Final Report RSC-4496-132

E83-10113

NASA-CR-167634

RANGELAND BIOMASS ESTIMATION DEMONSTRATION

by

W. E. Boyd
R. W. Newton
B. V. Clark

February 1982

(E83-10113) RANGELAND BIOMASS ESTIMATION DEMONSTRATION Final Report (Texas A&M Univ.) 58 p HC A04/MF A01 CSCL 02C
N83-15756
Unclas
G3/43 00113

Supported by
National Aeronautics and Space Administration
Johnson Space Center
Houston, Texas
Contract NAS 9-16369

TEXAS A&M UNIVERSITY
REMOTE SENSING CENTER
COLLEGE STATION, TEXAS

Final Report RSC-4496-132

RANGELAND BIOMASS ESTIMATION DEMONSTRATION

by

W. E. Boyd
R. W. Newton
B. V. Clark

Principal Investigator:

R. W. Newton

February 1982

Supported by:

National Aeronautics and Space Administration
Johnson Space Center
Houston, Texas
Contract NAS 9-16369

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

LIST OF TABLES

INTRODUCTION

Experiments have been conducted in the past demonstrating the capability to determine green biomass using Landsat spectral data. Rouse et al. (1974) utilized Landsat 1 to develop techniques for the quantitative estimation of green biomass over broad regions. A band ratio parameter (TVI-6) was shown to be highly correlated with green biomass and vegetation moisture content. Harlan et al. (1979) extended band ratioing techniques to semi-arid, low biomass sites. In an effort to identify procedures for reducing the ground truthing effort, Harlan et al. attempted a double sampling technique using field portable capacitance meters. This attempt at reducing the number of hand clipped field plots was unsuccessful.

Boyd et al. (1979), utilizing previously acquired data, generated several test products from Landsat images that provided spatial information on green biomass. These products were distributed to ranchers to determine their usefulness in ranch management situations. After evaluation, the ranchers comments were quite positive indicating that Landsat could be used to obtain vegetation information that could potentially improve the management efficiency of the cattle industry.

This project was designed to further develop and refine techniques and procedures formulated at Texas A&M University (TAMU) for generating rangeland green biomass estimates and organizing them into product formats that could be easily distributed to and utilized by the ranching community.

OBJECTIVES

The overall objectives of this effort were to further develop and test rangeland vegetation biomass information acquisition and presentation techniques based upon Landsat spectral measurement calibrated with ground data. More specifically, the goals were to:

1. Develop and demonstrate techniques of using hand-held radiometers to calibrate green biomass to Landsat spectral ratios as a step toward using hand-held radiometers to speed up ground data acquisition.
2. Utilize Landsat to estimate rangeland biomass over selected test areas containing cooperating ranches.
3. Develop and demonstrate techniques for the timely production of biomass and precipitation contour maps of use to ranch managers.

METHODS

In order that the above goals be achieved, a comprehensive data acquisition of simultaneous radiometer, vegetation clipping and Landsat imagery was necessary. Due to budgetary and time limitations, a single site was chosen. The site chosen for field data collection was the Texas Experimental Ranch (TEXR), Throckmorton County, Texas (Figure 1). The Experimental Ranch, located in the Rolling Plains Resource Area of North Texas, consists of approximately 7,200 acres of native range. Research at the ranch was initiated in 1958 following a cooperative agreement between the Swenson Land and Cattle Co., the Texas Agricultural Experiment Station, and a group of ranchers and businessmen comprising the Texas Experimental Ranch Committee. The ranch, staffed by Texas Agricultural Experiment Station employees, serves as a test bed for new and innovative ranching practices and as a field laboratory for basic research. It has been used previously for remote sensing research by Deering and Haas, 1973-77 (Rouse *et al*., 197-).

The key to Landsat/ground data calibration is to have a range of biomass values including both maximum and minimum values for an area, in the sample set. Maximum biomass production in the chosen test area occurs during May to June. By sampling during this period it was felt that the widest range of biomass conditions could be found within the test area. Based upon this known growth period, sampling was scheduled for either May 30 to June 2, 1981 or June 16 to 20, 1981, contingent upon weather forecasts, to coincide with a Landsat overflight. Unfortunately, only one Landsat acquisition and corresponding ground truth effort could be scheduled due to bu get limitations.

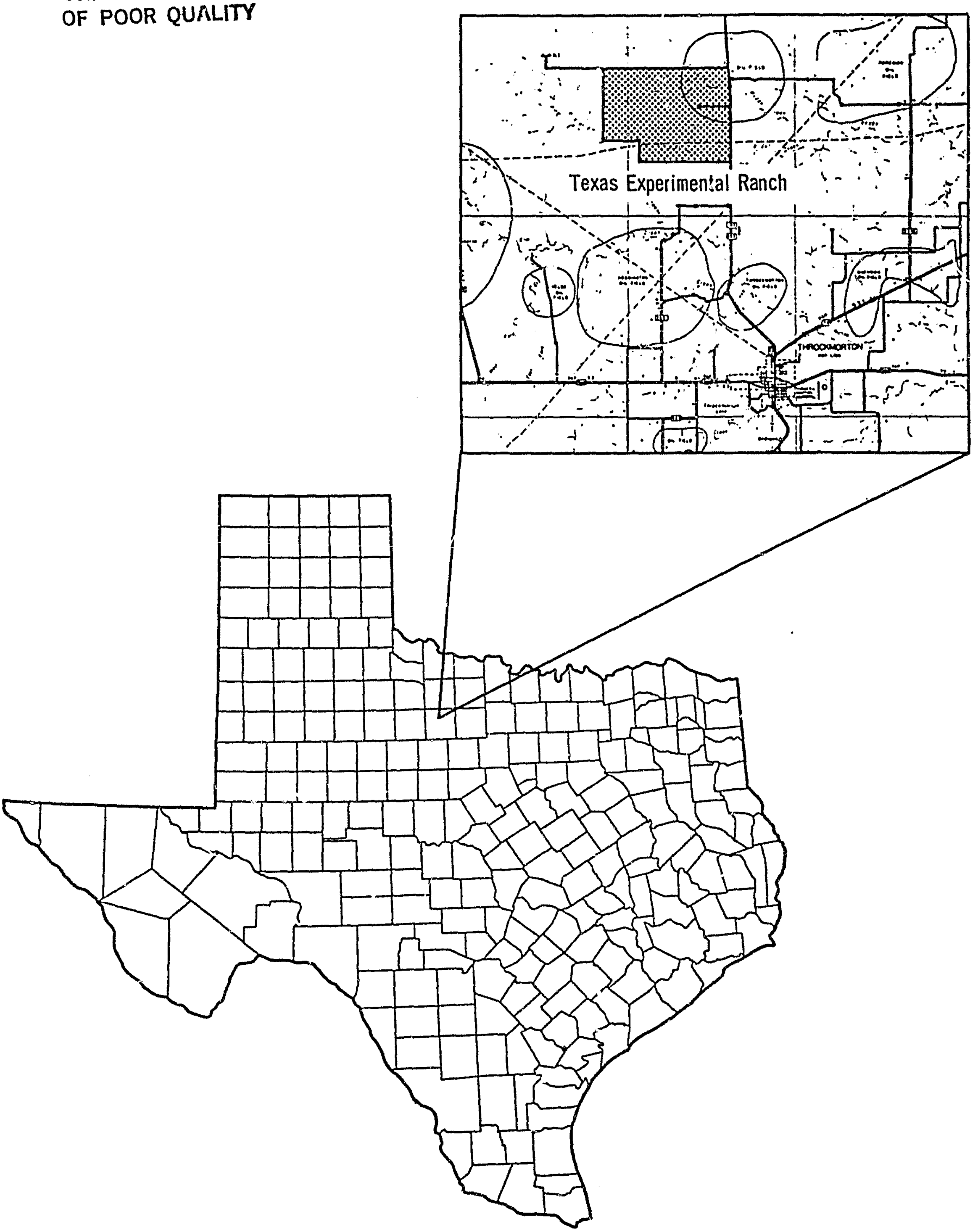

FIGURE 1. Location of the Texas Experimental Ranch (TEXR .

Dr. Rod Heitschmidt, Director of the Experimental Ranch, was consulted as to pasture biomass production. His estimates were confirmed by on-site evaluation the day prior to sampling initiation. A map of the ranch and the sampling locations appears as Figure 2.

Pasture 16 (P16) is one of four which are used in a long term test of the Merrill four pasture rotation grazing system. At the time of sampling for this experiment, the pasture had not been grazed for approximately eight months. Because of this "rest" period, P16 contained a lush vegetation with many flowers and matured cool season annuals present in addition to the more prevalent, although shorter, range grasses. Brush canopy in this pasture was minimal.

Pasture 17 (P17) is another pasture used in the Merrill rotation grazing test. At the time of sampling, this pasture was being grazed by cattle. The vegetation was not as tall and rank as that in P16.

Mesa is part of a yearlong continuous grazing pasture. This site is a mesa which is approximately 100 feet above general ground elevation. The vegetation on this site is quite short and produces less than most others on the ranch due to the shallow and droughty soils which have developed over a limestone substrate. Brush canopy on this site is minimal.

Burn is a site which is (was) part of a reserve pasture used as emergency forage for an eight pasture high intensity-low frequency grazing trail. During both the fall and spring prior to this sampling effort the area had burned accidentally. As a consequence, the vegetation was very tall and consisted primarily of ragweed and wild sunflowers. The soil surface beneath these tall weeds was blackened and very few plants of short stature were evident.

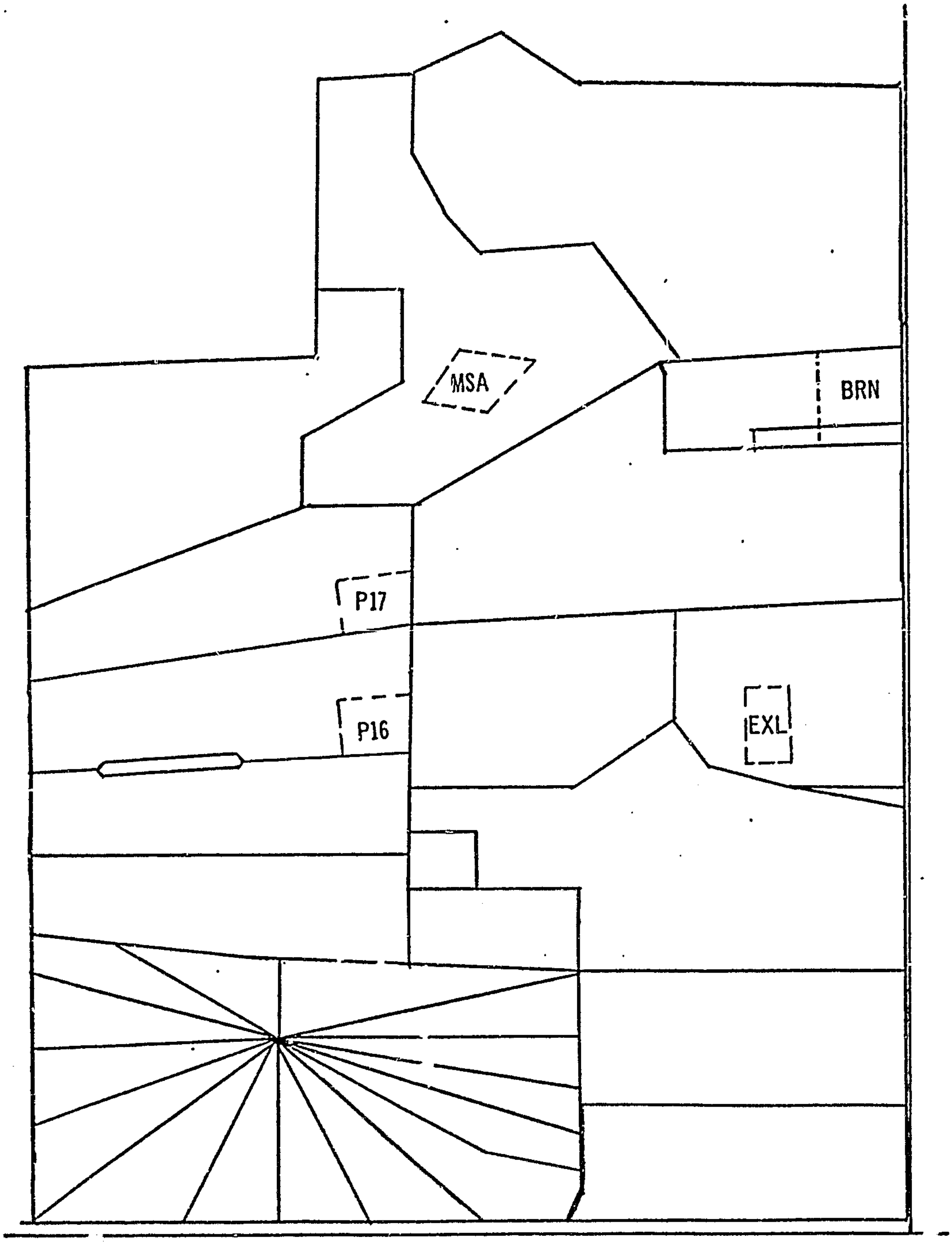

FIGURE 2. Identification of pasture boundaries within the Texas Experimental Ranch.

Exclosure is part of the reserve forage for a yearlong continuous grazing trial. Vegetation on this site was of medium height and consisted primarily of grasses. The effects of occasional grazing were present. Brush canopy was minimal.

Broomweed, an annual which periodically reaches epidemic proportions, was present in all pastures to some degree It was most prevalent on sites Burn and Exclosure. On most sites broomweed had grown to approximately one foot in height. Later in the growing season the canopy area of broomweed would greatly expand and would cause a shading of the grass and a subsequent reduction in grass biomass production.

Sampling for herbaceous vegetation production in each pasture was accomplished by standard clipping procedures. A minimum of thirty-nine semi-randomly distributed circular frames of .63 ft^2 (10.75 inch diameter circle) were clipped in each pasture. At the time of clipping, the vegetation was separated and bagged by type: green, dead and broomweed. All bags were weighed in the field for wet weight. Dry weights were determined after 48 hours of forced air drying at 50° C. Production values by pasture appear in Table 1.

Two hand-held radiometers (Tucker, 1980) were utilized to acquire vegetation reflectance measurements. The instruments are field portable units which have three sensor bands: Band 1 (0.63-0.69 μm), Band 2 (0.76-0.90 μm) and Band 3 (1.55-1.75 μm). These bands coincide with thematic mapper bands TM3, TM4 and TM5. The three bands were chosen for their sensitivities to chlorophyll density, green leaf density, and leaf water density.

TABLE 1. Pasture clipping values.

Pasture	N	Green*	Broomweed*	Green + Broomweed*	Dead*	Total*
Burn	40					
$\overline{X}$ (mean)		1450.7	654.9	2105.5	76.2	2181.7
C.V. (Coefficient of Variation)		68.0	112.6	62.7	263.1	61.3
St.D. (Standard Deviation)		986.9	737.2	1320.6	200.4	1337.7
Pasture 17	58					
$\overline{X}$		603.9	72.2	676.2	1013.6	1689.7
C.V.		94.6	291.9	85.1	75.9	46.8
St.D.		571.3	210.8	575.2	769.8	790.9
Exclosure	75					
$\overline{X}$		693.5	201.0	894.5	994.0	1888.5
C.V.		78.7	252.5	79.7	85.4	53.6
St.D.		546.1	507.7	712.8	848.7	1011.2
Mesa	39		X		376.8	
113.2 490.1	287.0	777.1				
C.V.		73.7	192.6	70.3	81.5	51.3
St.D.		277.8	218.1	344.5	234.0	398.4
Pasture 16	41					
$\overline{X}$		[illegible]58.4	11.1	969.5	2267.7	3237.3
C.V.		77.7	326.3	77.7	61.4	48.6
St.D.		744.7	36.4	753.1	1392.0	1572.3

*All values are oven dry weight in lbs/ac.

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

Additionally, two field reflectance panels were manufactured so that incoming radiation might be monitored concurrently with sampling. After field sampling, the field panels were compared to $BaSo_4$ standard reflectance panels and calibration coefficients for the field panel determined.

Pasture 16 (high biomass) and Mesa (low biomass) were chosen for radiometer/biomass sampling. These pastures were marked off in a rough grid with sample points being chosen at random from a grid intersection point. At each sample location, the following data were recorded: time of day, cloud cover, calibration panel reflectance readings, and vegetation reflectance readings. All radiometer readings were replicated three times and were taken one meter above the surface in question. After measurement acquisition was completed, the footprint area was marked and a frame placed on the surface to define the area for herbaceous biomass clipping.

Weather data for the four Landsat scene areas under investigation were transcribed from NOAA state weather summaries (Mitchel, 1981). A listing of weather stations follows as Appendix A.

Landsat MSS tapes for the sampling location and the large area test products were acquired via the Domsat link by NASA Johnson Space Center (JSC) personnel and were transported to TAMU for processing.

Uncorrected data tapes in NASA Landsat Universal format were provided in four two-volume sets. Software routines were prepared which extracted header information from the tapes. Using the center coordinates in latitude and longitude provided in the headers, the centers of each of the approximately 100 n. mi. by 100 n. mi. uncorrected scenes were plotted on a 1:1,000,000 scale map. Subscene areas of interest were identified on the map and the approximate line and pixel boundaries were extracted (Figure 3). A second software routine was prepared which extracted the selected subscene data from the larger scene. The subscenes extracted were always approximately 300 by 300 pixels in size, enough to contain the equivalent of a USGS 1:24,000 scale quadrangle sheet. These extractions produced a subscene tape file containing four bands in band-interleaved (BIL) format (Figure 4). Next, the existing greymapping software was used to produce a greymap of Band-4 from the subscene files. Each of these greymapped subscenes was then used to verify that the quad-sheet subscene of interest was contained within the subscene data set.

The third and fourth software routines used were the ND6 and TVI-6 biomass algorithms. These algorithms produced a single band output data set, Figure 5. Next, the biomass data was de-skewed (using another local utility routine) to account for earth rotation. Before preparing a greymap to overlay the quad-sheet of interest, the data were rectified (oriented to North-South) using a resampling technique available in the LMS software, Figure 6. Since LMS uses a unique format, the data were reformatted on both input and output.

After the quad-size greymap was produced, it was overlayed on the appropriate quad-sheet and the particular field of interest was outlined. Pixel and line number coordinates defining the field were noted and used in the fifth utility, routine to calculate the average radiance values for the field, Figure 7.

ORIGINAL PAGE IS
OF POOR QUALITY

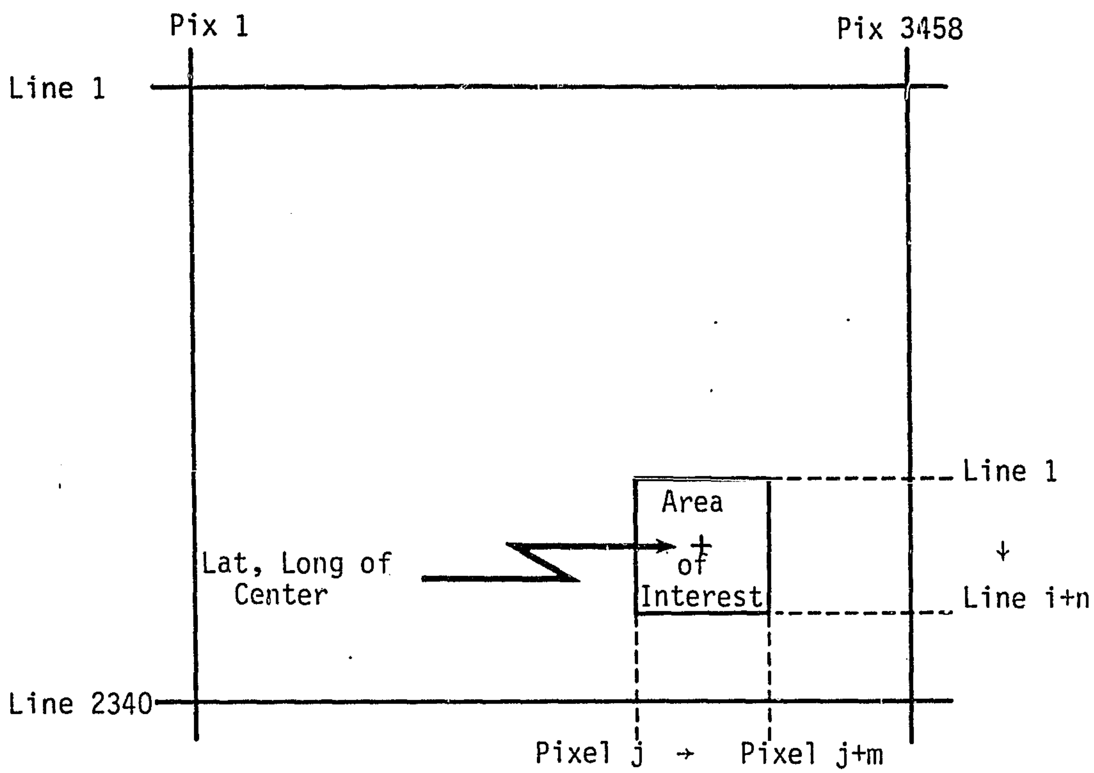

FIGURE 3. Locating areas of interest within the Landsat image.

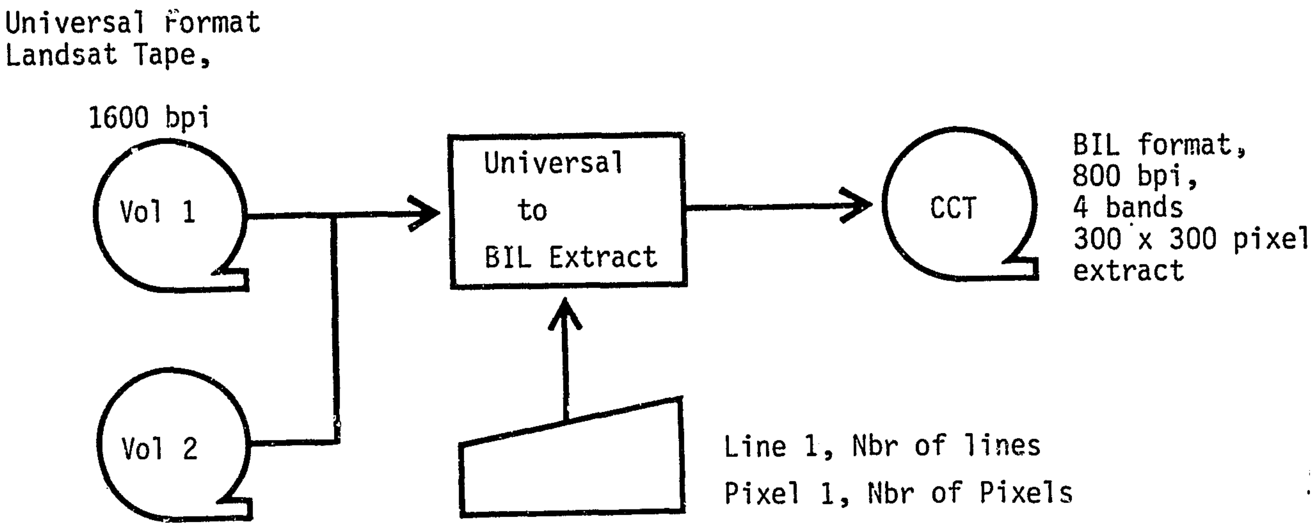

FIGURE 4. Procedure for creating a 300 x 300 pixel sub-scene tape.

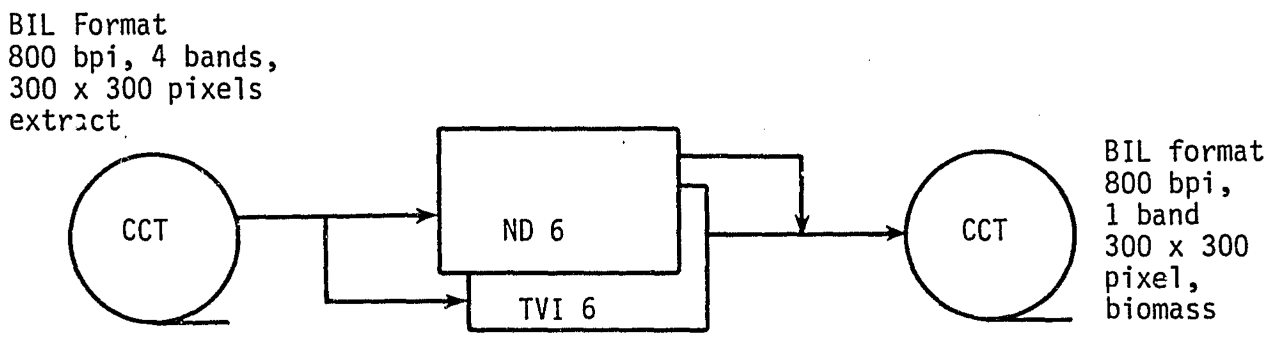

FIGURE.5. Conversion of the 300 x 300 pixel sub-scene to band ratios related to green biomass.

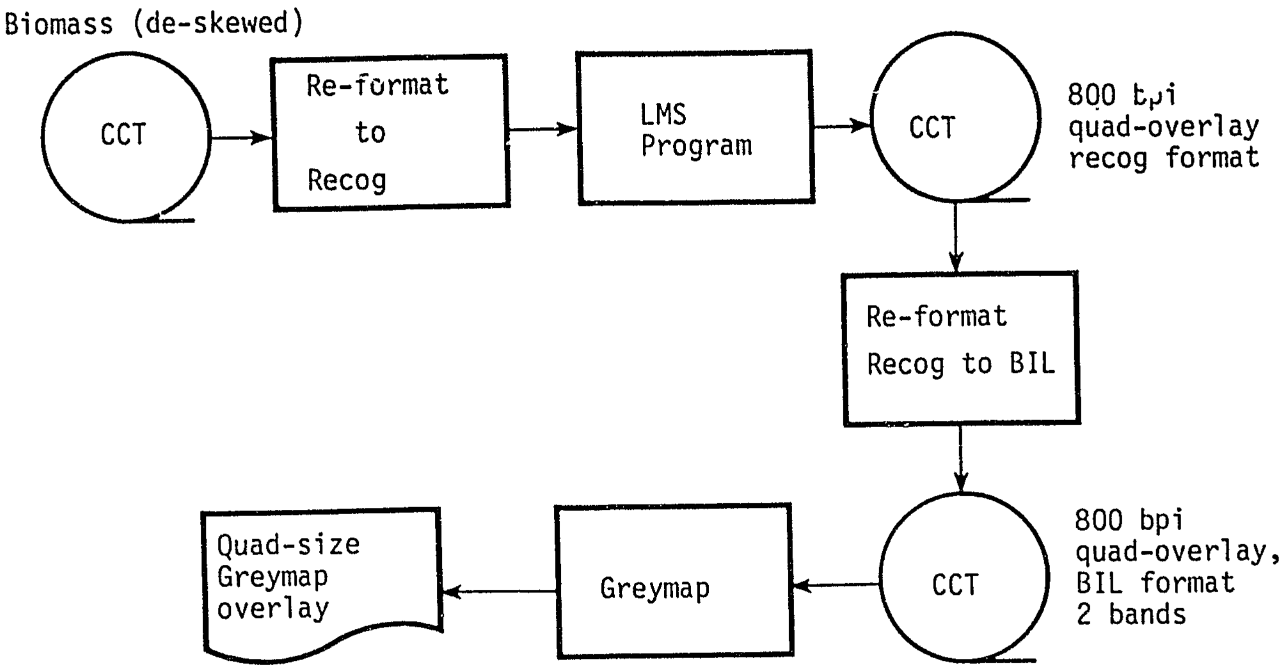

FIGURE 6. Orienting the data to fit a quad sheet.

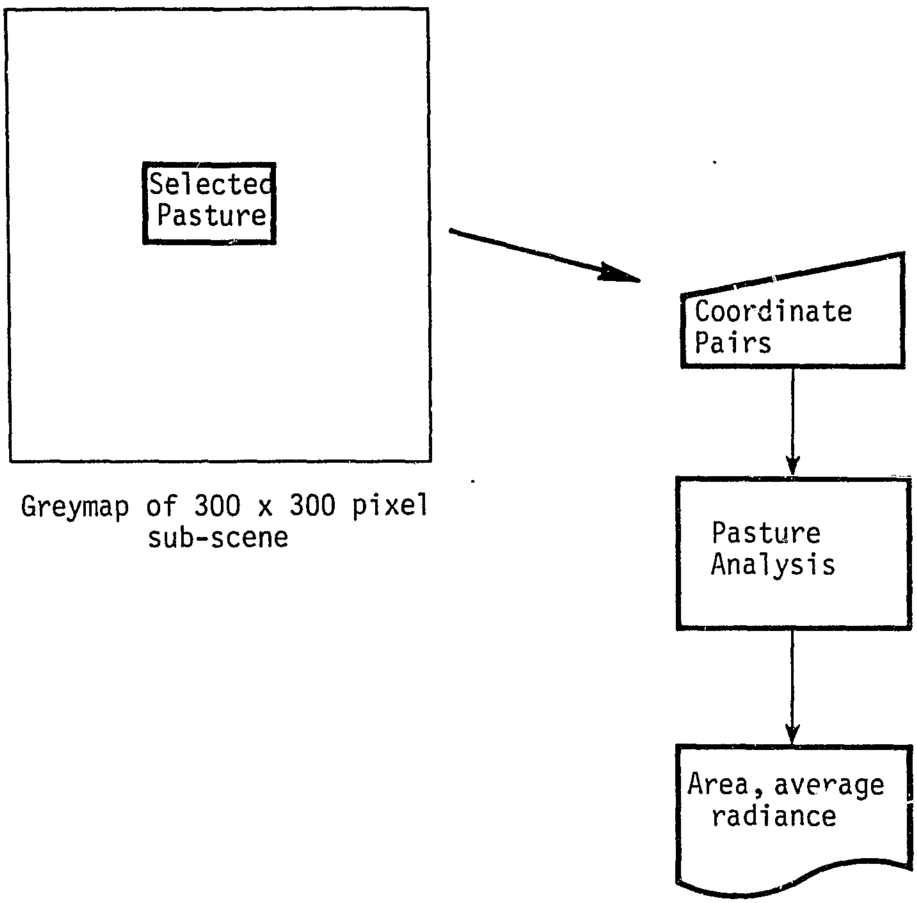

FIGURE 7. Procedure for computing the average radiance values over selected test pastures.

BIOMASS CORRELATION RESULTS

Landsat Correlation to Clipping Data

Before biomass production estimates can be made from the average Landsat band ratios, the relationship between actual ground biomass and Landsat measurements must be known. A calibration curve for the Texas Experimental Ranch was developed by relating ground biomass to ratioed Landsat pixel data. This was accomplished by extracting pixel values in bands 5 and 6 for each test field for which biomass clippings were made using the methods and procedures previously outlined. After extraction, the parameter ND6, ND6 = (Band6-5)/(Band 6+5), was calculated for each pixel. The individual pixel values generated in this manner were averaged over the entire test field. The average values were then compared to the green and broomweed (GBW) dry weight mean values for the sample locations. A linear regressions analysis of GBW on ND6 (Figure 8) results in the regression equation:

$$ND6 = 41.6190 + .0102\ (GBW)$$

with

$$r^2 = 0.867$$

This "calibration" curve compares favorably with the results of other researchers (Rouse et al. 1974, Harlan et al. 1979). This is discussed in more detail later.

Using the developed calibration curve, an ND6 greymap of biomass was produced at a 1:24,000 scale for the TEXR and surrounding area (Figure 9). Biomass increments are 300 lbs/ac.

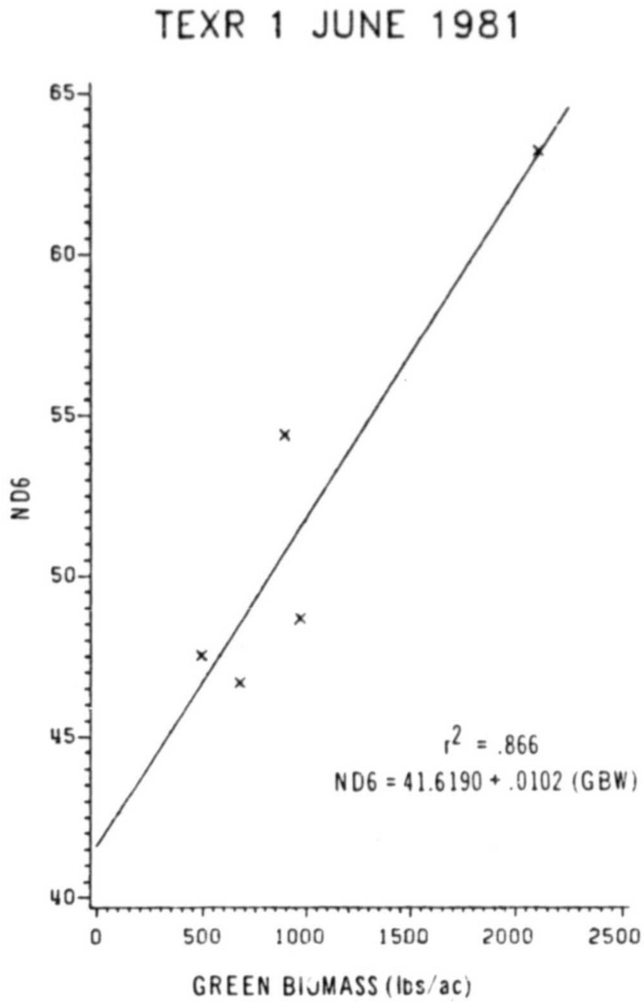

FIGURE 8. Comparison of green biomass to Landsat derived ND6 indices.

ORIGINAL PAGE IS
OF POOR QUALITY

FIGURE 9. Individual ranch product example.

Hand-Held Radiometer/Ground Clipping Data

Hand-held radiometer measurements were acquired only for pasture P16 and Mesa. These areas were chosen since they seemed to represent high and low biomass conditions. Linear regression analysis was performed between all of the clipped biomass measurements and all bands of the radiometers. The results are presented in Table 2.

In general the data show little correlation between radiometer values and green biomass. Correction factors were applied to raw radiometer data to account for time of day, sun angle differences (C meter) and to take reflectance panel readings (incoming radiation, bidirectional reflectance) into account. Bidirectional reflectance correction for incoming radiation was accomplished by dividing the calibration panel reflectance measurements into the radiometer measurements for each channel and multiplying it by the coefficient that references the field panels to the standard $BaSO_4$ panel. This correction (BRFP, Table 2) was applied to all individual channel data. In addition, each set of data (raw and corrected) was normalized (ND) by subtracting one channel from another.

The overwhelming conclusion, upon first glance, is that the radiometer data do not relate well to the clipped biomass data. This seems especially true of the red (.63-.69 μm) to near IR (.76-.90 μm) band comparisons (max r^2 = 0.19). It appears to be true regardless of the correction algorithm that was applied. Instrument failure was considered as a cause of error and rejected. The instrument was in proper working order before and after the sampling trip.

TABLE 2. Radiometer value versus clipped green biomass

Data Type	Channel	1(.63-.69 μm) r^2	2(.76-.90 μm) r^2	3(1.55-1.75 μm) r^2
Raw data	*n=80	.000334	.01573	.08618
C meter[1]	80	.010031	.190045	.039369
BrFP[2]	80	.006455	.190976	.113559

Ratioed band data vs. Green Biomass

ND 1/2[3]	.02724	CND 1/2[4]	.19355	BRND 1/2[5]	.142471
1/3	.099258	1/3	.063166	1/3	.153467
2/3	.048912	2/3	.263090	2/3	.351582

ORIGINAL PAGE IS OF POOR QUALITY

[1]Cmeter (sun angle correction): $\frac{\text{radiometer readings for a channel}}{\text{sun angle correction}}$

[2]Bidirectional reflectance: (BRFP) $\frac{\text{radiometer reading for a channel}}{\text{radiometer reading for the calib. panel}}$ X panel calibration coefficient

[3]ND: radiometer reading for a channel - radiometer reading for a channel

[4]CND: sun angle corrected radiometer reading for a channel - sun angle corrected radiometer reading for a channel

[5]BRND: Bidirectional reflectance for a channel - Bidirectional reflectance for a channel

*There were 39 samples clipped and metered from Mesa and 41 from Pasture 16.

In order to investigate the causes of this generally poor performance, a plot of panel readings vs. time was done (Figure 10) to see if clouds, which were prevalent in the area, were affecting the amount of incoming radiation on the calibration panel. A review of Figure 10 shows that the plot generally follows the arc of the available radiation expected from the sun's travel across the sky. Because of some variability associated with afternoon calibration panel readings, a new set of correlations was run which deleted all readings taken after 12:30 p.m. A summary appears as Table 3. This second set of correlations gave no significant improvement over those derived from the entire data set.

A further explanation for the poor correlation was sought. When the Landsat ND6 radiance values for pastures P16 and Mesa were reviewed (Figure 11), there appeared to be only a very small increase in radiance for a large increase in the amount of biomass. Mesa had a radiance of 47.51 and a clipped biomass of 490.08 lbs/ac, while P16 had a radiance of 48.67 and a clipped biomass of 969.5 lbs/ac. Another pasture which produced somewhat less biomass (XCL - 894.49 lbs/ac GBW) produced much higher ND6 Landsat values (54.40). It has generally been shown that the higher the amount of green biomass the higher the red near IR ratio value should be. A cause for the P16 divergence from this accepted understanding was sought.

Pictures taken during field sampling were reviewed for clues about each pasture. It was discovered that even though P16 had the higher biomass, it also contained much standing dead grass. A cool season annual grass (Little Barley, Hordeum vulgare) had matured and was overtopping much of the green material further down in the

ORIGINAL PAGE IS
OF POOR QUALITY

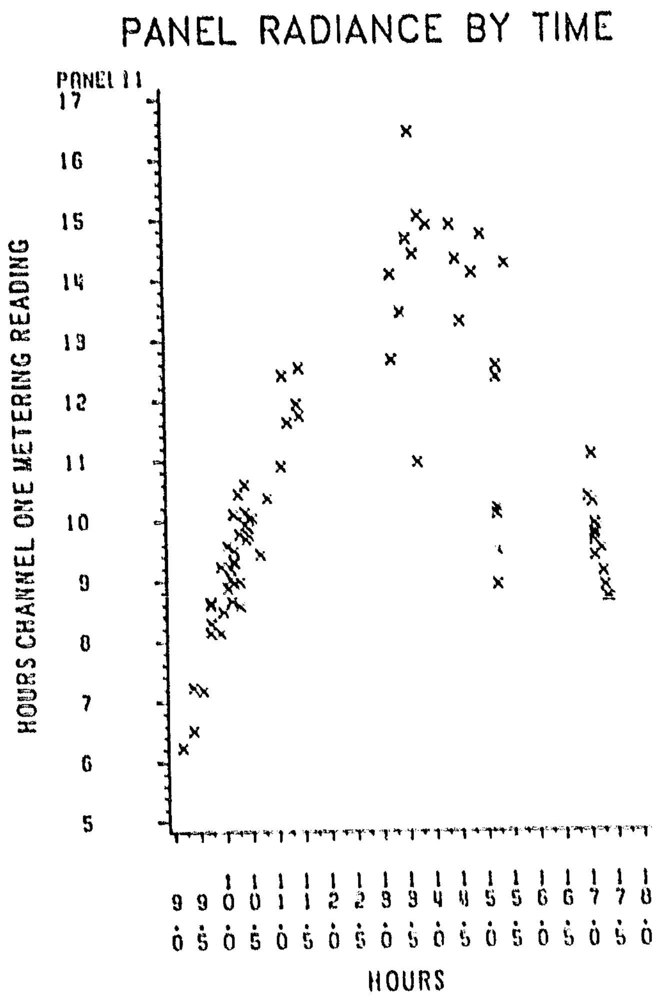

FIGURE 10. Channel 1 panel radiance by time of day.

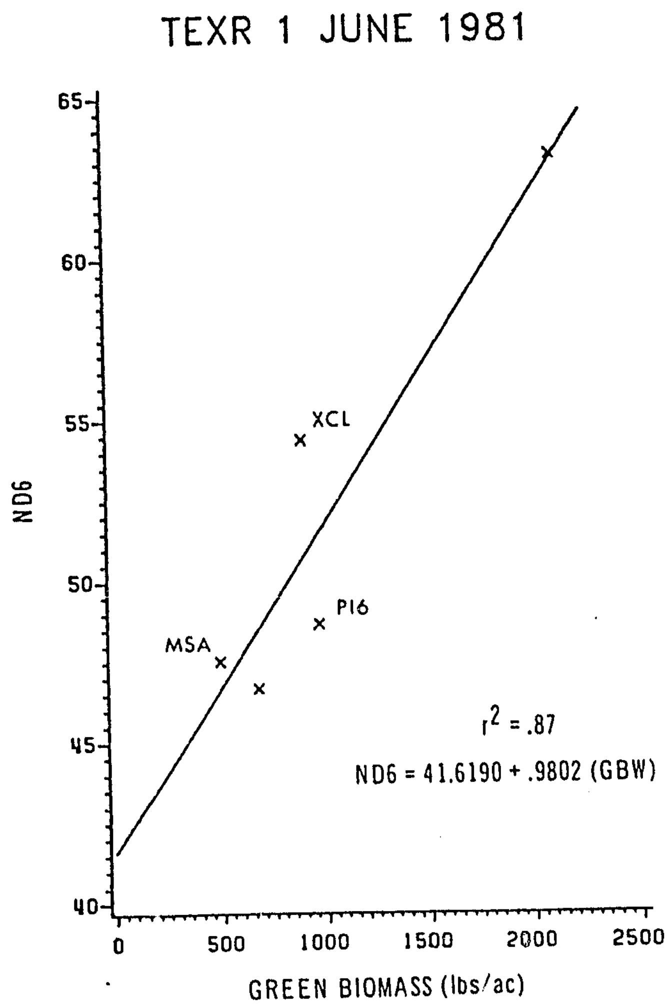

FIGURE 11. Comparison of green biomass to Landsat derived ND6 indices with pastures annotated.

TABLE 3. Radiometer value versus clipped green biomass (Morning Data)

Data Type	Channel	1(.63-.69 µm) r^2	2(.76-.90 µm) r^2	3(1.55-1.75 µm) r^2
Raw data	n=42	.0708	.293	.350
C meter[1]	42	.522	.207	.146
BrFP[2]	42	.006411	.457	.2080

Ratioed band data vs. Green Biomass

ND 1/2[3]	.157	CND 1/2[4]	.2078	BRND 1/2[5]	.008
1/3	.1423	1/3	.09210	1/3	.2890
2/3	.00087	2/3	.2643	2/3	.45828

[1]Cmeter (sun angle correction): $\frac{\text{radiometer readings for a channel}}{\text{sun angle correction}}$

[2]Bidirectional reflectance: (BRFP) $\frac{\text{radiometer reading for a channel}}{\text{radiometer reading for the calib. panel}}$ X panel calibration coefficient

[3]ND: radiometer reading for a channel - radiometer reading for a channel

[4]CND: sun angle corrected radiometer reading for a channel - sun angle corrected radiometer reading for a channel

[5]BRND: Bidirectional reflectance for a channel - Bidirectional reflectance for a channel

canopy. The effect was to shield the green biomass or reflect light off the dead material rather than the green. This shielding appears to account for the reduced reflectance readings both on the Landsat data and the radiometer. A plot of the ratioed reflectance corrected red/near IR radiometer readings (BRND 12) vs. biomass was produced (Figure 12). The plot approximates a horizontal line which results from very little relative reflectance change for the two communities even though the biomass range is large (0-2500 lbs/ac).

It appears that the radiometer was functioning properly and that the poor results stem more from a poor choice of experimental site than from the non-validity of radiometers as a sampling tool.

An additional sampling problem has been identified for this radiometer. This concerns the calibration panel. The panel as used was heavy, cumbersome and time consuming. It significantly slowed sample acquisition relative to clipping, and required a three man crew. Additionally, based upon the variability experienced in this ecosystem, approximately 275 radiometer samples would be needed in addition to 27 clipped/metered plots to adequately account for the variability of this community.

For radiometers to be time and cost effective, they must be self contained, hand-held and portable and include a built-in calibration technique that eliminates the need for external reflectance panel measurements.

Other scientists, using hand-held radiometers, have reported mixed results. Pearson _et al_. (1976) used a two band (.65-.7 μm, .775-.825 μm) radiometer to measure biomass on the Pawnee Grasslands

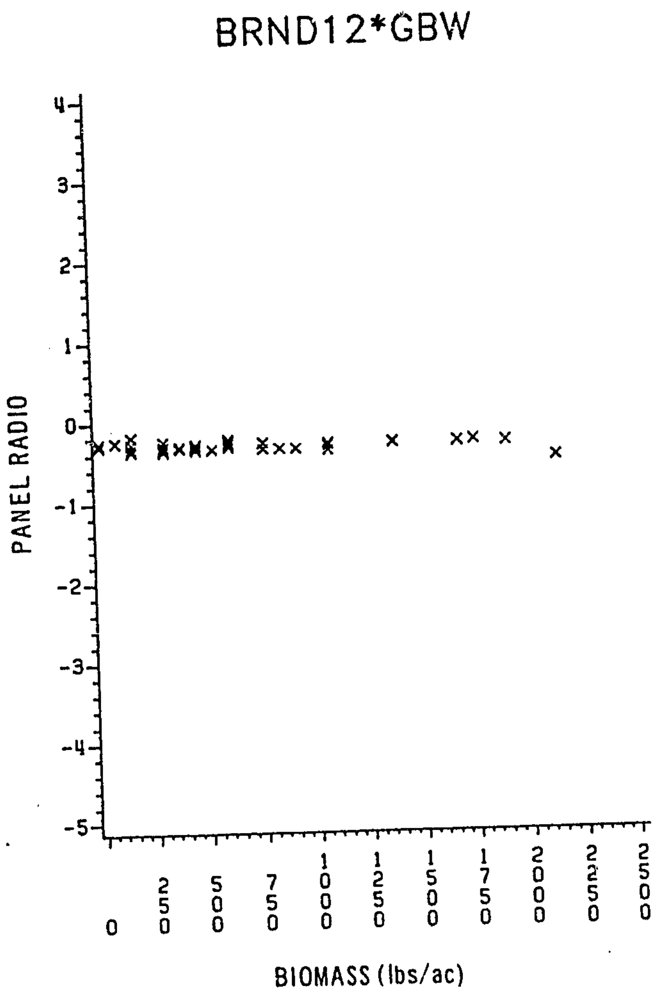

FIGURE 12. The bidirectional reflectance corrected difference between channels 1 and 2 compared to clipped green biomass dry weight.

in Colorado. Ratioed band data produced coefficients of determination (r^2) of 0.96 between radiometer readings and biomass. Tucker (1978) evaluated several spectral band ranges (.40-1.05 μm) using a mobile field spectrometer by comparing reflectance from blue grama grass to several plant parameters. Correlations were highest (r^2 approx. 0.87) for low variability scenes (June data). High variability scenes (September data) were not as strongly correlated (r^2 = 0.62 to 0.34). More recently, Waller et al. (1981) obtained mixed results from a portable radiometer measuring spectroreflectance readings compared to dry green biomass. Results ranged from poor (r^2 = 0.029) for only the ratio of bands versus biomass to very good (r^2 = 0.899) when values for calibration panel readings, sample variability and corrections for cloud cover were included in the regression equation. These investigations indicate that spectral reflectance values from hand-held instruments can be used to predict green biomass if the communities are fairly homogeneous.

Calibration Curve Comparison

The length of time a Landsat/biomass "calibration" curve remains valid for a region has never been documented. This experiment provided data which could be compared to previous work to address this issue. There are no experiments in the literature where data, both clipping and Landsat, for different years have been compared for the same ecosystem.

The clipping and Landsat pixel ratios for the Texas Experimental Ranch from this experiment were compared to those of Rouse et al. (1974) for the same area. None of Rouse's clipping sites were exactly resampled in 1981; however, at least two of the same general pastures were sampled. In general, grazing and management practices for the pastures sampled in 1981 were the same as in 1974.

In order to guarantee comparability of data between years, a standard radiance conversion was performed on the 1981 data. Rouse's original data (1972-74, Landsat 1) was in terms of TVI-6 ratioed radiance values. The general conversion used on the 1981 data (Landsat 2) is as follows:

$$R_i = \frac{BC_i(MAXC_i - MINC_i)}{127}$$

where R_i - radiance for band i

BC_i - count in band

$MAXC_i$ - maximum band sensor calibration

$MINC_i$ - minimum band sensor calibration

i - band subscript (band 4, 5 or 6)

The sensor band calibrations are from Landsat Newsletter #15.

The radiance values for bands 5 and 6 were then processed through a standard TVI-6 algorithm

$$\text{TVI-6} = \left(\sqrt{\frac{\text{Band 6-5}}{\text{Band 6+5}} + .05}\right)$$

A reproduction of Rouse's data appears as Figure 13. A plot of the 1981 data in TVI-6 format appears as Figure 14. A plot of both data sets together appears as Figure 15. A statistical comparison of both data sets using covariance analysis was performed. One result was that the y-intercepts of these lines were statistically different, which indicates that there is an offset between the two lines.

ORIGINAL PAGE IS
OF POOR QUALITY

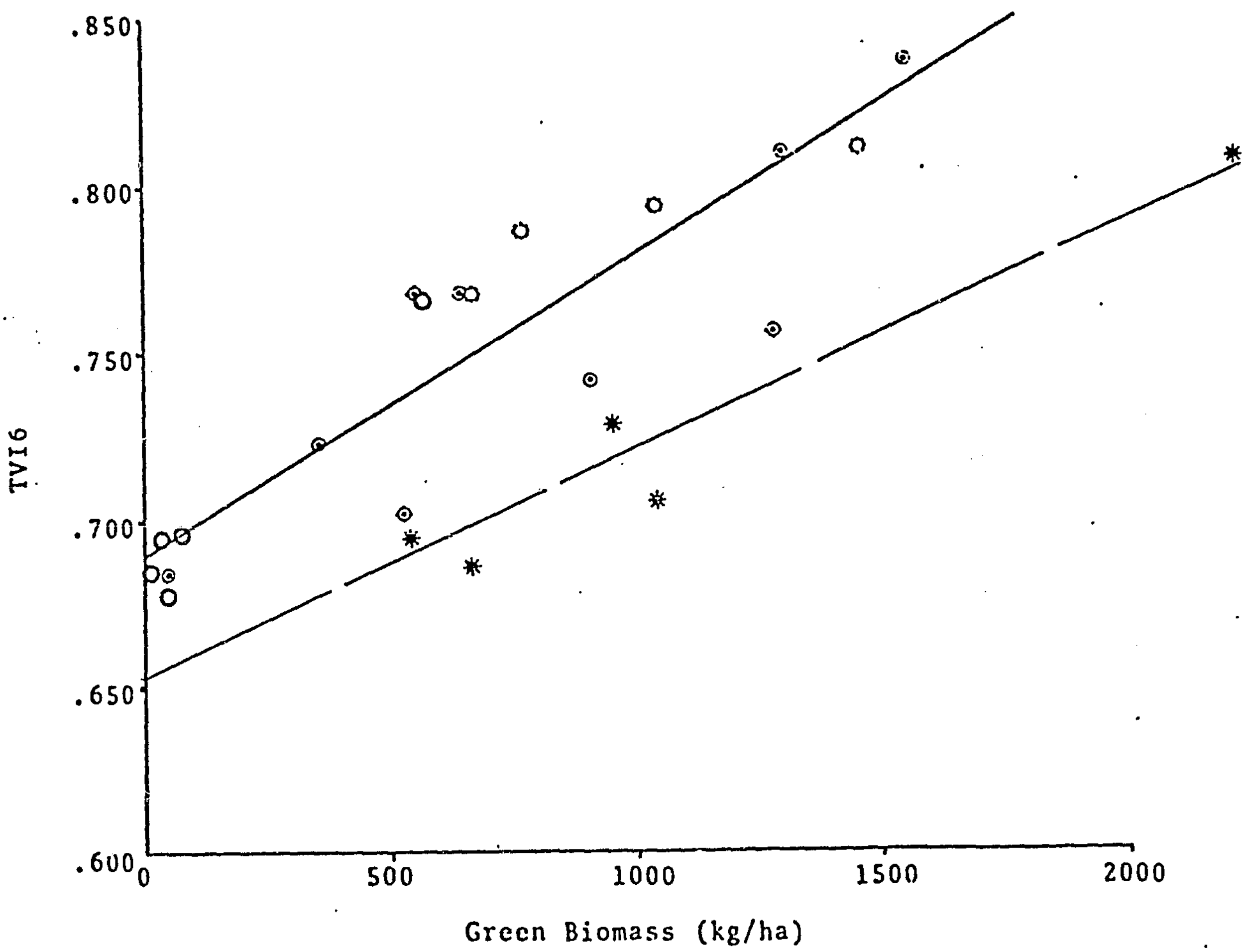

FIGURE 13. TVI-6 compared to green biomass dry weight (Rouse, et al., 1974).

ORIGINAL PAGE IS
OF POOR QUALITY

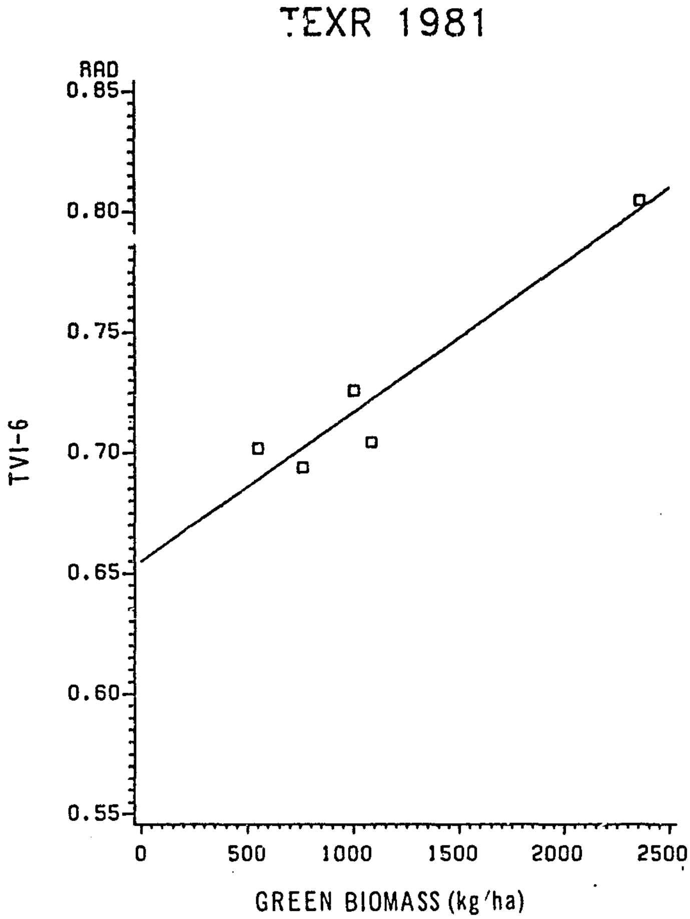

FIGURE 14. TVI-6 compared to green biomass dry weight for 1981.

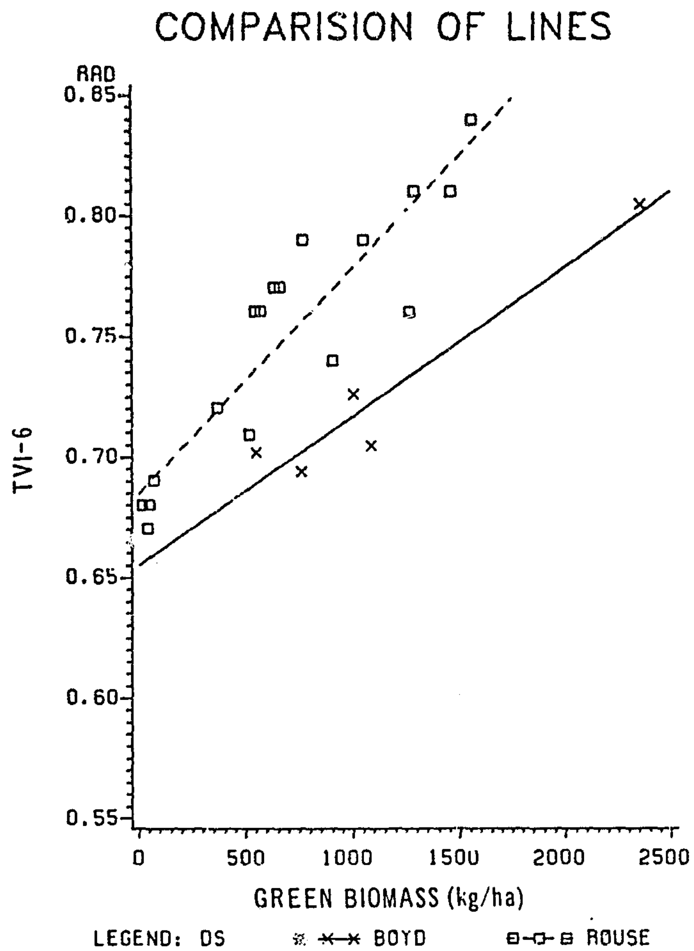

FIGURE 15. Rouse et al. (1974) and 1981 data plotted on the same axis.

However, if the slopes are the same, the vegetation calibration is essentially the same and the offset is constant and independent of the vegetation calibration. Therefore; the hypothesis was tested that the slopes of the regression lines generated from the different data sets were the same even though the intercepts were different. The result of this test shows that the slopes of the two lines, generated by data of at least eight years age difference, are non-statistically different at the 0.05 level of significance. This is significant in view of the fact that the data set for 1981 was small and contained what might be considered atypical fields (P16, Burn). Since there were only five points in the 1981 data set, this test is not conclusive; however, it is encouraging.

If these results are indeed valid, then future ground calibration expenses for an area could be amortized over a much longer period than has been considered in the past.

The key to calibration consistency is the non-alteration of the ecosystem in question. Assuming that other ecosystems and calibrations respond as this one does, then recalibration for biomass production would only need to be done following major ecosystem changes. These changes include a such things as brush canopy increases or decreases, range reseeding or major grazing management changes.

MAP PRODUCT GENERATION

One goal of the project was to use the Landsat biomass calibration curve described above to estimate the rangeland biomass over a four scene area and display this information spatially in a product format of use to ranchers. This was to be done by identifying 100 areas of homogeneous rangeland, extracting the Landsat pixels for these areas, estimating the biomass for these points, then using these estimates to produce a contour map of rangeland biomass for the region.

Regional Biomass Contour Map

Due to generally cloudy conditions over the majority of the four Landsat scene areas on June 1 and 2, the next Landsat pass date (June 18 and 19) tapes were chosen as substitutes from which a large area biomass map would be produced. Ground points for the estimation of biomass were chosen in a semi-random fashion for the whole four scene area using the following procedure (Figure 16). The master maps of USGS quad sheets for Texas and Oklahoma were marked as to Landsat scene boundaries (Path 30, Row 36; P30, R37; P31, R36; P31, R37). All the quad sheets within these boundaries were numbered. A number of quad sheets equal to the percentage of total area in each state (Texas 60; Oklahoma 40) were chosen at random but without replacement. These sheets were secured and reviewed as to likely areas of brush free grassland. The ASCS photography covering each Texas quad sheet was ordered and reviewed. Oklahoma photos were deleted at this time due to nonavailability. The only location where the state photo master sheets are available is at the the Oklahoma State ASCS office. The

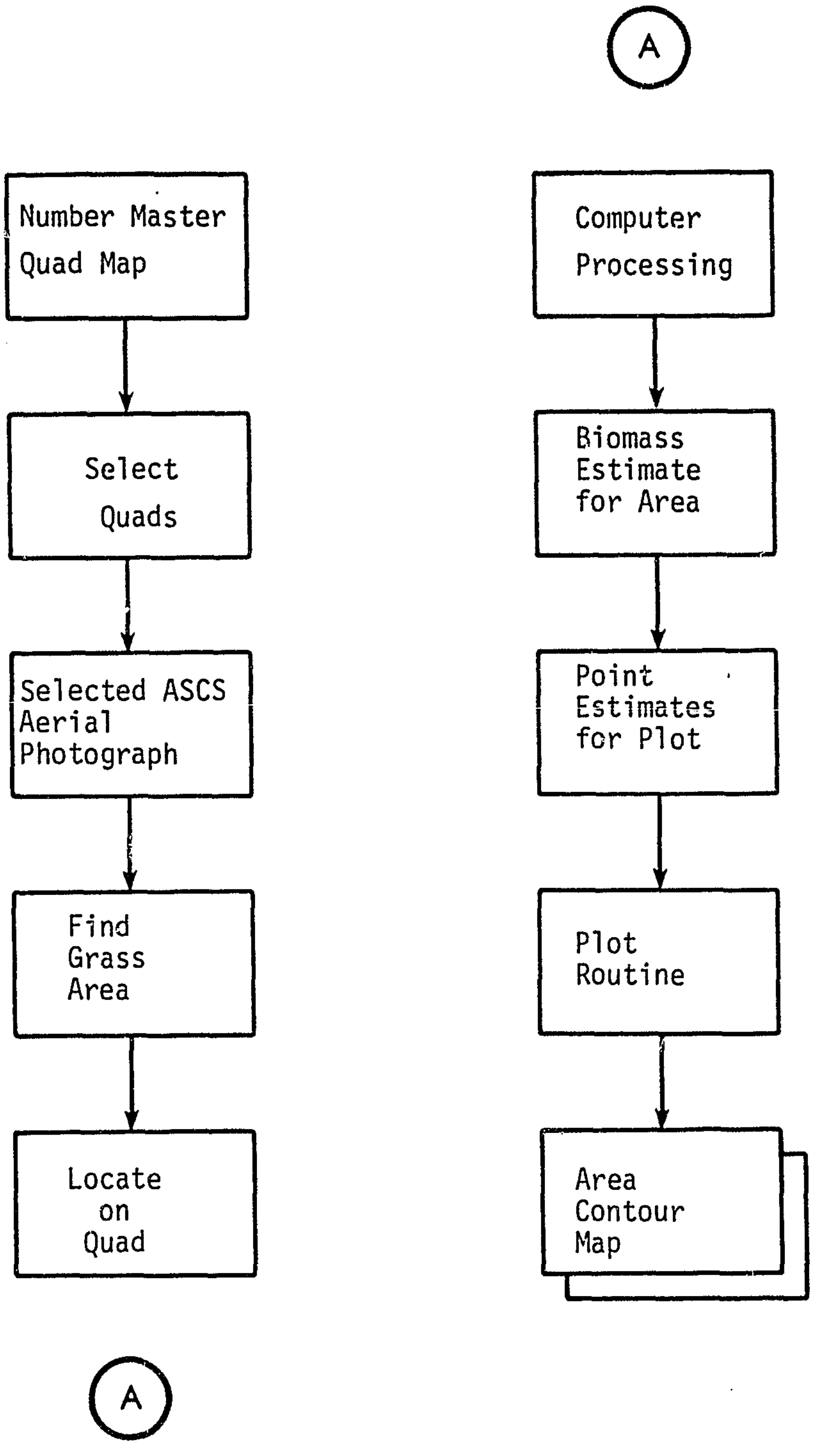

FIGURE 16. Selection process for the areas used to estimate biomass for which contours were generated.

necessary trip to Oklahoma was ruled out on the basis of budgetary considerations.

A fifty acre brush free area on each photo was selected based upon the photo signature. Each area was then located on the appropriate quad sheet. The Landsat data corresponding to the ground areas were stripped off Landsat tapes, transformed to TVI-6 values and an average biomass determined for each ground site. The average values were scaled according to a TVI-6 calibration curve (TVI-6 = .65506 + 6.1827 (Biomass); $r^2 = 0.92$) developed from the clipping data obtained at the Texas Experimental Ranch. The average site biomass values were used as input into a contour plot package. The results are displayed in Figure 17.

It should be noted that the biomass contour maps were generated from less than sixty points. Due to several problems, primarily developmental procedural problems and cloud shadows, only 28 points (Figure 18) were used in plotting the area biomass contour maps.

In an operational system all of the ground points for which Landsat data would be processed, would be visited to verify their size and characteristics. If any failed to meet the fifty acre, brush free, grass criterion, then a new location would be selected in the same general area. After this procedure had been accomplished the only reason for point deletion would be due to cloud cover.

On an operational basis, areas of clouds would be marked as clouded out, or a Landsat independent estimate of biomass would be made for these points and the contour continued with the estimated area marked.

ORIGINAL PAGE IS
OF POOR QUALITY

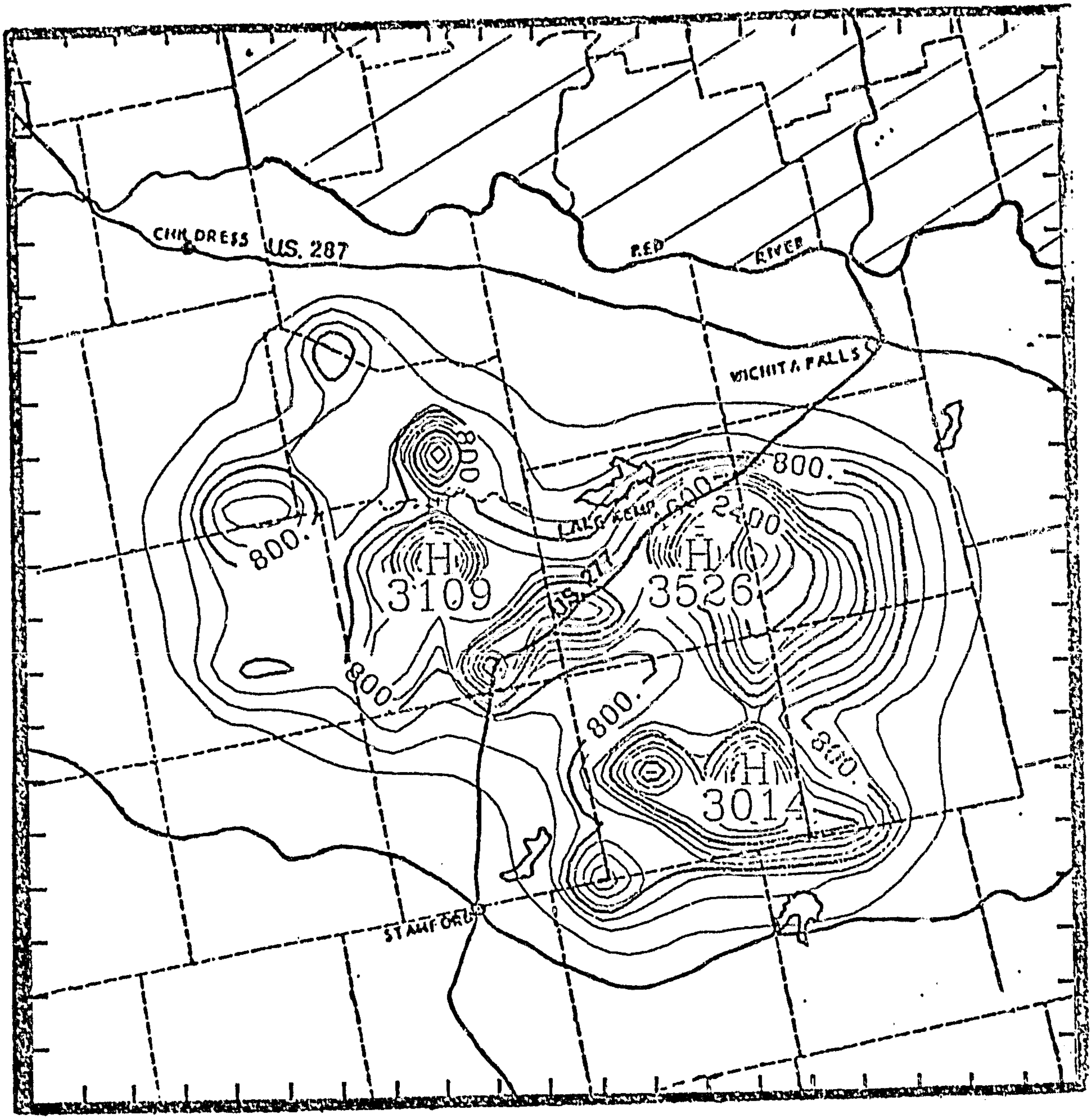

FIGURE 17. Area biomass - June 20, 1981 lbs/ac.

ORIGINAL PAGE IS
OF POOR QUALITY

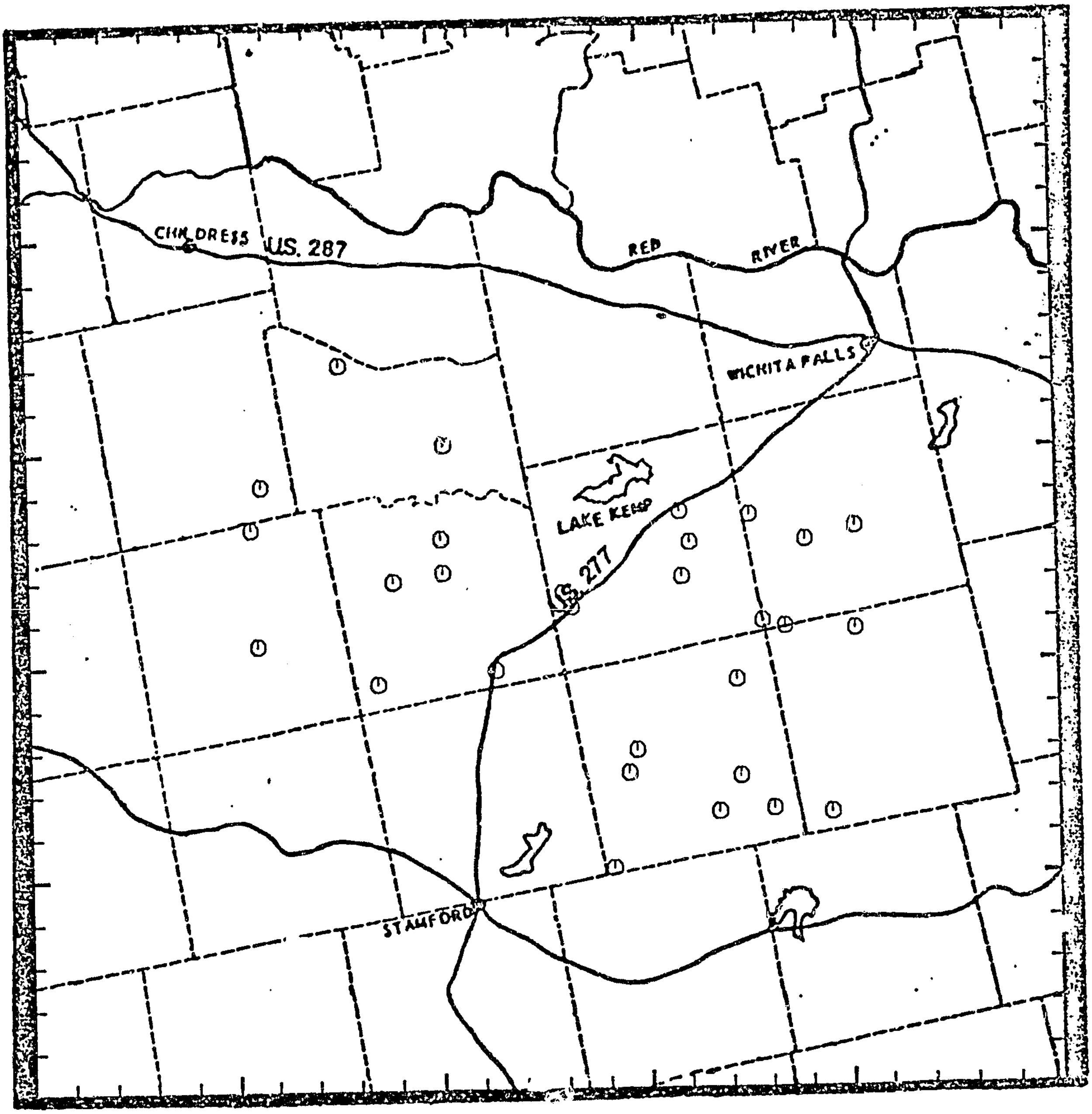

FIGURE 18. Area Biomass sampling points.

Regional Rainfall Maps

In order to better understand the spatial distribution of biomass production, rainfall data for the four scene area, which had been gleaned from NOAA sources, were accumulated for the 18 and 30 days prior to June 20. These values for 284 points were entered into a contour plot routine and produced in Figures 19 and 20. A location plot of the 284 points appears as Figure 21.

It should be noted that the areas of highest biomass production occur generally in areas that received the highest rainfall in the previous thirty days. This is as would be expected since one of the major contributory factors to plant growth is rainfall.

It must be remembered that the values of biomass represented on the contour map are only trend data and are probably not the absolute accurate values for any one spot in the area.

ORIGINAL PAGE IS
OF POOR QUALITY

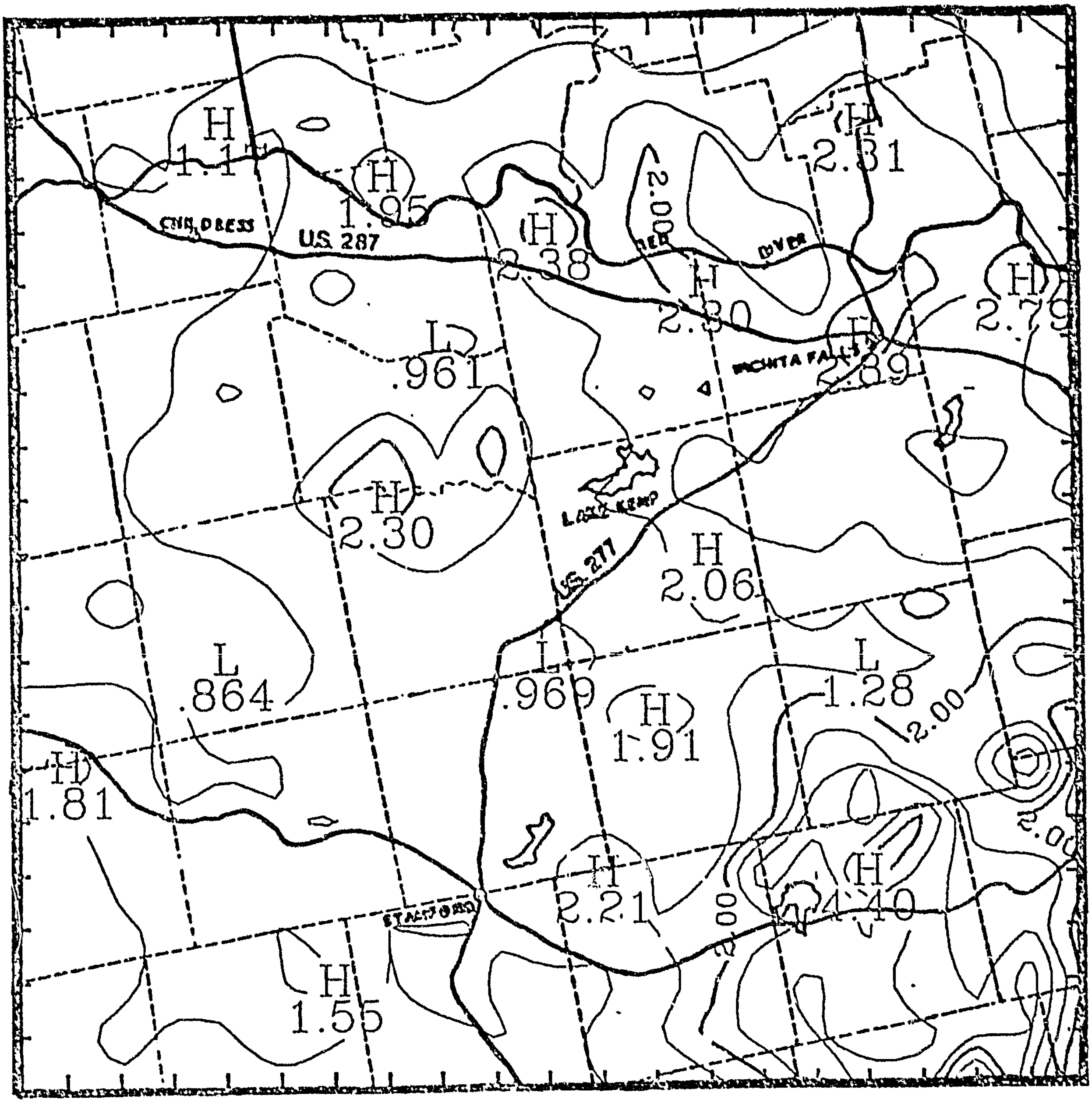

FIGURE 19. Rainfall (inches) accumulated during the 18 days prior to June 20.

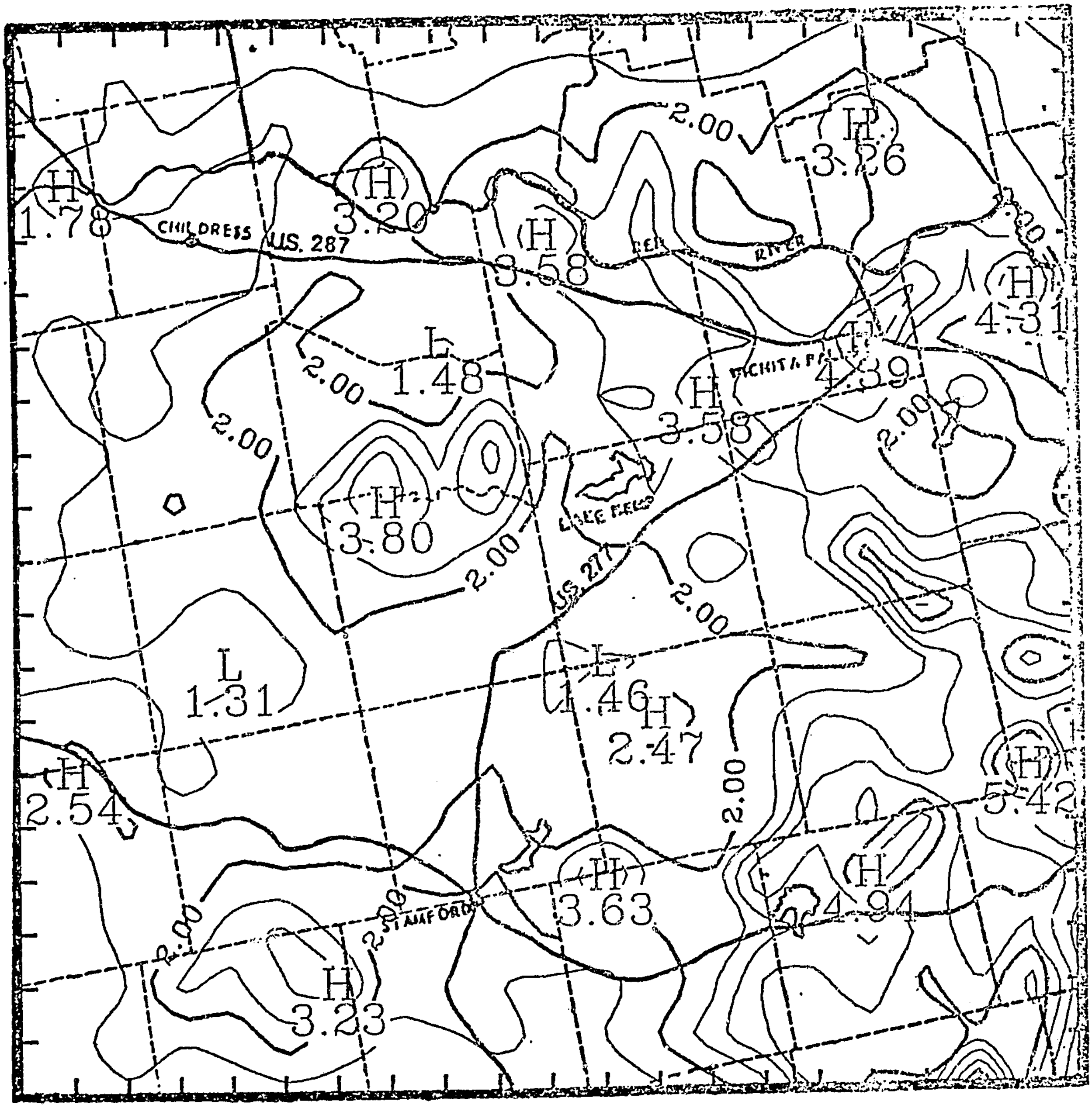

FIGURE 20. Rainall (inches) accumulated during the 30 days prior to June 30.

GAGE LOCATIONS

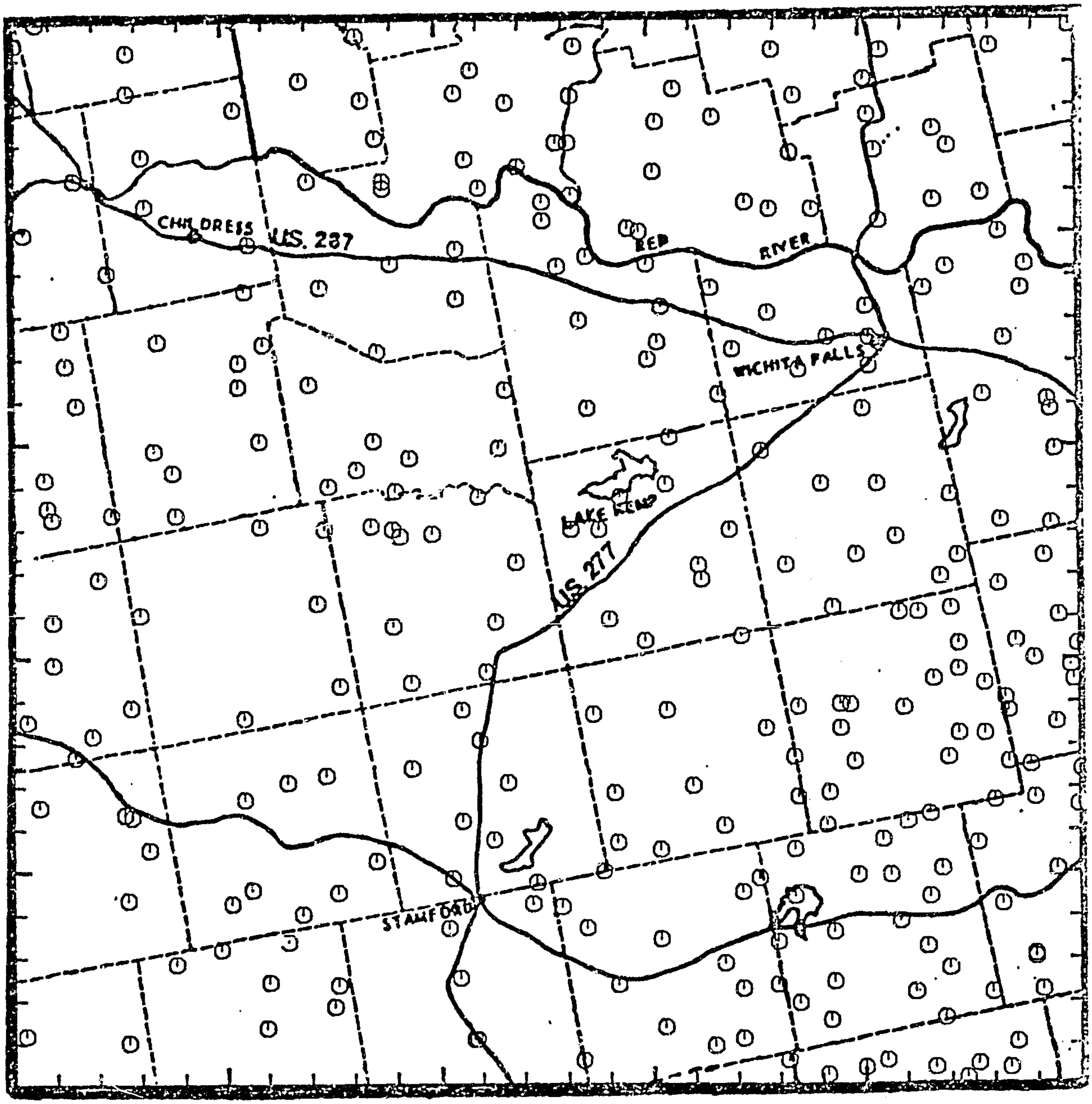

FIGURE 21. Rainfall gauge locations.

CONCLUSIONS

A very significant finding of this research effort is that the slope of the calibration line produced from 1981 data is not significantly different from that developed 8 years before. In light of the small 1981 data set, it is recommended that more field data be taken at the Texas Experimental Ranch to further confirm this very significant finding.

The participants in this effort believe that hand-held radiometers could be a viable double sampling tool with appropriate third generation hardware modifications. The problems encountered in this effort simply show that more research must be done to accurately define the types of environments in which radiometers are most appropriate. We recommend that a thorough test of appropriate radiometers on the Texas Experimental Ranch be supported. At a minimum, additional radiometer measurements should be made in all five test pastures to demonstrate a correlation between biomass and hand-held radiometer measurements. This would be of benefit in explaining why the hand-held radiometer measurements of P16 demonstrated such a low radiance ratio.

Techniques have been and can be developed for the production of fast turnaround range related products. The key to fast product generation is a sophisticated computing system and the availability of near real time satellite data.

REFERENCES

Boyd, W. E., H. Chilton, J. C. Harlan. 1979. Landsat Range Resource Information System Project. Progress Report 3697-5. Remote Sensing Center, Texas A&M University, College Station, Texas.

Harlan, J. C., W. E. Boyd, C. CLark, S. Clarke and O. C. Jenkins. 1979. Rangeland resource evalatuion from Landsat. Progress Report 3715-2. Remote Sensing Center, Texas A&M University, College Station, Texas.

Harlan, J. C., D. W. Deering, R. H. Haas and W. E. Boyd. 1979. Determination of Range Biomass Using Landsat. Thirteenth International Symposium on Remote Sensing of Environment. ERIM, Ann Arbor, MI.

Mitchell, D. B. 1981. Climatological Data - Texas. 86:5. NOAA, Asherville, N.C.

______. 1981. Climatological Data - Texas. 86:6. NOAA, Asherville, N.C.

______. 1981. Climatological Data - Oklahoma. 90:5. NOAA, Asherville, N.C.

______. 1981. Climatological Data - Oklahoma. 90:6. NOAA, Asherville, N.C.

Pearson, R. L., L. D. Miller and C. J. Tucker. 1976. Hand-held spectral radiometer to estimate gramineous biomass. Applied Optics 15:416-418.

Richardson, A. J. and C. L. Weigand. 1977. Distinguishing Vegetation from Soil Background Information. Photgr. Eng. and Remote Sensing 43:1541-1552.

Rouse, J. W., Jr., R. H. Haas, J. A. Schell, D. W. Deering and J. C. Harlan. 1974. Monitoring the vernal advancement and retrogradation (greenwave effect) of natural vegetation. RSC-1978-4. Remote Sensing Center, Texas A&M University, College Station, Texas 77843.

Rouse, J. W., Jr., D. W. Deering, R. H. Haas, R. I. Welch, J. C. Harlan and P. R. Whitney. 1977. Applied regional monitoring of the vernal advancement and retrogradation (Greenwave Effect) of natural vegetation in the Great Plains corridor. Final Report 3018-6. Remote Sensing Center, Texas A&M University, College Station, Texas.

Tucker, C. J. 1978. A Comparison of satellite sensor bands for vegetation monitoring. Photogrammetric Engin. and Remote Sensing 44:1369-1380.

Tucker, C. J., W. H. Jones, W. A. Kley and G. J. Sundstrom. 1980. The GSFC Mark-11 Threeband hand-held radiometers. NASA Technical Memo. 80641. NASA/Goddard Space Flight Center, Greenbelt, Maryland, 20771.

Waller, S. S., M. A. Brown and J. K. Lewis. 1981. Factors involved in estimating green biomass by canopy spectroreflectance measurements. J. of Range Management 34:105-108.

APPENDIX A

CLIMATOLOGICAL DATA

TEXAS

Name (Gage)	Latitude	Longitude	Inches of Rainfall: 20 June 18 days previous	Inches of Rainfall: 20 June 30 days previous
Abilene	32 25	99 41	2.73	3.69
Albany	32 44	99 17	1.94	2.50
Antelope	33 26	98 22	5.25	8.31
Archer City	33 36	98 38	2.79	4.22
Aspermont 1 E	33 09	100 13	2.42	4.44
Bowie	33 34	97 51	1.81	5.76
Brazos	32 40	98 07	4.82	5.16
Canadian 1 ENE	35 55	100 22	1.24	1.62
Childress FAA AP	34 26	100 17	1.60	3.52
Crowell	33 59	99 43	4.51	8.22
Dickens	33 37	100 50	3.54	7.20
Dublin	32 06	98 20	5.83	6.39
Dumont	33 48	100 31	3.57	5.63
Dundee 6 NNW	33 49	98 56	3.31	4.46
Electra	34 02	98 55	4.05	7.36
Flomor 4 NE	34 16	100 56	3.48	4.48
Gail	32 46	101 27	0.68	1.70
Graham	33 06	98 35	5.11	5.74
Guthrie	33 37	100 19	1.96	5.98
Hackberry	33 56	100 08	2.82	5.80
Hamlin	32 53	100 08	3.27	4.81
Haskell	33 10	99 44	1.19	3.85
Hawley	32 37	99 49	4.64	5.64
Henrietta	33 49	98 12	2.36	6.60
Huckabay 2 NW	32 21	98 19	5.88	6.60
Jacksboro	33 14	98 09	5.14	5.36
Jayton	33 15	100 34	1.97	4.61
Knapp 2 SW	32 38	101 38	2.46	3.29
Latimer Ranch	33 53	100 23	4.60	6.80
Lake Abilene	32 14	99 54	3.35	4.52
Lake Colorado City	32 20	100 55	2.25	5.05
Lake Kemp	33 45	99 09	3.63	6.44
Lawn	32 09	99 45	2.73	4.27
Lipan	32 31	98 03	6.18	6.41
Matador	34 01	100 50	1.55	2.21
McLean 3 E	35 14	100 36	1.20	2.47
Memphis	34 44	100 33	4.00	4.25
Mineral Wells FAA AP	32 47	98 04	1.81	3.65
Morgan Mill	32 22	98 10	5.48	5.70
Munday	33 27	99 38	2.78	3.98
Newport	33 29	98 02	2.50	8.75
Northfield	34 17	100 36	2.90	5.40
Olney	33 22	98 46	5.61	6.23
Olney 5 NNW	33 26	98 47	4.93	6.13
Paducah	34 01	100 18	3.35	5.71
Paducah 17 SSE	33 47	100 12	4.06	6.00

TEXAS

Name (Gage)	Latitude	Longitude	Inches of Rainfall 20 June 18 days previous	 20 June 30 days previous
Palo Pinto	32 46	98 19	4.14	4.70
Pithfork Ranch	33 36	100 32	1.49	4.35
Proctor Res	31 58	98 30	6.92	7.62
Putnam	32 22	99 11	4.29	6.06
Quanah 5 SE	34 15	99 41	3.66	5.64
Ringgold	33 49	97 56	1.76	6.54
Rising Star	32 06	98 58	3.99	6.11
Roscoe	32 27	100 32	2.15	3.77
Rotan	32 52	100 28	2.24	3.49
Seymour	33 36	99 15	3.14	4.25
Shamrock	35 12	100 15	1.65	3.21
Shamrock Radio KBYP	35 14	100 15	1.88	3.12
Snyder	32 43	100 55	3.08	4.01
Stamford	32 56	99 47	2.58	3.76
Stephenville	32 13	98 11	7.08	7.71
Strawn 8 NNE	32 40	98 28	4.17	4.57
Tampico	34 28	100 49	2.25	4.15
Throckmorton 2 W	33 11	99 12	2.14	2.86
Thurber 5 NE	32 32	98 20	4.90	5.69
Trent	32 29	100 08	2.45	3.54
Truscott	33 45	99 49	4.34	8.69
Turkey 2 WSW	34 23	100 56	2.20	4.62
Vernon	34 10	99 18	5.14	8.04
Wellington	34 51	100 13	3.37	4.96
Wheeler	35 26	100 17	2.04	4.04
Wichita Falls WSO AP	33 58	98 29	2.41	7.41
Woodson 5 NNE	33 05	99 02		

TEXAS

Name (Gage)	Latitude	Longitude	Inches of Rainfall 20 June 18 days previous	 20 June 30 days previous
Abernathy	33 50	101 51	.34	.75
Ackerly	32 32	101 43	4.30	5.53
Adamsville	31 18	98 10	6.89	8.09
Aledo 4 SE	32 39	97 34	4.11	4.97
Amarillo WSO AP	35 14	101 42	.77	2.64
Anna	33 21	96 31	5.95	10.20
Arlington	32 42	97 07	6.05	8.77
Ballinger 1SW	31 44	99 58	--	2.69
Bateman Ranch 2	33 36	100 13	2.39	5.57
Belton Dam	31 06	97 29	10.84	12.70
Benbrook Dam	32 39	97 27	4.38	5.77
Benjamin 15W	33 35	100 02	6.21	8.55
Big Lake 2	31 12	101 28	2.30	4.80
Big Spring	32 15	101 27	1.96	3.19
Borger 3W	35 39	101 27	2.42	3.89
Boyd	33 04	97 34	1.33	4.68
Brady	31 07	99 20	3.22	4.27
Brekenridge	32 45	98 56	6.22	7.13
Bridgeport	33 13	97 45	3.84	9.15
Brownwood	31 41	98 58	3.85	3.95
Burkett	32 00	99 14	2.88	4.98
Burleson 2 SSW	32 31	97 20	4.72	6.35
Canyon	34 59	101 56	0.32	1.65
Case Ranch 3S	31 38	101 02	2.04	8.04
Center City	31 28	98 25	4.51	5.02
Chalk Mountain	32 09	97 55	6.41	6.89
Channing 2	35 41	102 20	.81	2.14
Claredon	34 56	100 53	1.61	2.62
Claude	35 07	101 22	2.02	2.91
Cleburne	32 20	97 24	6.13	8.51
Coleman	31 50	99 26	2.69	6.48
Comanche	31 54	98 35	4.10	4.82
Cope Ranch	31 34	101 15	2.15	7.53
Copperas Cove	31 07	97 54	8.95	11.27
Cresson	32 32	97 37	3.48	4.01
Crosbytor	33 40	101 14	2.35	4.10
DAI-FTW Reg WSCMO AP	32 54	97 02	6.57	9.76
Decatur	33 14	97 36	3.83	9.32
Denton 2 SE	33 12	97 06	3.27	6.95
Dumas	35 52	101 58	.72	2.06
Eagle Mountain Lake	32 53	97 27	4.23	8.14
Eden 1	31 13	99 50	1.60	3.05
Evant	31 29	98 09	9.12	9.12
Floydada	33 58	101 20	1.72	2.79
Floydada 9 SE	33 52	101 15	.97	3.10
Forestberg 4 S	33 29	97 34	1.29	5.06
Forsan	32 06	101 22	2.32	3.74

TEXAS

Name (Gage)	Latitude	Longitude	Inches of Rainfall: 20 June 18 days previous	Inches of Rainfall: 20 June 30 days previous
Funk Ranch	31 29	100 48	2.07	4.88
Gainesville	33 38	97 08	1.10	5.80
Garden City	31 52	101 28	1.58	3.56
Gatesville	31 26	97 46	9.11	10.00
Glen Rose 2W	32 14	97 48	5.72	6.21
Goldthwaite 1WSW	31 27	98 35	6.78	7.35
Grapevine Dam	32 58	97 03	--	1.14
Hamilton 1 NW	31 43	98 09	7.95	8.16
Hewitt 1 SE	31 27	97 11	8.41	10.12
Hico	31 59	98 02	9.50	9.83
Hillsboro	32 01	97 07	14.28	15.22
Hords Creek Dam	31 51	99 34	1.37	2.41
Hurst Springs	31 39	97 43	12.36	13.09
Indian Gap	31 40	98 25	6.35	7.20
Kempner	31 05	98 00	9.11	11.76
Killeen Airport	31 05	97 41	9.68	12.22
Lamesa 1 SSE	32 42	101 56	2.48	3.32
Lampasas	31 03	98 11	6.80	9.60
Lenorah	32 18	101 53	.62	1.43
Lewisville Dam	33 04	97 01	5.51	9.10
Lillian 3 W	32 30	97 14	4.87	6.24
Lorenzo	33 40	101 32	.48	2.80
Lubbock WSFO Ap	33 39	101 49	.32	1.88
McGregor	31 26	97 25	6.05	7.55
Meridian State Park	31 53	97 42	8.41	8.41
Mertzon	31 16	100 49	2.00	4.71
Miami	35 42	100 38	2.61	3.66
Morgan 3 WNW	32 01	97 39	8.58	8.58
Muenster	33 39	97 22	1.10	5.79
Mullin	31 34	98 40	2.68	2.87
Nix Store 1 W	31 07	98 22	10.76	12.20
Oak Creek Lake	32 03	100 18	2.22	3.59
O C Fisher Dam	31 28	100 29	2.18	6.13
Paint Rock	31 3[illegible]	99 55	2.29	3.88
Pampa 2	35 34	100 57	2.86	3.45
Panhandle	35 21	101 23	2.03	4.01
Plainview	3[illegible] 11	101 42	.86	2.88
Post	33 12	101 24	1.80	3.81
Rainbow	32 16	97 42	5.75	6.17
Red Bluff Crossing	31 13	98 35	6.54	7.77
Reno	32 57	97 34		
Richland Springs	31 16	98 57	1.80	2.60
Roanoke	33 00	97 13	4.20	7.64
Robert Lee	31 54	100 29	2.95	5.85
San Angelo WSO Ap	31 22	100 30	1.76	3.86
San Saba	31 11	98 43	4.37	5.22
Silverton	34 29	101 19	.60	1.42

TEXAS

Name (Gage)	Latitude	Longitude	Inches of Rainfall 20 June 18 days previous	20 June 30 days previous
Silver Valley	31 57	99 33	1.95	3.62
Slaton 5 SE	33 22	101 36	1.64	3.95
Slidell	33 21	97 23	3.75	8.40
Sterling City	31 51	100 59	1.87	4.96
Sterling City 6 NE	31 55	100 53	2.02	5.48
Stillhouse Hollow Dam	31 02	97 32	13.33	15.27
Sunray 4 SW	35 58	101 52	.13	1.63
Tahoka	33 10	101 49	1.07	2.92
Temple	31 05	97 20	13.58	15.13
Troy	31 12	97 18	8.76	10.57
Tulia	34 32	101 46	.69	2.83
Valley View	33 29	97 10	2.80	6.35
Waco Dam	31 36	97 13	7.50	8.80
Waco WSO Ap	31 37	97 13	7.18	8.37
Water Valley	31 40	100 43	2.19	5.84
Water Valley 10 NNE	31 48	100 39	2.71	7.04
Weatherford	32 46	97 49	2.43	3.86
Whitney Dam	31 51	97 22	13.37	14.37
Wink FAA Airport	31 47	103 12	.02	1.26
Winters	31 58	99 57	2.18	4.05

OKLAHOMA

Name (Gage)	Latitude	Longitude	Inches of Rainfall: 20 June 18 days previous	Inches of Rainfall: 20 June 30 days previous
Anadarko 2 NNE	35 06	98 14	3.03	3.76
Altus Dam	34 53	99 18	4.40	7.33
Altus Irrig Resch Station	34 35	99 20	3.39	6.47
Blanchard	35 09	97 40	4.97	5.57
Carnegie 4 ENE	35 08	98 33	4.90	5.48
Chattanooga 3 NE	34 27	98 37	4.70	8.40
Chichasha Exp. Station	35 03	97 55	6.01	6.84
Clinton	35 31	98 58	3.13	3.67
Comanche	34 22	97 58	2.97	8.15
Cordell	35 17	98 59	4.55	6.08
Duncan	34 30	97 58	5.15	7.11
Elk City 1 E	35 25	99 23	3.67	4.22
Erick 4 E	35 12	99 48	3.42	4.24
Frederick	34 24	99 01	4.96	10.29
Grandfield	34 14	98 41	5.36	10.15
Hammon 1 NNE	35 38	99 22	2.58	4.06
Healdton	34 14	97 27	3.35	7.45
Hobart FAA AP	35 00	99 03	3.58	5.39
Lawton	34 37	98 27	5.01	7.91
Lindsay	34 50	97 37	5.05	6.34
Lookeba 2 ENE	35 22	98 20	5.80	7.05
Magnum Rsch Station	34 50	99 26	4.98	6.61
Marlow 1 WSW	34 39	97 59	5.65	7.53
Moravia 2 NNE	35 08	99 30	3.50	4.48
Paul's Valley	34 44	97 16	5.51	8.85
Purcell	35 00	97 22	6.68	7.87
Roosevelt	34 51	99 01	4.22	6.01
Sayre 1 NE	35 18	99 37	2.88	5.03
Snyder	34 39	98 57	4.27	6.36
Vinson 3 WNW	34 55	99 55	4.07	6.63
Walters	34 21	98 18	5.28	8.19
Waurika	34 10	98 00	1.86	6.77
Wichita Mt Wl Ref	34 44	98 43	3.91	5.89

OKLAHOMA

Name (Gage)	Latitude	Longitude	Inches of Rainfall 20 June 18 days previous	 20 June 30 days previous
Cheyenne	35 36	99 40	1.38	2.67
Cox City 1 E	34 44	97 43	3.00	5.58
El Reno 1 N	35 33	97 58	5.59	7.65
Geary	35 38	98 19	4.10	5.07
Guthrie	35 52	97 24	2.49	3.53
Kingfisher 2 E	35 51	97 54	5.32	7.02
Leedey	35 52	99 21	1.78	1.98
Marietta 3 NW	33 59	97 07	2.34	8.88
Norman	35 11	97 27	2.83	3.13
Oklahoma City WSFO Ap R	35 24	97 36	4.01	5.96
Perkins	35 58	97 02	2.37	4.34
Reydon	35 39	99 55	1.34	1.89
Union City	35 23	97 56	5.75	8.31
Weatherford	35 32	98 42	2.45	3.65
Willow	35 03	99 30	4.74	7.52