valley Corridors. This introduced additional noise into the system, but the resulting algorithms should be more useful on a broad scale. Applications of the fraction green algorithms utilizing the satellite data include:

1. Determination of fraction green cover resulting from foliage on the land surface.
2. Timing of the passage of the green wave northward in spring and its recession (brown wave) southward in autumn.
3. Determination of the time between green and brown wave passage (growing season).
4. Crop identification and inventory.

Applications of the plant height algorithms include:

1. A rough indication of relative biomass.
2. Crop identification and inventory when used with fraction green algorithms.

An application of the fraction green times height equations is to provide a rough indication of relative biomass.

Fraction Green, Green Wave and Growing Season

Determination of fraction green for all foliage in general can be accomplished by employing the equation developed for winter wheat using BRP i.e., $G = 1.19 (\text{BRP}) + .2679$. This equation is not as crop

specific as the other types of equations and it fits quite well between the values for alfalfa and range at lower values of fraction green as depicted in Figure 29. Its use at higher values of fraction green would be questionable.

Assuming the green wave or brown wave occurs when the landscape is one-tenth covered by green foliage, the value for the BRP at green wave occurrence is $BRP_{GW} = -.141 = \frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}$.

For the detection of the green or brown wave resulting from other crops, the appropriate crop-specific equation from Tables 1 and 2 should be used. For alfalfa, either the G-A-ABIO or the G-A-12R equation is satisfactory. For pure stands of alfalfa, the equation $G = ABIO$ is appropriate. For winter wheat, the G-W-12R equation is suitable. If a simpler equation is needed for wheat, the G-W-BRP is not as good, but is adequate. The equation G-R-12R should be used for rangeland. It is doubtful that the equation G-R-BRP would be satisfactory due to its very low R^2 value.

Figures 9 through 28 are graphs of the ground truth data (taken every sixth day) for fraction green on alfalfa, winter wheat, and rangeland. The fraction green algorithms for each crop should be expected to produce results equivalent to these figures if enough samples of satellite data are available. These graphs also clearly identify the growing season (see Appendix 2) for each crop. However, the ERTS-1 data available for this investigation could not have

"exactly" duplicated all of Figures 9 through 28 since the satellite data were taken only on every eighteenth day and an average of 61 percent of the satellite data were not useful because of cloud cover. (See Appendix 2.)

Plant Height and Biomass

Plant height for alfalfa can be determined by using the satellite data in the H-A-12R or the H-A-ABIO algorithms listed in Tables 1 and 2. For winter wheat the most appropriate equation is H-W-12R. The H-R-12R is likewise the equation most applicable for plant height on rangeland. These four equations can be expected to give only a relative indication of the biomass for each crop.

The fraction green times plant height equation GH-A-ABIO, listed in Table 1 can also be expected to provide a relative indication of biomass for alfalfa. Other equations could be generated by multiplying the:

G-A-12R equation by the H-A-12R equation,

G-W-12R equation by the H-W-12R equation,

G-R-12R equation by the H-R-12R equation.

Crop Identification and Inventory

As indicated in the section entitled "Development and Use of the ABIO Algorithm", a fraction green equation by itself could be used under certain circumstances to identify and inventory the acreage of a certain crop. At best, this method would only be applicable

for alfalfa. Either equation G-A-AB10 or G-A-12R (from Tables 1 and 2) could be used to determine fraction green from satellite data taken when the alfalfa crop was known to be more than 12 inches high. According to Figure 33, the fraction green for such a crop would be near 1.0. Thus, any pixel of satellite data which gave a fraction green near 1.0, when using either of the above named equations, would be counted as alfalfa. There are several problems with the above system, but one major problem is obtaining satellite information on a date when the crop is more than 12 inches high.

The same system could be used with wheat and range, but the fraction green never reaches 1.0 and determination of fraction green over broad areas would be difficult. However, this problem could be overcome if the plant height were available (from ground truth sources or phenological history) and Figure 33 could then indicate the relation between fraction green and plant height.

A more appropriate method requiring only satellite data would be to use algorithms for fraction green and plant height simultaneously on each pixel or group of pixels. This method does not require that the height of the crop be known, as in the above method, but would use satellite data to determine both height and fraction green. A "calibration curve" for each crop would be required, such as the three curves in Figure 33. Then the value of fraction green and plant height from any pixel must fall on or near the calibration

curve for that crop. For example, if it is desired to know the total acreage of wheat in a certain area, satellite data for that area is injected into algorithms G-W-12R and H-W-12R to determine which pixels produce points falling on or near the wheat curve in Figure 33. This system can function even though the crop never produces a fraction green cover of 1.0 and ground truth or phenological history is not available indicating plant height. The reliability of both methods proposed above has not been adequately tested, but the methods show a feasibility for determination of crop identity and acreage from ERTS-1.

This investigation has provided some definite and some possible answers to the question of what ERTS-1 satellite data can to provide certain phenological information about plants from approximately 500 miles away. For the three crops, irrigated alfalfa, dryland winter wheat and rangeland, methods have been presented whereby satellite data will indicate the fraction green ground cover and plant height. Furthermore, the feasibility exists whereby these crops may be identified and inventoried from satellite data. The ability of these equations to reject data from pixels where the subject crop does not exist needs further testing. Will the G-A-12R equation reject clover? Will the G-W-12R equation reject barley and other small grains? Perhaps not, but equations presented in this investigation will almost certainly differentiate between alfalfa, wheat, and rangeland.

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APPENDICES

Appendix 1

**Site Location, Altitude,
Satellite Overpass Schedule, and
Tentative Schedule for Site Photography**

ROCKY MOUNTAIN CORRIDOR

*Actual Overpass Date

Montana:

Browning (48°44'N, 113°11'W)

4800 Feet

Date

November 2, 8*, 14, 20, 26*
December 2, 8, 14*, 20, 26
January 1*, 7, 13, 19*, 25, 31
February 6*, 12, 18, 24*
March 2, 8, 14*, 20, 26
April 1*, 7, 13, 19*, 25
May 1, 7*, 13, 19, 25*, 31

Time of Overpass ~ 1056 LST

Date

June 6, 12*, 18, 24, 30*
July 6, 12, 18*, 24, 30
August 5*, 11, 17, 23*, 29
September 4, 10*, 16, 22, 28*
October 4, 10, 16*, 22, 28
November 3*

Montana:

Logan (45°47'N, 111°27'W)

4320 Feet

Date

October 31
November 6*, 12, 18, 24*, 30
December 6, 12*, 18, 24, 30*
January 5, 11, 17*, 23, 29
February 4*, 10, 16, 22*, 28
March 6, 12*, 18, 24, 30*
April 5, 11, 17*, 23, 29

Time of Overpass ~ 1045 LST

Date

May 5*, 11, 17, 23*, 29
June 4, 10*, 16, 22, 28*
July 4, 10, 16*, 22, 28
August 3*, 9, 15, 21*, 27
September 2, 8*, 14, 20, 26*
October 2, 8, 14*, 20, 26
November 1*

Idaho:

Camas (43°58'N, 112°18'W)

4800 Feet

Date

October 31
November 6*, 12, 18, 24*, 30
December 6, 12*, 18, 24, 30*
January 5, 11, 17*, 23, 29
February 4*, 10, 16, 22*, 28
March 6, 12*, 18, 24, 30*
April 5, 11, 17*, 23, 29

Time of Overpass ~ 1046 LST

Date

May 5*, 11, 17, 23*, 29
June 4, 10*, 16, 22, 28*
July 4, 10, 16*, 22, 28
August 3*, 9, 15, 21*, 27
September 2, 8*, 14, 20, 26*
October 2, 8, 14*, 20, 26
November 1*

Utah:

Snowville (41°59'N, 112°39'W)

4700 Feet

Date

October 31
November 6*, 12, 18, 24*, 30
December 6, 12*, 18, 24, 30*
January 5, 11, 17*, 23, 29
February 4*, 10, 16, 22*, 28
March 6, 12*, 18, 24, 30*
April 5, 11, 17*, 23, 29

Time of Overpass ~ 1047 LST

Date

May 5*, 11, 17, 23*, 29
June 4, 10*, 16, 22, 28*
July 4, 10, 16*, 22, 28
August 3*, 9, 15, 21*, 27
September 2, 8*, 14, 20, 26*
October 2, 8, 14*, 20, 26
November 1*

ROCKY MOUNTAIN CORRIDOR

*Actual Overpass Date

Utah:

Kanosh (38°49'N, 112°33'W)
4760 Ft.

Time of Overpass ~ 1041 LST

Date

Date

October 30
November 5*, 11, 17, 23*, 29
December 5, 11*, 17, 23, 29*
January 4, 10, 16*, 22, 28
February 3*, 9, 15, 21*, 27
March 5, 11*, 17, 23, 29*
April 4, 10, 16*, 22, 28

May 4*, 10, 16, 22*, 28
June 3, 9*, 15, 21, 27*
July 3, 9, 15*, 21, 27
August 2*, 8, 14, 20*, 26
September 1, 7*, 13, 19, 25*
October 1, 7, 13*, 19, 25, 31*

Arizona:

Colorado City (36°59'N, 112°59'W)
4950 Ft.

Time of Overpass ~ 1030 LST

Date

Date

October 30
November 5*, 11, 17, 23*, 29
December 5, 11*, 17, 23, 29*
January 4, 10, 16*, 22, 28
February 3*, 9, 15, 21*, 27
March 5, 11*, 17, 23, 29*
April 4, 10, 16*, 22, 28

May 4*, 10, 16, 22*, 28
June 3, 9*, 15, 21, 27*
July 3, 9, 15*, 21, 27
August 2*, 8, 14, 20*, 26
September 1, 7*, 13, 19, 25*
October 1, 7, 13*, 19, 25, 31*

COLUMBIA CORRIDOR

*Actual Overpass Date

Montana:

Ilavre (48°27'N, 109°47'W)
2900 Ft.
Date

October 31
November 6*, 12, 18, 24*, 30
December 6, 12*, 18, 24, 30*
January 5, 11, 17*, 23, 29
February 4*, 10, 16, 22*, 28
March 6, 12*, 18, 24, 30*
April 5, 11, 17*, 23, 29

Time of Overpass ~ 1045 LST

Date

May 5*, 11, 17, 23*, 29
June 4, 10*, 16, 22, 28*
July 4, 10, 16*, 22, 28
August 3*, 9, 15, 21*, 27
September 2, 8*, 14, 20, 26*
October 2, 8, 14*, 20, 26
November 1*

Montana:

Charlo (47°27'N, 114°09'W)
3030 Ft.
Date

November 3, 9*, 15, 21, 27*
December 3, 9, 15*, 21, 27
January 2*, 8, 14, 20*, 26
February 1, 7*, 13, 19, 25*
March 3, 9, 15*, 21, 27
April 2*, 8, 14, 20*, 26
May 2, 8*, 14, 20, 26*

Time of Overpass ~ 1056 LST

Date

June 1, 7, 13*, 19, 25
July 1*, 7, 13, 19*, 25, 31
August 6*, 12, 18, 24*, 30
September 5, 11*, 17, 23, 29*
October 5, 11, 17*, 23, 29
November 4*

Idaho:

Helmer (46°50'N, 116°27'W)
2910 Ft.
Date

November 4, 10*, 16, 22, 28*
December 4, 10, 16*, 22, 28
January 3*, 9, 15, 21*, 27
February 2, 8*, 14, 20, 26*
March 4, 10, 16*, 22, 28
April 3*, 9, 15, 21*, 27
May 3, 9*, 15, 21, 27*

Time of Overpass ~ 1002 LST

Date

June 2, 8, 14*, 20, 26
July 2*, 8, 14, 20*, 26
August 1, 7*, 13, 19, 25*, 31
September 6, 12*, 18, 24, 30*
October 6, 12, 18*, 24, 30
November 5*

Washington:

Bickleton (46°03'N, 120°13'W)
3000 Ft.
Date

October 31
November 6, 12*, 18, 24, 30*
December 6, 12, 18*, 24, 30
January 5*, 11, 17, 23*, 29
February 4, 10*, 16, 22, 28*
March 6, 12, 18*, 24, 30
April 5*, 11, 17, 23*, 29

Time of Overpass ~ 1019 LST

Date

May 5, 11*, 17, 23, 29*
June 4, 10, 16*, 22, 28
July 4*, 10, 16, 22*, 28
August 3, 9*, 15, 21, 27*
September 2, 8, 14*, 20, 26
October 2*, 8, 14, 20*, 26
November 1, 7*

Appendix 2

Usefulness Rating of Satellite Imagery and
Site Clarity

Site Clarity for 1973 Growing Season

<u>Site Designator</u>	<u>Growing Season</u>	<u># of Over-pass Dates</u>	<u># of Totally Clear Images*</u>	<u>Clarity Factor</u>
RM-1	1 May to 1 Oct	9	4	4/9
RM-2	10 Apr to 20 Nov	13	3	3/13
RM-3	15 Apr to 15 Nov	12	3	3/12
RM-4	5 Apr to 20 Nov	13	8	8/13
RM-5	5 Apr to 30 Nov	13	9	9/13
RM-6	5 Feb to 30 Nov	16	6	6/16
CV-7	5 Apr to 10 Nov	12	5	5/12
CV-8	20 Mar to 30 Nov	14	2	2/14
CV-9	15 Mar to 15 Nov	14	5	5/14
CV-10	5 Mar to 5 Dec	15	5	5/15

* Visual inspection of images indicated no clouds, haze, or system malfunction were in area of test site to degrade quality or visual clarity.

Usefulness Rating of Satellite Imagery

Relative quality determinations include these three categories:

- ++ Good, the image includes the test site and is of high quality with little or no cloud cover
- + Fair, the image includes the study site but the photography is of low quality or contains excessive cloud cover
- or -- Poor, the image is of little or no value due to poor clarity at the test site or malfunctions in the data acquisition system

RM-1 Site:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-28-1972	++	0
9-15	-	75
10-3	+	5
10-21	++	50
11-8	++	50
11-26	--	80
12-14	++	20
1-1-1973	--	100
1-18	+	50
1-19	++	20
2-3	--	80
2-6	++	0

Site RM-1 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
2-24-1973	--	50
3-13	--	65
3-14	+	50
3-31	-	50
4-1	-	55
4-18	++	20
4-19	-	90
5-6	-	35
5-7	+	50
5-24	--	55
6-11	++	trace
6-12	--	40
6-29	-	10
6-30	-	75
7-17	--	80
7-18	++	0
8-5	-	60
9-10	++	1
9-28	++	0
10-16	-	65
11-3	--	75

Site RM-2:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-26-1972	++	trace
9-13	++	10
10-1	+	trace
11-6	++	0
11-24	-	80
12-12	-	50
12-30	++	10
1-17-1973	++	10
2-4	--	65
2-22	++	0
3-12	++	trace
3-29	+	30
3-30	+	45
4-17	--	80
5-5	--	60
6-9	+	45
6-10	-	70
6-27	+	60
6-28	+	20
7-15	++	10

Site RM-2 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
7-16-1973	++	5
9-8	--	95
9-26	++	5
10-14	++	65
11-1	--	85

Site RM-3:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-26-1972	++	5
9-13	++	10
10-1	+	50
10-1	-	30
11-6	--	70
11-24	--	60
12-12	--	45
12-30	--	70
12-30	--	70
1-17-1973	--	70
2-4	--	85
2-4	--	85
2-22	--	25
3-12	+	75
3-12	+	20
3-30	+	20
3-30	-	30
4-17	--	80
5-5	-	60
5-5	-	40

Site RM-3 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
5-23-1973	-	30
5-23	-	80
6-10	+	30
6-28	-	25
7-16	++	20
9-8	--	95
9-26	++	5
10-14	++	10
10-14	++	0
11-1	--	45
11-1	--	75
11-10	--	90

Where duplicate dates exist above, successive samples of the satellite imagery overlapped enough to provide duplicate coverage of the test site on the same date.

Site RM-4:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8- 7-1972	++	0
8-25	-	10
8-26	++	5
9-12	++	5
9-13	++	0
9-30	++	0
10-1	-	60
10-18	--	75
11-2	--	95
11-6	++	0
11-23	++	5
11-24	--	30
12-11	++	0
12-12	--	90
12-29	+	60
12-30	--	20
1-17-1973	-	40
2-3	--	30
2-21	+	10
2-22	+	10

Site RM-4 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
3-11-1973	--	100
3-12	++	40
3-29	+	75
3-30	-	25
4-16	-	45
4-17	--	85
5-4	-	85
5-5	+	20
5-22	++	0
5-23	++	30
6-9	++	5
6-10	++	25
6-27	++	5
6-28	-	45
7-15	+	25
7-16	++	5
9-7	++	1
9-8	--	90
9-26	++	5
10-13	++	0

Site RM-4 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
10-14	++	0
10-31	--	90
11-1	++	45

Site RM-5:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-7-1972	++	0
8-25	+	75
9-12	++	0
9-30	--	50
10-18	--	95
11-5	--	85
11-23	--	30
12-11	-	40
12-29	--	80
1-16-1973	--	95
2-3	--	95
2-21	--	95
3-11	--	75
3-29	--	80
4-15	+	35
4-16	++	0
5-4	++	10
5-22	++	15
6-8	++	trace
6-9	-	60

Site RM-5 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
6-26-1973	++	0
6-27	++	10
7-14	++	25
7-15	++	25
9-7	++	0
10-13	++	0
10-31	++	5

Site RM-6:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-7-1972	++	0
8-25	--	95
9-12	++	5
9-30	++	10
10-18	--	95
11-5	+	40
11-23	+	45
12-11	-	35
12-29	+	25
1-16-1973	--	90
2-3	--	90
3-11	--	90
3-29	--	80
4-16	++	5
5-4	-	35
5-22	++	10
6-9	++	10
6-27	-	25
7-15	+	10
9-7	++	0

Site RM-6 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
10-13-1973	++	0
10-31	++	0

Site CV-7:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-25-1972	++	10
8-26	++	0
9-12	--	95
9-13	++	5
9-30	++	20
10-1	-	55
10-18	++	10
11-5	--	100
11-23	--	50
11-24	--	55
12-6	++	20
12-11	--	95
12-12	-	50
12-29	--	95
12-30	++	0
1-16-1973	++	10
1-17	-	35
2-3	--	70
2-21	++	0
2-22	++	0

Site CV-7 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
3-11-1973	++	35
3-12	++	5
3-29	++	10
3-30	++	10
4-16	+	40
4-17	-	55
5-4	--	75
5-5	-	45
5-22	++	5
5-23	++	10
6-9	-	50
6-10	++	40
6-27	++	20
6-28	+	40
7-15	++	0
7-16	++	25
9-7	--	90
9-8	--	85
9-20	++	0
10-13	--	55

Site CV-7 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
10-14-1973	--	55
10-31	-	70

Site CV-8:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-10-1972	++	5
8-11	++	10
8-28	++	0
8-29	++	5
9-15	++	15
10-3	++	0
10-4	--	75
10-21	--	80
10-22	-	50
11-8	--	95
11-27	-	45
12-14	-	60
1-2-1973	++	10
1-10	--	95
1-19	-	75
1-20	++	10
2-6	-	50
2-7	++	0
2-24	-	10
3-4	--	100

Site CV-8 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
3-14-1972	--	100
4-1	--	95
4-19	+	50
5-7	-	80
6-11	-	50
6-12	+	30
6-30	--	30
7-18	++	5
7-19	++	trace
9-10	-	5
9-26	++	0
9-28	++	0
9-29	++	0
10-16	-	50
11-3	+	35

Site CV-9:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-11-1972	++	10
8-12	++	5
8-29	++	5
8-30	++	5
9-16	-	85
9-17	-	50
10-5	++	0
10-22	-	50
10-23	-	45
11-10	--	55
11-27	+	45
11-28	++	0
12-15	--	90
12-16	--	100
1-2-1973	++	10
1-3	-	35
1-21	+	40
2-8	++	0
2-26	++	10
4-2	--	80

Site CV-9 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
4-3-1973	+	10
4-20	-	80
4-21	++	5
5-9	-	75
5-26	-	75
5-27	+	20
6-13	-	50
6-14	--	95
7-2	-	80
7-19	++	trace
7-20	--	100
9-12	++	5
9-26	++	0
9-29	++	0
9-30	--	75
10-10	+	25
10-17	++	0
10-18	++	35
11-3	--	85

Site CV-10:

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
8-14-1972	--	85
9-1	++	0
9-19	++	35
10-7	++	0
10-25	+	45
11-12	-	50
11-30	--	95
12-18	--	85
1-5-1973	--	75
1-23	+	25
3-18	+	30
4-5	+	30
4-23	-	40
5-11	++	0
5-29	++	0
6-16	-	60
7-4	++	10
7-22	++	10
7-27	++	0
8-14	--	85

Site CV-10 (Continued):

<u>Satellite Overpass Date</u>	<u>Clarity in Vicinity of Test Site</u>	<u>% Cloud Cover on the Total Imagery</u>
9-14-1973	-	40
10-2	-	5
10-20	-	50
11-7	--	95

Appendix 3

Green Cover and Plant Height Ground Truth

Information on Plant Height and Percent Green for Alfalfa, Wheat and Range in the Rocky Mountain and Columbia Valley Corridors

Plant height measurements were initiated for all three subsites at each of the 10 sites with the onset of green growth in the late winter or spring of 1973 and were continued throughout the 1973 growing season. These height measurements were made by the observers at the time photographs were taken. Thus, information on plant height is usually available at 6-day intervals. While these height measurements reflect the average height of the plants in the field, observers sometimes reported a range of heights and these are given in the tables as reported.

Tables 1-30 list the height of the crops for each of the three subsites at all 10 sites in the Rocky Mountain and Columbia Valley Corridors. Also included in the tables is the associated percent of the foliage that was green (percent green) as explained in another section where more complete information on percent green is given. Information on percent green, listed along with plant height in these tables, could be helpful in evaluating the probable height of plants during periods when height measurements are not recorded.

The product of "plant height" times "percent green" serves as an "Index of Green Biomass" (not included in these tables) which is one of the variables in some of the regression equations reported elsewhere in this report.

The date of observation is given in column 1. Plant height as measured by the observer, and notes made at the time, are given in column 2. Percent green is given in column 3.

Tables 1-10 give plant height and percent green for alfalfa at each of the 10 sites in the Rocky Mountain and Columbia Valley Corridors except for Site CV-9 where meadow is used instead of alfalfa. Tables 11-20 give plant height and percent green for dryland winter wheat at all sites in the Rocky Mountain and Columbia Valley Corridors except for Site RM-1 where dryland spring barley is grown instead of wheat. Tables 21-30 give plant height and percent green for range at all 10 sites in the Rocky Mountain and Columbia Valley Corridors.

As a very rough estimate, Index of Green Biomass times 10^{-3} is equivalent to tons of harvestable alfalfa on the field.

For wheat, a very rough conversion is the highest Index of Green Biomass attained during the growing season times 10^{-2} is equal to final yield of dryland winter wheat in bushels per acre.

Table 1: Plant Height and Percent Green for Alfalfa at Site RM-1

Date	Height (Inches)	Percent Green
5- 7-73	1	5.0
5-13-73	1½	11.0
5-19-73	3	53.0
5-26-73	5	75.0
6- 6-73	8	92.0
6-18-73	8	93.0
6-24-73	12	95.8
7- 6-73	13	95.8
7-12-73	15	95.0
7-18-73	cut	33.0
7-30-73	cut	12.0
8- 5-73	5	13.0
8-11-73	6	17.0
8-17-73	8	20.0
8-23-73	cut & grazed	19.0
8-29-73	grazed	10.0
9- 4-73	no new growth	4.2
9-10-73	no new growth	3.4
9-16-73	no new growth	5.2
9-22-73	no new growth	6.4
9-28-73	no new growth	4.4
10- 4-73	no new growth	2.6

Table 1 (cont.) Alfalfa at Site RM-1

Date	Height (Inches)	Percent Green
10-10-73	no new growth	4.4
10-16-73	no new growth	1.8
10-22-73	no new growth	.4
11- 9-73	no new growth	0
11-15-73	no new growth	0
11-21-73	no new growth	0
11-27-73	no new growth	0
12- 3-73	no new growth	0

Table 2: Plant Height and Percent Green for Alfalfa at Site RM-2

Date	Height (Inches)	Percent Green
3-24-73	$\frac{1}{2}$	0
3-30-73	1	0
4-5-73	1	.8
4-11-73	1	1.8
4-17-73	1	6.2
4-23-73	$1\frac{1}{2}$	6.0
4-29-73	$1\frac{1}{2}$	8.0
5-5-73	2	19.0
5-11-73	$2\frac{1}{2}$	32.0
5-17-73	5	64.0
5-23-73	9	87.0
5-29-73	11	95.0
6-4-73	17	99.0
6-10-73	21	99.0
6-16-73	24	99.0
6-22-73	28	99.0
6-28-73	30	99.0
7-4-73	cut	15.0
7-10-73	cut	14.0
7-16-73	cut	35.0
7-22-73	12	74.0
7-28-73	16	92.0

Table 2 (cont.) Alfalfa at Site RM-2

Date	Height (Inches)	Percent Green
8- 3-73	23	99.0
8-15-73	26	99.0
8-27-73	cut	44.0
9- 2-73	5	30.0
9- 8-73	5	39.0
9-21-73	5	79.0
9-26-73	4	94.0
10- 2-73	9	99.0
10- 8-73	4	96.4
10-14-73	3	98.2
10-20-73	4	95.6
11-19-73	4	3.6
11-27-73	1	2.6

Table 3: Plant Height and Percent Green for Alfalfa at Site RM-3

Date	Height (Inches)	Percent Green
4-17-73	$\frac{1}{2}$	1.0
4-23-73	$1\frac{1}{2}$	10.0
4-29-73	2	15.0
5- 5-73	4	22.0
5-11-73	5	34.0
5-17-73	7	63.0
5-24-73	10	86.0
6- 4-73	16	93.0
6-11-73	19	99.0
6-18-73	23	99.0
6-22-73	25	99.0
6-28-73	27	99.0
7- 4-73	32	99.0
7-10-73	mowed	9.0
7-16-73	3	11.0
7-22-73	7	16.0
7-28-73	17	26.0
8- 3-73	19	51.0
8- 9-73	23	77.0
8-15-73	26	80.0
8-21-73	28	99.0
9- 2-73	in swath	24.0

Table 3 (cont.) Alfalfa at Site RM-3

Date	Height (Inches)	Percent Green
9-14-73	4	28.0
9-20-73	6	26.0
9-26-73	6	28.0
10- 2-73	7	26.0
10- 8-73	6	27.0
10-14-73	7	27.0
10-20-73	7	27.0
10-26-73	7	24.0
11- 1-73		18.0
11- 7-73		11.0

Table 4: Plant Height and Percent Green for Alfalfa at Site RM-4

Date	Height (Inches)	Percent Green
3-24-73	dormant	0
3-30-73	dormant	0
4- 5-73	dormant	.2
4-11-73	dormant	1.8
4-18-73	1½	11.0
4-23-73	¾	16.0
4-29-73	1½	38.0
5- 5-73	3	61.0
5-11-73	7	92.0
5-17-73	11	96.6
5-23-73	12	99.0
5-29-73	16	99.0
6- 4-73	21	99.0
6-10-73	25	99.0
6-16-73	27	99.0
6-22-73	2	40.0
6-28-73	2	31.0
7- 4-73	5	51.0
7-10-73	10	90.0
7-16-73	16	99.0
7-22-73	20	99.0
7-28-73	28	99.0

Table 4 (cont.) Alfalfa at Site RM-4

Date	Height (Inches)	Percent Green
8- 3-73	33	99.0
8- 9-73	33	99.0
8-15-73	2	37.0
8-21-73	3½	49.0
8-28-73	7	72.0
9- 3-73	10	86.0
9- 9-73	13	94.0
9-14-73	14	95.0
9-20-73	14	97.4
9-26-73	14	96.6
10- 2-73	14	95.8
10-26-73	12	32.0
11- 1-73	12	4.4
11- 8-73	10	1.0
11-13-73	8	1.8
11-19-73	8	.4

Table 5: Plant Height and Percent Green for Alfalfa at Site RM-5

Date	Height (Inches)	Percent Green
4- 4-73	$\frac{1}{4}$ - $\frac{1}{2}$	1.6
4-16-73	1	5.2
4-22-73	2	12.0
4-28-73	3 - 5	28.0
5- 4-73	8	47.0
5-10-73	9	72.0
5-16-73	11	96.4
5-22-73	12 - 14	99.0
5-28-73	14 - 16	99.0
6- 3-73	16 - 18	99.0
6- 9-73	18 - 20	99.0
6-15-73	20	79.0
6-21-73	20	38.0
6-27-73	20	11.0
7- 3-73	18	9.0
7- 9-73	cut	4.4
7-15-73	cut	4.4
7-21-73	4 cut	10.0
7-27-73	8	37.0
8- 2-73	12	89.0
8- 8-73	14	99.0
8-14-73	20	99.0

Table 5. (cont.) Alfalfa at Site RM-5

Date	Height (Inches)	Percent Green
8-20-73	20.	99.0
8-26-73	24.	99.0
9- 1-73	cut	33.0
9- 7-73	cut	2.8
9-13-73	3	6.0
9-19-73	6	32.0
9-25-73	6 - 8	52.0
10- 1-73	10	68.0
10- 7-73	11	72.0
10-13-73	10 - 12	73.0
10-19-73	12	82.0
10-25-73	12	88.0
10-31-73	frost bitten	75.0
11- 6-73	frozen down	60.0
11-12-73	grazed	42.0
11-18-73	3 grazed	36.0
11-24-73	grazed	24.0
11-30-73		0

Table 6: Plant Height and Percent Green for Alfalfa at Site RM-6

Date	Height (Inches)	Percent Green
4- 4-73	1½	53.0
4-10-73	2	67.0
4-22-73	4½	89.0
4-28-73	6	95.0
5- 4-73	10	99.0
5-12-73	14	99.0
5-16-73	19	99.0
5-22-73	28	99.0
5-28-73	31	99.0
6- 4-73	cut	99.0
6- 9-73		2.8
6-15-73		8.0
6-21-73		30.0
6-27-73		87.0
7- 3-73		97.4
7- 9-73		99.0
7-15-73		99.0
7-23-73		19.0
7-31-73	3	7.0
8- 8-73	5	11.0
8-14-73	7	21.0
8-20-73	10	26.0

Table 6 (cont.) Alfalfa at Site RM-6

Date	Height (Inches)	Percent Green
8-26-73	12	31.0
9- 1-73		39.0
9- 7-73		63.0
9-13-73		79.0
9-19-73		84.0
9-25-73		85.0
10- 1-73		80.0
10- 7-73		73.0
10-25-73		17.0
10-31-73		4.4
11- 6-73		1.8
11-12-73		.8
11-30-73		.2
12- 6-73		0
12-12-73		0
12-24-73		0

Table 7: Plant Height and Percent Green for Alfalfa at Site CV-7

Date	Height (Inches)	Percent Green
5- 5-73	1½	10.0
5-11-73	4½	17.0
5-17-73	10	28.0
5-23-73	12	44.0
5-29-73	16	69.0
6- 4-73	15½	87.0
6-10-73	26	95.8
6-22-73	alfalfa mowed	74.0
6-28-73	6	40.0
7- 4-73	10	41.0
7-10-73	12	60.0
7-16-73	17	68.0
7-22-73	17	79.0
7-28-73	21	80.0
8- 3-73	alfalfa cut	21.0
8- 9-73	alfalfa cut	23.0
8-15-73	10	28.0
8-21-73	12	34.0
8-27-73	15	48.0
9- 2-73	20	55.0
9- 8-73	20	70.0
9-14-73	20	66.0

Table 7 (cont.) Alfalfa at Site CV-7

Date	Height (Inches)	Percent Green
9-20-73	20	63.0
9-26-73	12	48.0
10- 2-73	24	47.0
10- 8-73	22	39.0
10-14-73	22	37.0
10-20-73	22	29.0
10-26-73	20	14.0
11-13-73	20	5.0

Table 8: Plant Height and Percent Green for Alfalfa at Site CV-8

Date	Height (Inches)	Percent Green
3-21-73	3/4	.6
3-27-73	1	1.8
4- 9-73	2	6.2
4-15-73	2½ - 3	24.0
4-20-73	2½ - 3	33.0
4-27-73	3½	43.0
5- 2-73	4	53.0
5- 8-73	6	60.0
5-14-73	7 - 8	79.0
5-21-73	8 - 10	84.0
5-29-73	12 - 14	92.0
6- 1-73	14 - 16	95.8
6- 7-73	17 - 20	99.0
6-13-73	16 - 24 - 28	99.0
6-20-73	20 - 28	99.0
7- 2-73	4 cut	.8
7- 9-73	4	7.2
7-13-73	4 - 5	38.0
7-19-73	10 - 15	67.0
7-25-73	13 - 16	88.0
7-31-73	16 - 28	94.0
8- 6-73	9 - 23	97.4

Table 8 (cont.) Alfalfa at Site CV-8

Date	Height (Inches)	Percent Green
8-12-73	8 - 20	36.0
8-18-73	8 - 20	2.6
8-24-73	8 - 17	14.0
8-30-73		20.0
9-11-73		44.0
9-17-73		48.0
9-29-73		50.0
10-11-73		51.0
10-23-73		49.0

Table 9: Plant Height and Percent Green for Meadow at Site CV-9

Date	Height (Inches)	Percent Green
3- 4-73	no growth	3.4
3-10-73	no growth	5.4
3-16-73	0	6.4
3-22-73	very little	11.2
3-28-73	1	16.0
4- 9-73	1	25.0
4-15-73	2	51.0
4-21-73	2	70.0
4-27-73	3	87.0
5- 3-73	3	95.8
5- 9-73	5	96.6
5-15-73	9	98.2
5-21-73	12	99.0
5-27-73	13	99.0
6- 2-73	14	99.0
6- 8-73	14	98.2
6-20-73	16	87.8
6-26-73	18	92.8
7- 2-73	harvested	92.8
7- 8-73		88.8
7-14-73		83.0
7-20-73		82.0

Table 9 (cont.) Meadow at Site CV-9

Date	Height (Inches)	Percent Green
7-26-73		75.0
8- 1-73		60.0
8- 7-73		41.0
8-13-73		35.0
8-19-73		24.0
8-25-73		18.0
8-31-73		8.2
9- 6-73		1.0
9-12-73		1.0
9-18-73		1.0
9-30-73		59.0
10- 6-73		40.0
10-12-73		38.0
10-18-73		39.0
10-24-73		51.0
10-30-73		56.0
11-11-73		58.0
11-12-73		56.0
11-17-73		49.0

Table 10: Plant Height and Percent Green for Alfalfa at Site CV-10

Date	Height (Inches)	Percent Green
4- 5-73	2	27.0
4-11-73	4	38.0
4-17-73	5	50.0
4-23-73	6	64.0
4-29-73	7	74.0
5-11-73	10	88.0
5-17-73	17	95.0
5-23-73	21	95.8
5-29-73	21	93.0
6- 4-73	21	92.0
6-10-73	25	78.0
6-16-73	5	84.0
6-22-73	5	57.0
6-29-73	5	42.0
7- 5-73	8	37.0
7-12-73	11	11.0
7-16-73	12	2.6
7-22-73	14	4.4
7-28-73	15	9.0
8- 3-73	16	16.0
8- 9-73	16	25.0
8-16-73	cut 2nd time	18.0
8-21-73	5	13.0

Table 10 (cont.) Alfalfa at Site CV-10

Date	Height (Inches)	Percent Green
8-27-73	5	22.0
9- 2-73	6	52.0
9- 8-73	8	27.0
9-14-73	9	28.0
9-20-73	10	33.0
9-26-73	5	37.0
10- 2-73	3	35.0
10- 8-73	3	39.0
10-14-73	2	38.0
10-20-73	2	38.0
10-26-73	2	34.0
11- 1-73	2	.2
11-19-73	2	35.0
12- 1-73	2	10.0

Table 11: Plant Height and Percent Green for Wheat at Site RM-1

Date	Height (Inches)	Percent Green
5-19-73	1	5.2
5-26-73	1½	14.0
6- 6-73	4	36.0
6-13-73	5	48.0
6-24-73	8	66.0
7- 6-73	11	55.0
7-12-73	no new growth	52.0
7-18-73	no new growth	44.0
7-24-73	no new growth	27.0
7-30-73	no new growth	4.2
8- 5-73	no new growth	1.0
8-11-73	no new growth	1.0
8-17-73	cut	1.0
8-23-73	cut	1.8
8-29-73	cut	.6
9- 4-73	no new growth	.6
9-10-73	no new growth	.6
9-16-73	no new growth	.6
9-22-73	no new growth	1.0
9-28-73	no new growth	1.0
10- 4-73	no new growth	1.0

Table 11(cont.) Wheat at Site RM-1

Date	Height (Inches)	Percent Green
10-10-73	plowed	0
10-16-73	no new growth	0
10-22-73	no new growth	0
10-28-73	no new growth	0
11- 9-73	no new growth	0
11-15-73	no new growth	0
11-21-73	no new growth	0
11-27-73	no new growth	0
12- 3-73	no new growth	0

Table 12: Plant Height and Percent Green for Wheat at Site RM-2

Date	Height (Inches)	Percent Green
3-24-73	$\frac{1}{2}$	1.0
3-30-73	$1\frac{1}{2}$	1.0
4- 5-73	$2\frac{1}{2}$	1.0
4-11-73	3	1.0
4-17-73	$3\frac{1}{2}$	1.8
4-23-73	4	3.4
4-29-73	4	6.0
5- 5-73	$4\frac{1}{2}$	8.0
5-11-73	$6\frac{1}{2}$	12.0
5-17-73	$8\frac{1}{2}$	16.0
5-23-73	10	25.0
5-29-73	12	31.0
6- 4-73	13	37.0
6-10-73	18	47.0
6-16-73	19	71.0
6-22-73	21	66.0
6-28-73	33	58.0
7- 4-73	28	51.0
7-10-73	31	47.0
7-16-73	33	20.0
7-22-73	29	2.8
7-28-73	28	0
8- 3-73	28	0

Table 12 (cont.) Wheat at Site RM-2

Date	Height (Inches)	Percent Green
8-15-73	8 stubble	0
8-21-73	10 stubble	0
8-27-73	stubble	0
9- 2-73	10 stubble	0
9- 8-73	stubble	.2
9-15-73	stubble	.8
9-21-73	stubble	1.0
9-26-73	stubble	5.4
10- 2-73	stubble	11.0
10- 8-73	4 stubble	10.0
10-14-73	4 stubble	11.0
10-20-73	4 stubble	12.0
10-26-73	stubble	26.0
11-13-73	stubble	26.0
11-19-73	stubble	.4
11-27-73	4 stubble	7.0

Table 13: Plant Height and Percent Green for Wheat at Site RM-3

Date	Height (Inches)	Percent Green
4- 5-73	1	.4
4-17-73	1	.8
4-23-73	2	1.8
5- 5-73	5	6.0
5-11-73	5	8.0
5-17-73	5	11.0
5-24-73	6	25.0
6- 4-73	9	35.0
6-11-73	11	46.0
6-18-73	14	65.0
6-22-73	15	57.0
6-28-73	17	61.0
7- 4-73	21	61.0
7-10-73	21	39.0
7-22-73	21	17.0
7-28-73	20	12.0
8- 3-73	21	13.0
8- 9-73	harvested, stubble	10.0
8-15-73	stubble	9.0
8-21-73	4 stubble	10.0
9- 2-73	plowed	6.2
9-14-73	2	6.2

Table 13 (cont.) Wheat at Site RM-3

Date	Height (Inches)	Percent Green
9-20-73	3	6.2
9-26-73	5	6.2
10- 2-73	5	5.2
10- 8-73	5	5.2
10-14-73	5	3.4
10-20-73	5	2.6
10-26-73	5	4.4
11- 1-73		1.8
11- 7-73		1.0

Table 14: Plant Height and Percent Green for Wheat at Site RM-4

Date	Height (Inches)	Percent Green
3-24-73	dormant	0
3-30-73	dormant	0
4- 5-73	$\frac{1}{2}$	0
4-11-73	$1\frac{1}{2}$	.2
4-18-73	2	1.0
4-23-73	3	1.0
4-29-73	3	5.0
5- 5-73	4	7.0
5-11-73	5	10.0
5-17-73	$5\frac{1}{2}$	14.0
5-23-73	7	17.0
5-29-73	7	16.0
6- 4-73	9	22.0
6-10-73	$10\frac{1}{2}$	20.0
6-16-73	12	25.0
6-22-73	13	24.0
6-28-73	13	21.0
7- 4-73	13	19.2
7-10-73	13	1.0
7-16-73	13	.4
7-22-73	13	0
7-28-73	13	0

Table 14 (cont.) Wheat at Site RM-4

Date	Height (Inches)	Percent Green
8- 3-73	13	0
8- 9-73	13	0
8-15-73	13	.2
8-21-73	13	.8
8-28-73	13	1.0
9- 3-73	13	1.0
9- 9-73	5	.8
9-14-73	5	5.0
9-20-73	5	4.2
9-26-73	5	4.2
10- 2-73	5	4.2
10-26-73	5	4.2
11- 1-73	5	1.8
11- 8-73	5	1.8
11-13-73	4	3.4
11-19-73	4	0

Table 15: Plant Height and Percent Green for Wheat at Site RM-5

Date	Height (Inches)	Percent Green
3-11-73	1	1.0
3-17-73	2	1.0
3-23-73	2	1.0
4- 4-73	2	1.0
4-16-73	2 - 3	1.8
4-22-73	3	2.6
4-28-73	4	4.2
5- 4-73	5	6.0
5-10-73	8	8.0
5-16-73	9	11.0
5-22-73	10	13.0
5-28-73	12	18.0
6- 3-73	14	21.0
6- 9-73	18	24.0
6-15-73	18	25.0
6-21-73	24	25.0
6-27-73	22 - 24	24.0
7- 3-73	24	4.2
7- 9-73	24	0
7-15-73	24	0
7-21-73	20 harvesting	1.0
7-27-73	24	1.0

Table 15 (cont.) Wheat at Site RM-5

Date	Height (Inches)	Percent Green
8- 2-73	cut	1.0
8- 8-73	cut	1.0
8-14-73	cut	1.0
8-20-73	cut	1.0
8-26-73	cut	1.0
9- 1-73	cut	1.0
9- 7-73	cut	1.0
9-13-73	cut	1.0
9-19-73	cut	.8
9-25-73	cut	.4
10- 1-73	stubble	.2
10- 7-73	cut	0
10-13-73	cut	0
10-19-73	dry	0
10-25-73	dry stubble	0
10-31-73	stubble	0
11- 6-73	stubble	0
11-12-73	dry	0
11-18-73	dry	0
11-24-73	dry	0
11-30-73		0

Table 16: Plant Height and Percent Green for Wheat at Site RM-6

Date	Height (Inches)	Percent Green
4- 4-73	2	33.0
4-10-73	3	42.0
4-16-73	4½	47.0
4-22-73	6	51.0
4-28-73	7	66.0
5- 4-73	11	79.0
5-12-73	14	87.0
5-16-73	19	90.0
5-22-73	27	92.0
5-28-73	30	90.0
6- 4-73	37	76.0
6- 9-73	33	57.0
6-15-73	33	40.0
6-21-73		8.4
6-27-73		1.8
7- 3-73		.4
7- 9-73		.4
7-15-73		.4
7-23-73		0
7-31-73		0
8- 8-73		0
8-14-73		0

Table 16 (cont.) Wheat at Site RM-6

Date	Height (Inches)	Percent Green
8-20-73		0
8-26-73		0
9- 1-73		0
9- 7-73		0
9-13-73		0
9-19-73		0
9-25-73		0
10- 1-73		0
10- 7-73		0
10-25-73		0
10-31-73		0
11- 6-73		0
11-12-73		0
11-30-73		0
12- 6-73		0
12-12-73		0
12-24-73		0

Table 17: Plant Height and Percent Green for Wheat at Site CV-7

Date	Height (Inches)	Percent Green
4-17-73	1 - 2	3.4
4-23-73	3	2.6
4-29-73	5	7.0
5- 5-73	7	11.0
5-11-73	8	17.0
5-17-73	11	24.0
5-23-73	12	36.0
5-29-73	10 - 12	57.0
6- 4-73	16 $\frac{1}{2}$	75.0
6-10-73	19	73.0
6-22-73	27	67.0
6-28-73	30	59.0
7- 4-73	28	45.0
7-10-73	36	6.4
7-16-73	35	2.6
7-22-73	26	.4
7-28-73	35	.2
8- 3-73		0
8- 9-73		0
8-15-73		0
8-21-73		0
8-27-73		0

Table 17 (cont.) Wheat at Site CV-7

Date	Height (Inches)	Percent Green
9- 2-73		0
9- 8-73		0
9-14-73		0
9-20-73		0
9-26-73		0
10- 2-73		.4
10- 8-73		.8
10-14-73		1.0
10-20-73		1.8
10-26-73		2.6
11-13-73		.6

Table 18: Plant Height and Percent Green for Wheat at Site CV-8

Date	Height (Inches)	Percent Green
3-21-73	2½	4.2
3-27-73	3 - 3½	11.0
4- 2-73	3 - 3½	14.0
4- 9-73	3½ - 4	20.0
4-15-73	4 - 5	26.0
4-20-73	5 - 5½	36.0
4-27-73	5½	44.0
5- 2-73	6	49.0
5- 8-73	6 - 9	62.0
5-14-73	7 - 9	63.0
5-21-73	8 - 10	53.0
5-29-73	10 - 13	55.0
6- 1-73	12 - 13	49.0
6- 7-73	13 - 16	66.0
6-13-73	17 - 19	67.0
6-20-73	14 - 20	68.0
7- 2-73	13 - 20	36.0
7- 9-73	17 - 20	2.6
7-13-73	17 - 21	.6
7-19-73	17 - 20	.6
7-25-73	17 - 21	.6
7-31-73	17 - 21	.4

Table 18 (cont.) Wheat at Site CV-8

Date	Height (Inches)	Percent Green
8- 6-73	15 - 20	.4
8-12-73	17 - 21	0
8-18-73		0
8-24-73	17 - 21	0
8-30-73		0
9-11-73		0
9-17-73		0
9-29-73		0
10-11-73		.6
10-23-73		.8

Table 19: Plant Height and Percent Green for Wheat at Site CV-9

Date	Height (Inches)	Percent Green
3- 4-73	no growth	1.0
3-10-73	1	1.0
3-16-73	1	1.0
3-22-73	2	1.0
3-28-73	2	1.0
4- 9-73	2½	1.0
4-15-73	3½	1.8
4-21-73	4	2.6
4-27-73	5	5.2
5- 3-73	6	9.0
5- 9-73	7	15.0
5-15-73	11	28.0
5-21-73	12	43.0
5-27-73	13	55.0
6- 2-73	14	68.0
6- 8-73	14	73.0
6-20-73	20	79.0
6-26-73	20	90.0
7- 2-73	20	92.0
7- 8-73	24	87.0
7-14-73	26	71.0
7-20-73		34.0
7-26-73		2.6

Table 19 (cont.) Wheat at Site CV-9

Date	Height (Inches)	Percent Green
8- 1-73		.6
8- 7-73		0
8-13-73		0
8-19-73		0
8-25-73		0
8-31-73		.8
9- 6-73		.2
9-12-73		.4
9-18-73		.4
9-30-73		11.0
10- 6-73		13.0
10-12-73		14.0
10-18-73		19.0
10-24-73		20.0
10-30-73		21.0
11-11-73		17.0
11-12-73		16.0
11-17-73		31.0

Table 20: Plant Height and Percent Green for Wheat at Site CV-10

Date	Height (Inches)	Percent Green
4- 5-73	6	33.0
4-11-73	9	40.0
4-17-73	11	46.0
4-23-73	13	51.0
4-29-73	13	59.0
5-11-73	18	70.0
5-17-73	18	77.0
5-23-73	20	84.0
5-29-73	22	82.0
6- 4-73	28	82.0
6-10-73	28	68.0
6-16-73	28	53.0
6-22-73	28	15.0
6-29-73	28	2.6
7- 5-73	28	0
7-12-73	28	0
7-16-73	28	0
7-22-73	28	0
7-28-73	cut	0
8- 3-73		0
8- 9-73		0
8-16-73		0
8-21-73		0

Table 20 (cont.) Wheat at Site CV-10

Date	Height (Inches)	Percent Green
8-27-73		0
9- 2-73		0
9- 8-73		0
9-14-73		0
9-20-73		0
9-26-73		0
10- 2-73		0
10- 8-73		0
10- 1-73		0
10-20-73		0
10-26-73		0
11- 1-73		0
11-19-73		0
12- 1-73		0

Table 21: Plant Height and Percent Green for Range at Site RM-1

Date	Height (Inches)	Percent Green
4- 7-73	1½	0
4-13-73	1½	0
4-19-73	2	.8
4-25-73	2	1.8
5- 1-73	2	3.4
5- 7-73	2	7.0
5-13-73	3	13.0
5-19-73	3	21.0
5-26-73	3	27.0
6-18-73	5	30.0
6-24-73	7	32.0
7- 6-73	dried up	33.0
7-12-73	dried up	28.0
7-18-73	dried up	14.0
7-24-73	dried up	12.0
7-30-73	dried up	5.2
8- 5-73	no new growth	4.4
8-11-73	no new growth	2.6
8-17-73	no new growth	2.6
8-23-73	no new growth	2.6
8-29-73	no new growth	1.0
9- 4-73	no new growth	1.0

Table 21 (cont.) Range at Site RM-1

Date	Height (Inches)	Percent Green
9-10-73	no new growth	1.0
9-16-73	no new growth	1.0
9-22-73	no new growth	0
9-28-73	no new growth	0
10- 4-73	no new growth	0
10-10-73	no new growth	0
10-16-73	no new growth	.2
10-22-73	no new growth	0
10-28-73	no new growth	0
11- 9-73	no new growth	0
11-15-73	no new growth	0
11-21-73	no new growth	0
11-27-73	no new growth	0
12- 3-73	no new growth	0

Table 22: Plant Height and Percent Green for Range at Site RM-2

Date	Height (Inches)	Percent Green
3-24-73	$\frac{1}{2}$	0
3-30-73	1	0
4- 5-73	1	0
4-11-73	1	0
4-17-73	1	.8
4-23-73	$1\frac{1}{2}$	.8
4-29-73	$1\frac{1}{2}$	5.2
5- 5-73	2	8.0
5-11-73	2	12.0
5-17-73	3	17.0
5-23-73	4	27.0
5-29-73	5	31.0
6- 4-73	6	38.0
6-10-73	6	32.0
6-16-73	6	36.0
6-22-73	6	37.0
6-28-73	6	33.0
7- 4-73	8	34.0
7-10-73	8	32.0
7-16-73	8	21.0
7-22-73	9	16.0
7-28-73	12	9.4
8- 3-73	12	3.4

Table 22 (cont.) Range at Site RM-2

Date	Height (Inches)	Percent Green
8- 9-73	12	.8
8-15-73	18	.8
8-21-73	sage 8, grass 5	.6
8-27-73	dry	.4
9- 2-73	4 - 24	1.0
9- 8-73	4 - 6	2.6
9-15-73	4 - 7	7.0
9-21-73	4 - 6	13.0
9-26-73	6	15.0
10- 2-73	4 - 7	25.0
10- 8-73	4	15.2
10-14-73	4	9.0
10-20-73	3	6.2
10-26-73	3 - 4	3.4
11-13-73	2 - 3	.4
11-19-73	3 - 4	.2
11-27-73	grazed	.6

Table 23: Plant Height and Percent Green for Range at Site RM-3

Date	Height (Inches)	Percent Green
4-17-73	0 - 4	0
4-23-73	2	0
4-29-73	4	1.0
5- 5-73	5	1.0
5-11-73	5	5.0
5-17-73	6	6.0
5-24-73	6	10.0
6- 4-73	8	13.0
6-11-73	9	15.0
6-18-73	10	15.0
6-22-73	10	15.0
6-28-73	10	12.2
7- 4-73	10	11.2
7-10-73	10	10.2
7-16-73	10	2.6
7-22-73	10	1.0
7-28-73	10	1.0
8- 3-73	10	5.2
8- 9-73	10	5.4
8-15-73	10	4.4
8-21-73	10	2.6
9- 2-73	10	2.8
9-14-73		2.8

Table 23 (cont.) Range at Site RM-3

Date	Height (Inches)	Percent Green
9-20-73	7	.4
9-26-73	7	.4
10- 2-73	7	.4
10- 8-73	7	.4
10-14-73	7	0
10-20-73	7	0
10-26-73	7	0
11- 1-73		0
11- 7-73		0

Table 24: Plant Height and Percent Green for Range at Site RM-4

Date	Height (Inches)	Percent Green
3-24-73	1½	.2
3-30-73	1½	.2
4- 5-73	1½	.8
4-11-73	2	1.0
4-18-73	3	3.4
4-23-73	3½	6.2
4-29-73	3½	12.0
5- 5-73	5	15.0
5-11-73	6	17.0
5-17-73	6½	26.0
5-23-73	6½	30.0
5-29-73	8	31.0
6- 4-73	8½	30.0
6-10-73	9	28.0
6-16-73	10	35.0
6-22-73	10	31.0
6-28-73	10	31.0
7- 4-73	10	22.0
7-10-73	10	12.0
7-16-73	10	13.0
7-22-73	10	10.0
7-28-73	10	10.0

Table 24.(cont.) Range at Site RM-4

Date	Height (Inches)	Percent Green
8- 3-73	10	5.4
8- 9-73	10	4.4
8-15-73	10	1.8
8-21-73	10	1.0
8-28-73	10	1.0
9- 3-73	10	1.0
9- 9-73	10	1.0
9-14-73	10	11.0
9-20-73	10	17.0
9-26-73	10	25.0
10- 2-73	10	23.0
10-26-73	10	11.2
11- 1-73	10	.6
11- 8-73	10	.6
11-13-73	10	.4
11-19-73	10	0

Table 25: Plant Height and Percent Green for Range at Site RM-5

Date	Height (Inches)	Percent Green
3-11-73	$\frac{1}{2}$	1.8
3-17-73	$\frac{1}{2}$	1.8
3-23-73	$\frac{1}{2}$	1.8
4- 4-73	1 - 2	1.0
4-16-73	$\frac{1}{2}$ - 3	5.2
4-22-73	2 $\frac{1}{2}$	6.2
4-28-73	3 - 4	7.2
5- 4-73	5	11.0
5-10-73	6	22.0
5-16-73	9	27.0
5-22-73	8	23.2
5-28-73	9	13.2
6- 3-73	10	11.2
6- 9-73	8	6.6
6-15-73	8 - 9	4.4
6-21-73	7 - 8 drying	.2
6-27-73	6	0
7- 3-73	6, dry	.2
7- 9-73	dry	0
7-15-73	dry	0
7-21-73	dry	.2
7-27-73	dry	.4

Table 25 (cont.) Range at Site RM-5

Date	Height (Inches)	Percent Green
8- 2-73	dry	.6
8- 8-73	dry	.6
8-14-73	dry	.8
8-20-73	dry	.4
8-26-73	dry	.2
9- 1-73	dry	.2
9- 7-73	dry	0
9-13-73	dry	0
9-19-73	dry	0
9-25-73	dry	0
10- 1-73	dry	0
10- 7-73	dry	0
10-13-73	dry	0
10-19-73	dry	.2
10-25-73	dry	0
10-31-73	dry	0
11- 6-73	dormant	0
11-12-73	dry	0
11-18-73	dry	0
11-24-73	dry	0
11-30-73	dry	.0

Table 26: Plant Height and Percent Green for Range at Site RM-6

Date	Height (Inches)	Percent Green
4- 4-73	just starting to grow	5.2
4-10-73	$\frac{1}{2}$	8.0
4-16-73	2	9.0
4-22-73	3	12.0
4-28-73	4	16.0
5- 4-73	6	18.0
5-12-73	12	26.0
5-16-73	17	32.0
5-22-73	18	32.0
5-28-73	18	26.0
6- 4-73	18	23.0
6- 9-73		17.0
6-15-73		17.0
6-21-73		17.0
6-27-73		19.0
7- 3-73		22.0
7- 9-73		22.0
7-15-73		25.0
7-23-73		26.0
7-31-73		27.0
8- 8-73		27.0
8-14-73		23.0
8-20-73		26.0

Table 26 (cont.) Range at Site RM-6

Date	Height (Inches)	Percent Green
8-26-73		29.0
9- 1-73		30.0
9- 7-73		14.0
9-13-73		1.0
9-19-73		1.0
9-25-73		1.0
10- 1-73		1.0
10- 7-73		1.0
10-25-73		.6
10-31-73		.6
11- 6-73		.6
11-12-73		0
11-30-73		0
12- 6-73		0
12-12-73		0
12-24-73		.2

Table 27: Plant Height and Percent Green for Range at Site CV-7

Date	Height (Inches)	Percent Green
5- 5-73	2½	1.0
5-11-73	3½	1.8
5-17-73	5	5.0
5-23-73	10	6.0
5-29-73	10	8.0
6- 4-73	11½	9.0
6-10-73	13	9.0
6-22-73	16	16.0
6-28-73	18	17.0
7- 4-73	19	19.0
7-10-73	18½	25.0
7-16-73	20	27.0
7-22-73	20	27.0
7-28-73	21	23.2
8- 3-73	21	16.2
8- 9-73	21	12.2
8-15-73	21	4.6
8-21-73	21	1.8
8-27-73	21	1.6
9- 2-73	16	.6
9- 8-73	16	.6
9-14-73		.8

Table 27 (cont.) Range at Site CV-7

Date	Height (Inches)	Percent Green
9-20-73		.4
9-26-73		.4
10- 2-73		.4
10- 8-73		.4
10-14-73		.4
10-20-73		.4
10-26-73	12	.4
11-13-73		0

Table 28: Plant Height and Percent Green for Range at Site CV-8

Date	Height (Inches)	Percent Green
3-21-73	2	0
3-27-73	2	.2
4- 2-73	2	0
4- 9-73	2 - 2½	.6
4-15-73	3	1.8
4-20-73	4	1.8
4-27-73	4	5.0
5- 2-73	4	6.0
5- 8-73	4½ - 5	14.0
5-14-73	5 - 5½	16.0
5-21-73	5½ - 6½	15.0
5-29-73	6 - 7	22.0
6- 1-73	7 - 10	29.0
6- 7-73	7 - 14	34.0
6-13-73	8 - 15	45.0
6-20-73	7 - 15	46.0
7- 2-73	10 - 22	33.0
7- 9-73	7 - 16	29.0
7-13-73	8 - 21	26.0
7-19-73	8 - 20	24.0
7-25-73	8 - 20	20.0
7-31-73	8 - 20	8.2

Table 28 (cont.) Range at Site CV-8

Date	Height (Inches)	Percent Green
8- 6-73	12 - -29	8.2
8-12-73	cut	5.0
8-18-73	6	5.2
8-24-73	5 - 6	3.4
8-30-73		1.0
9-11-73		.8
9-17-73		.8
9-29-73		.8
10-11-73		.8
10-23-73		1.0

Table 29: Plant Height and Percent Green for Range at Site CV-9

Date	Height (Inches)	Percent Green
3- 4-73	no growth	.2
3-10-73	no growth	0
3-16-73	no growth	0
3-22-73	very little	0
3-28-73	1	0
4- 9-73	1	0
4-15-73	2	.6
4-21-73	2	.8
4-27-73	3	1.8
5- 3-73	3	4.4
5- 9-73	5	10.0
5-15-73	10	14.0
5-21-73	10	19.0
5-27-73	11	32.0
6- 2-73	12	52.0
6- 8-73	12	55.0
6-20-73	14	57.0
6-26-73	15	69.0
7- 2-73	dormant	71.0
7- 8-73		58.0
7-14-73		42.0
7-20-73		37.0
7-26-73		9.0

Table 29 (cont.) Range at Site CV-9

Date	Height (Inches)	Percent Green
8- 1-73		3.6
8- 7-73		1.8
8-13-73		1.0
8-19-73		.8
8-25-73		.8
8-31-73		.8
9- 6-73		.4
9-12-73		.2
9-18-73		.2
9-30-73		.8
10- 6-73		1.0
10-12-73		1.8
10-18-73		.4
10-24-73		.8
10-30-73		1.0
11-13-73		.6

Table 30: Plant Height and Percent Green for Range at Site CV-10

Date	Height (Inches)	Percent Green
4- 5-73	2	1.0
4-11-73	3	2.6
4-17-73	4	2.6
4-23-73	6	4.2
4-29-73	7	8.0
5-11-73	8	7.0
5-17-73	10	8.0
5-23-73	12	11.0
5-29-73	12	12.0
6- 4-73	12	12.0
6-10-73	12	12.0
6-16-73	12	12.0
6-22-73	12	7.0
6-29-73	12	4.4
7- 5-73	12	2.6
7-12-73	12	4.4
7-16-73	12	2.8
7-22-73	12	2.8
7-28-73	12	1.8
8- 3-73	12	1.0
8- 9-73	12	1.0
8-16-73	12	1.0
8-21-73	12	1.0

Table 30 (cont.) Range at Site CV-10

Date	Height (Inches)	Percent Green
8-27-73	12	.8
9- 2-73	12	0
9- 8-73	12	.8
9-14-73	12	0
9-20-73	12	0
9-26-73	12	0
10- 2-73	12	0
10- 8-73	12	0
10-14-73	12	.2
10-20-73	12	0
10-26-73	12	.4
11- 1-73	12	0
11-19-73	12	1.6
12- 1-73	12	3.4

Appendix 4

Species of Plants in the Range Test Plots

Approximate Percentage of the Total Vegetative Cover for the
Predominant Species at Each of the Range Sites in the Rocky
Mountain and Columbia Valley Corridors.

<u>Scientific Name</u>	<u>Percent</u>	<u>Common Name</u>
RM-1 <i>Festuca scabrella</i>	60	Range fescue
<i>Festuca idahoensis</i>	20	Idaho fescue
<i>Koeleria cristata</i>	10	Prairie Junegrass
RM-2 <i>Bromus tectorum</i>	30	Cheatgrass brome
<i>Stipa comata</i>	30	Needle-and-thread
<i>Agropyron smithii</i>	20	Western wheatgrass
RM-3 <i>Stipa comata</i>	90	Needle-and-thread
<i>Opunh'a polyacantha</i>	Trace	Prickley Pear
<i>Artemisia tridentata</i>	Trace	Big Sagebrush
RM-4 <i>Agropyron desertorum</i>	60	Crested wheatgrass
<i>Bromus tectorum</i>	20	Cheatgrass (annual)
<i>Juniperus osteosperma</i>	10	Utah Juniper
RM-5 <i>Ranunculus testiculatus</i>	60	Buttercup, testiculate
<i>Bromus tectorum</i>	20	Cheatgrass
<i>Sarcobatus vermiculatus</i>	10	Greasewood
RM-6 <i>Artemisia filifolia</i>	30	Sand sagebrush
<i>Gutierrezia sp.</i>	20	Snakeweed
<i>Bromis tectorum</i>	20	Cheatgrass
<i>Aristida sp.</i>	20	Three-Awns
CV-7 <i>Stipa comata</i>	40	Needle-and-thread
<i>Bouteloua gracilis</i>	10	Blue grama
<i>Poa secunda</i>	10	Sandberg bluegrass
<i>Agropyron smithii</i>	10	Western wheatgrass
CV-8 <i>Poa pratensis</i>	40	Kentucky bluegrass
<i>Cirsium arvense</i>	30	Canada thistle
<i>Agropyron smithii</i>	20	Western wheatgrass
CV-9 <i>Festuca idahoensis</i>	70	Idaho fescue
<i>Phleum pratense</i>	10	Timothy
<i>Bromus inermis</i>	10	Smooth brome
CV-10 <i>Poa secunda</i>	30	Sandberg bluegrass
<i>Agropyron spicatum</i>	20	Bluebush wheatgrass
<i>Chrysothamnus nauseosus</i>	10	Rubber rabbitbrush
<i>Sitanion hystrix</i>	10	Bottlebrush squirreltail

Appendix 5

Percent Green Versus Plant Height

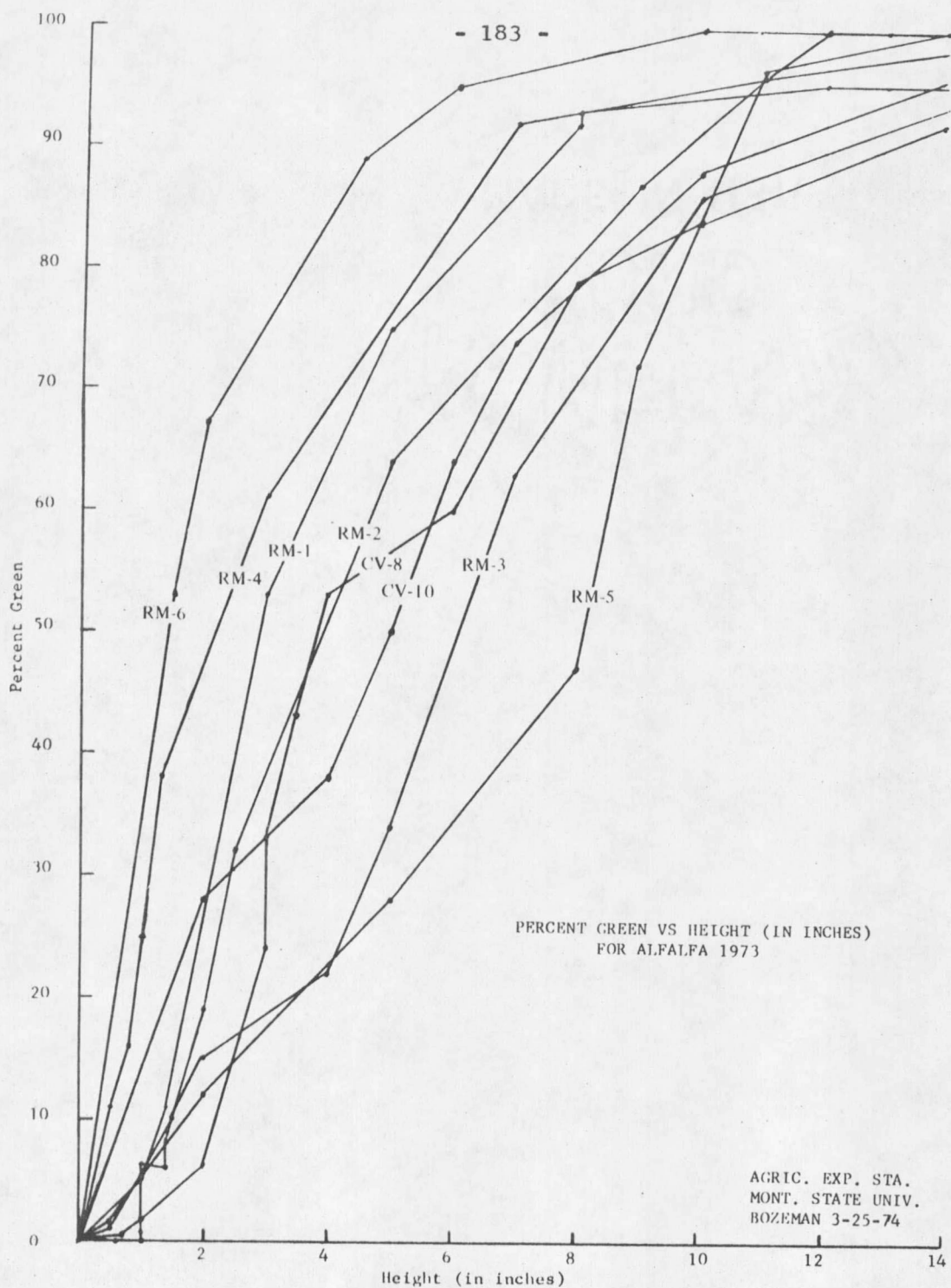


Fig. 34 Percent Green vs Plant Height of Irrigated Alfalfa-1973

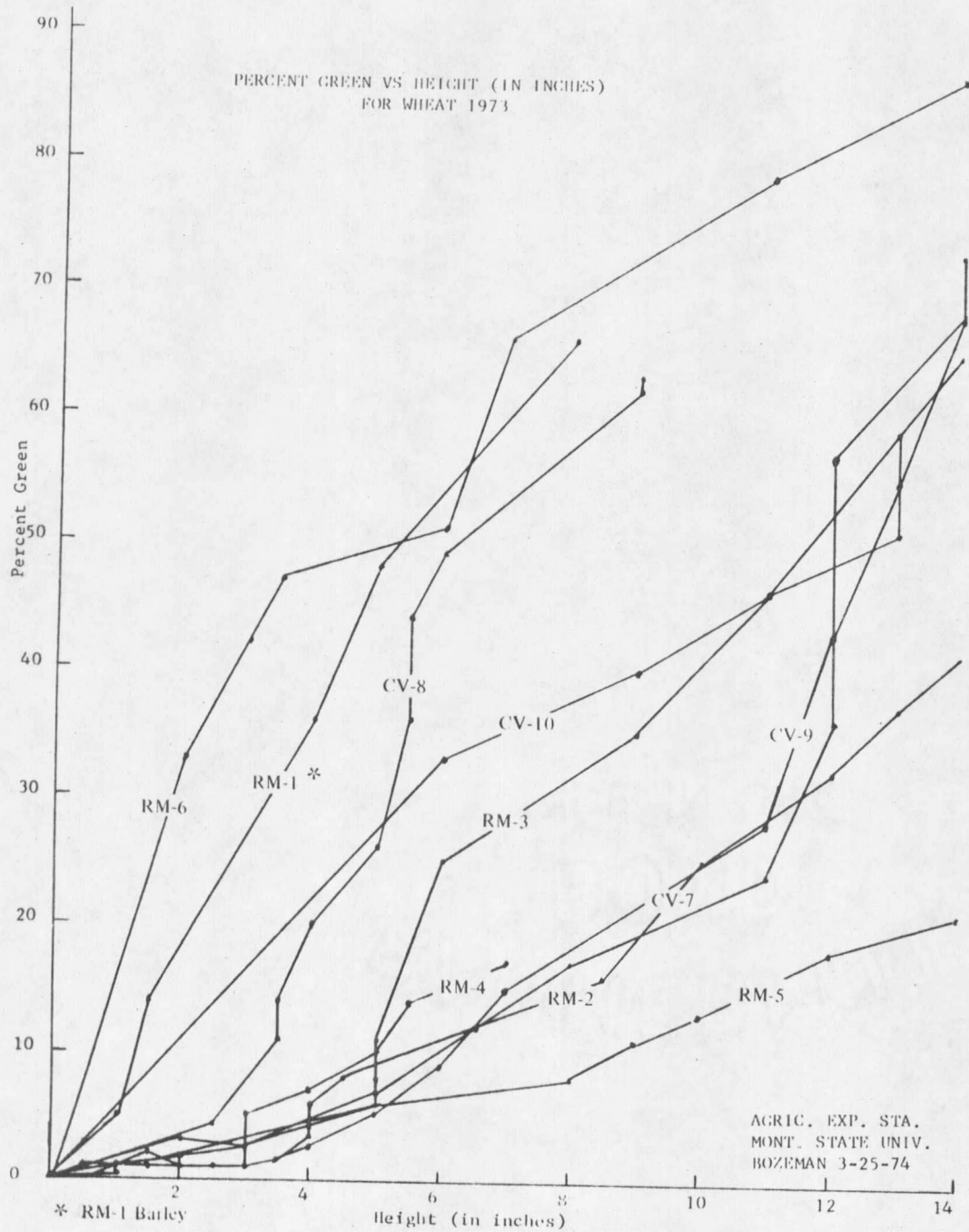


Fig. 35 Percent Green vs Plant Height of Dryland Winter Wheat-1973

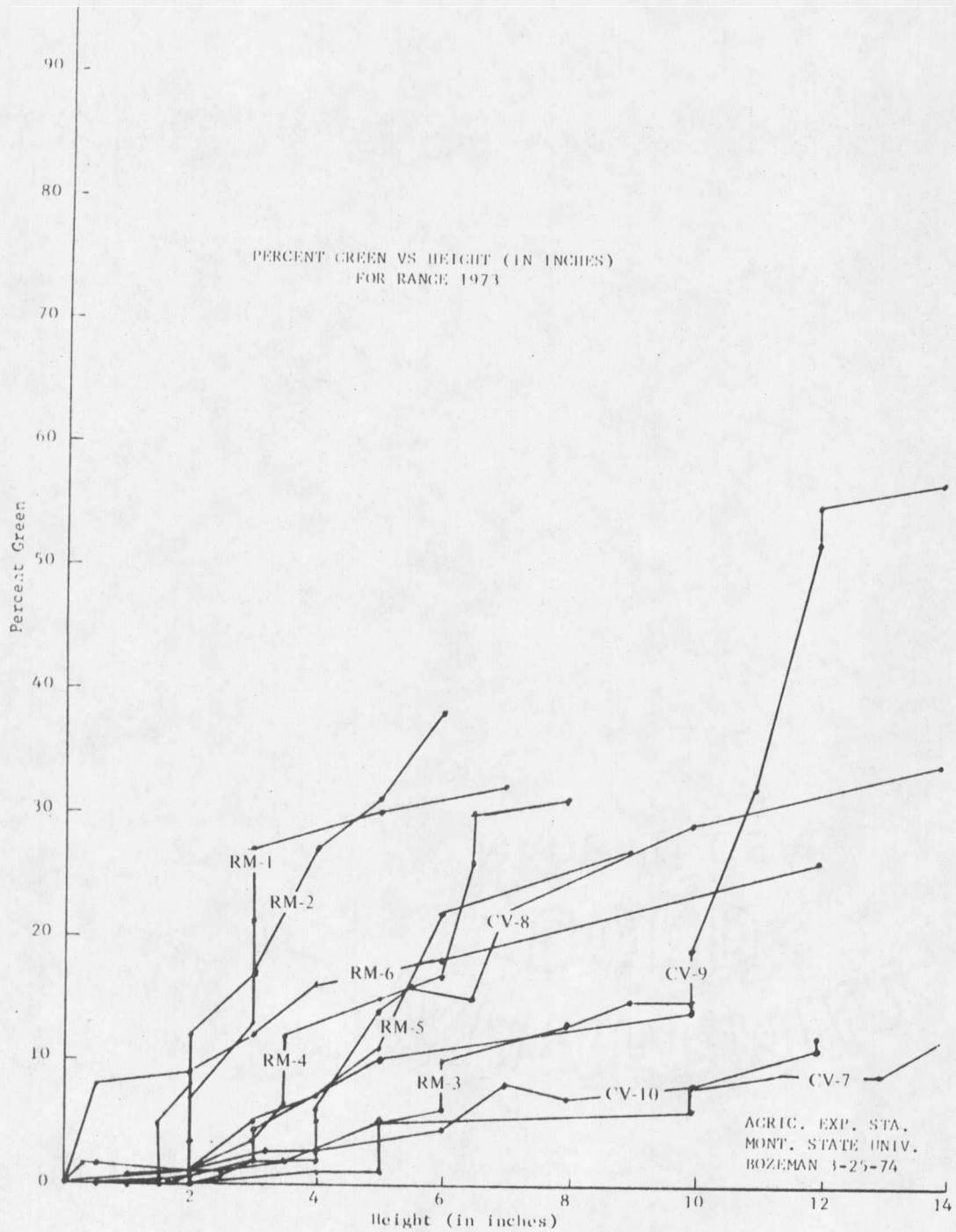


Fig. 36 Percent Green vs Plant Height of Nonirrigated Rangeland-1973

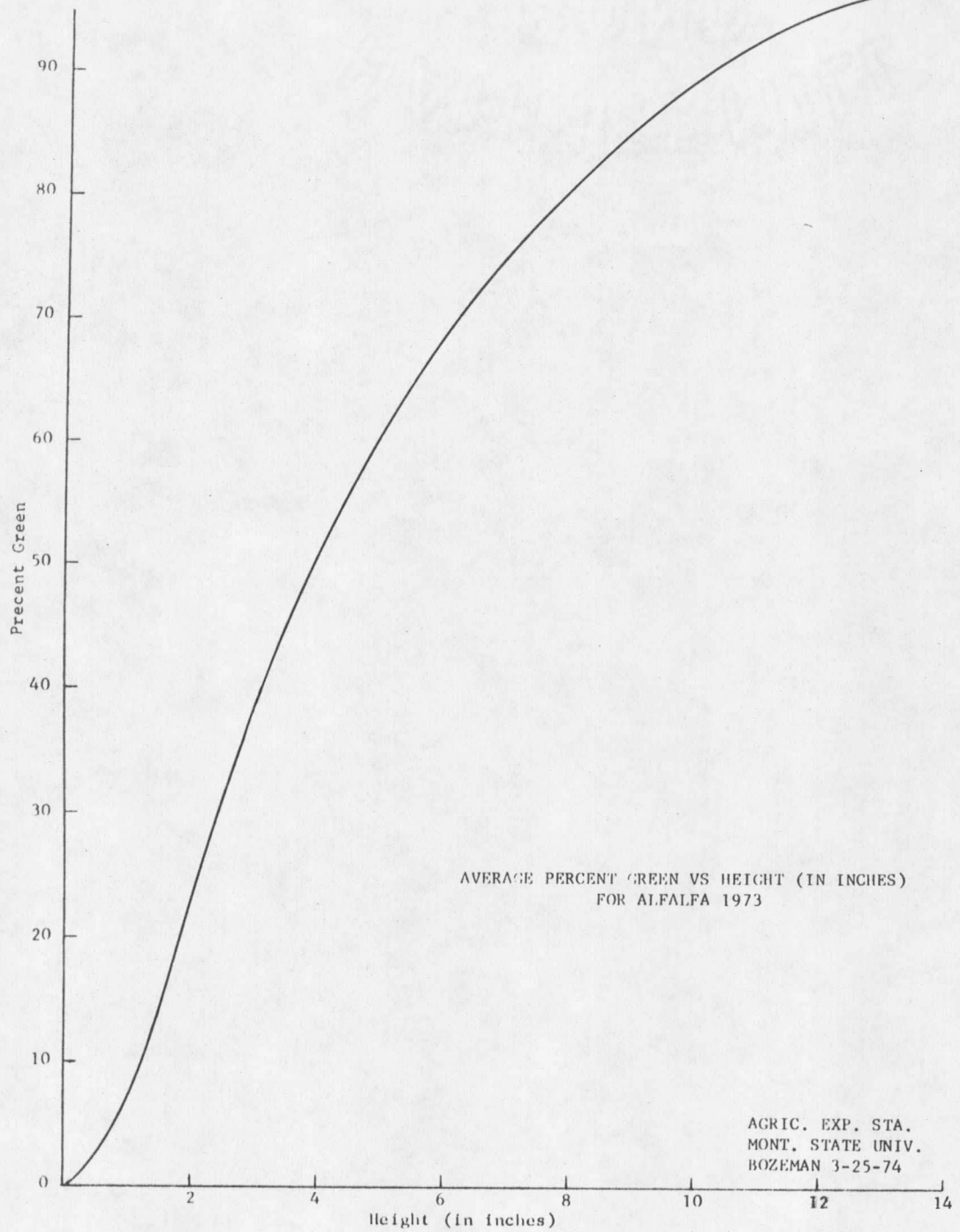


Fig. 37 Average Percent Green vs Height of Irrigated Alfalfa-1973

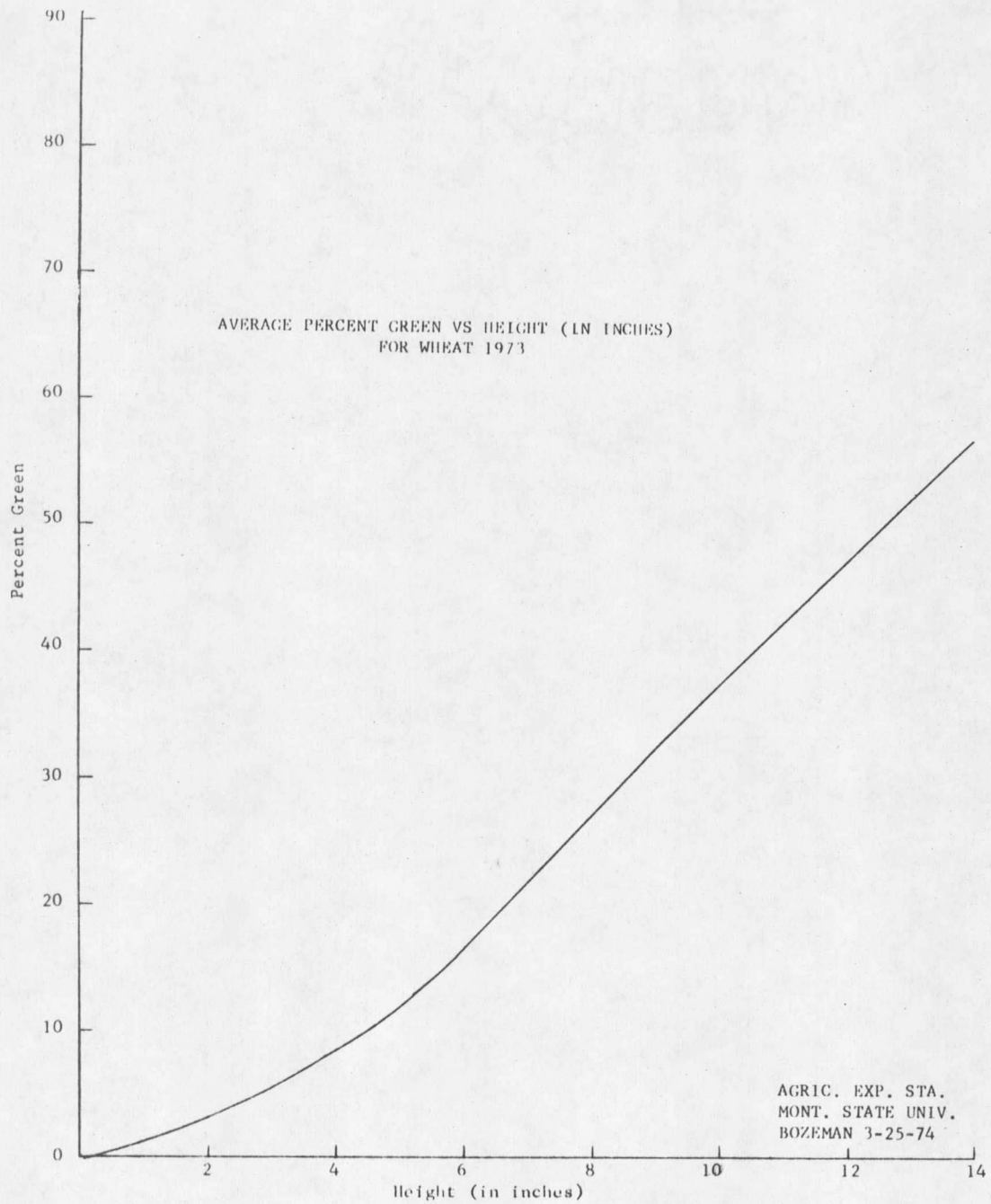


Fig. 38 Average Percent Green vs Height of Dryland Winter Wheat-1973

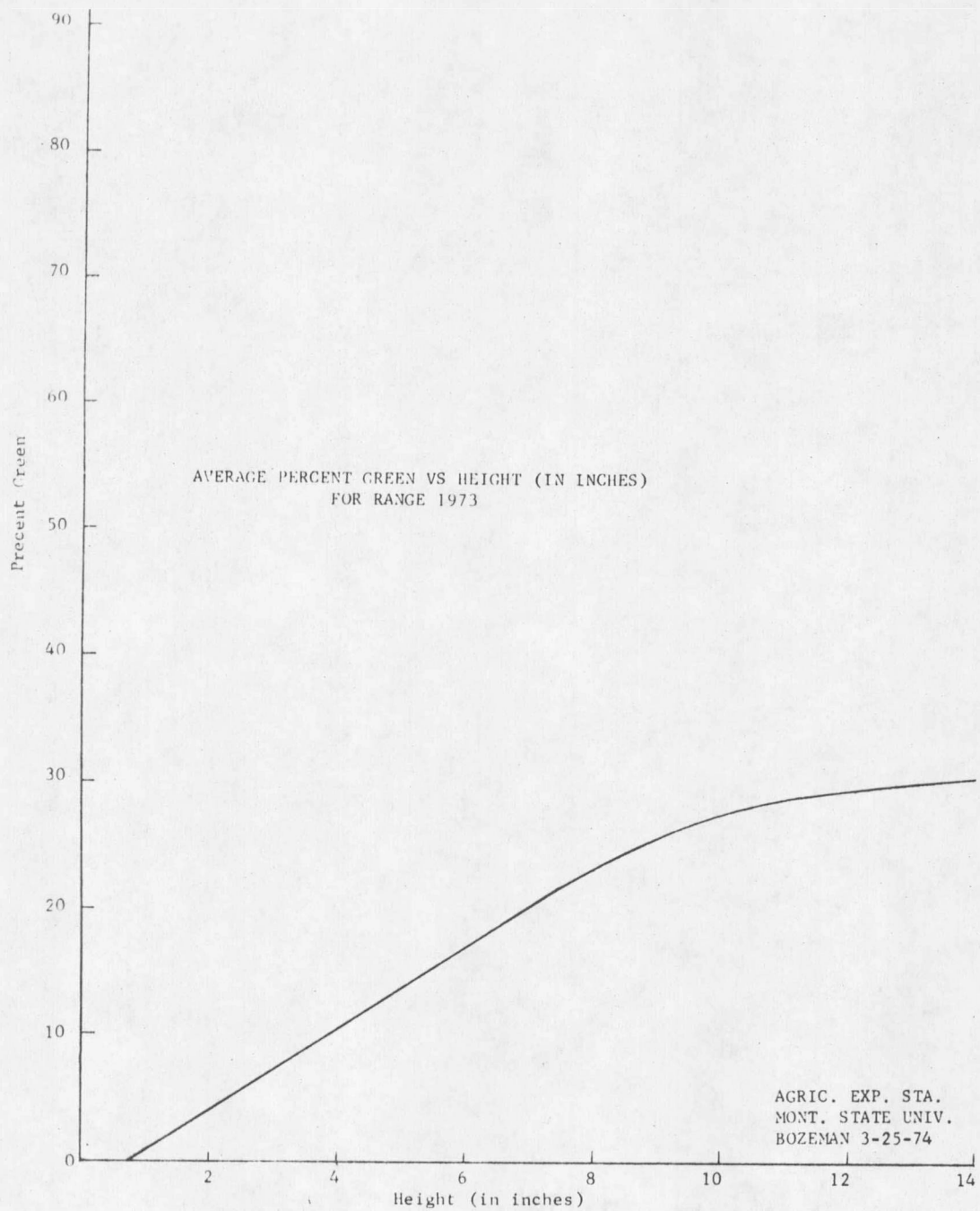


Fig. 39 Average Percent Green vs Height of Nonirrigated Range-1973



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D378 Jones, Charles M
J712 Plant phenology in the
cop.2 western United States
using the ERTS-1
satellite

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