2. # AgRISTARS

E83-10045

7. EW-U2-04320 ~~IA-85765~~

JSC-18255

CR-169606

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Early Warning and Crop Condition Assessment

6. JUNE 1982

ESTIMATING TOTAL STANDING HERBACEOUS BIOMASS PRODUCTION WITH LANDSAT MSS DIGITAL DATA

3. A. J. RICHARDSON, J. H. EVERITT, C. L. WIEGAND

(E83-10045) ESTIMATING TOTAL STANDING HERBACEOUS BIOMASS PRODUCTION WITH LANDSAT MSS DIGITAL DATA Progress Report (Agricultural Research Service) 26 p HC A03/MF A01 CSCL 02C

N83-13536

Unclas G3/43 00045

NASA ACCESS

4. USDA/ARS
SOIL AND WATER CONSERVATION RESEARCH
WESLACO, TEXAS 78596

Lyndon B. Johnson Space Center
Houston, Texas 77058

1. Report No. EW-U2-04320 JSC-18255	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Estimating Total Standing Herbaceous Biomass Production With Landsat MSS Digital Data		5. Report Date June 1982
		6. Performing Organization Code
7. Author(s) A. J. Richardson, J. H. Everitt, C. L. Wiegand		8. Performing Organization Report No.
9. Performing Organization Name and Address USDA-ARS Soil and Water Conservation Research Weslaco, Texas 78596		10. Work Unit No.
		11. Contract or Grant No.
		13. Type of Report and Period Covered Progress Report
12. Sponsoring Agency Name and Address USDA Johnson Space Center/SK Houston, TX 77058		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Rangeland biomass data were correlated with spectral vegetation indices, derived from Landsat MSS data. Landsat data from five range and three other land use sites in Willacy and Cameron Counties were collected on October 17 and December 10, 1975, and on July 31 and September 23, 1976. The overall linear correlation of total standing herbaceous biomass with the Landsat derived perpendicular vegetation index was highly significant ($r = 0.90^{**}$) for these four dates. The standard error of estimate was 722 kg/ha. Biomass data were recorded for two of these range sites for 8 months (March through October) during the 1976 growing season. Standing green biomass accounted for most of the increase in herbage, starting in June and ending about September and October. These results indicated that satellite data may be useful for the estimation of total standing herbaceous biomass production that could aid range managers in assessing range condition and animal carrying capacities of large and inaccessible range holdings.

17. Key Words (Suggested by Author(s)) Rangeland Production estimates Satellite Green biomass Vegetative Index	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 24	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

A. J. RICHARDSON
J. H. EVERITT
C. L. WIEGAND
USDA, SEA, AR
Soil and Water Conservation Research
Weslaco, Texas 78596

Estimating Total Standing Herbaceous Biomass Production With LANDSAT MSS Digital Data

The Landsat derived perpendicular vegetation index may be useful to range managers in estimating herbaceous biomass production.

ABSTRACT: Rangeland biomass data were correlated with spectral vegetation indices, derived from LANDSAT MSS data. LANDSAT data from five range and three other land use sites in Willacy and Cameron Counties were collected on October 17 and December 10, 1975, and on July 31 and September 23, 1976. The overall linear correlation of total standing herbaceous biomass with the LANDSAT derived perpendicular vegetation index was highly significant ($r = 0.90^{**}$) for these four dates. The standard error of estimate was 722 kg/ha. Biomass data were recorded for two of these range sites for 8 months (March through October) during the 1976 growing season. Standing green biomass accounted for most of the increase in herbage, starting in June and ending about September and October. These results indicated that satellite data may be useful for the estimation of total standing herbaceous biomass production that could aid range managers in assessing range condition and animal carrying capacities of large and inaccessible range holdings.

INTRODUCTION

To make proper range management decisions, range managers need to know more about (1) the duration of the safe grazing season in relation to weather conditions and current herbage production, (2) how to control seasonal grazing to maintain adequate herbage and ground cover, (3) the stage of vegetation development to properly assess range readiness for grazing, (4) yearly effects of weather phenomena on forage development to plan cattle movements, (5) the effects of evapotranspiration and animal consumption on water ponds in grazing areas, and (6) the degree of range utilization in relation to its effects on long-term range productivity.

This information if timely would help private range operators to assess animal-carrying capacities of large and inaccessible range holdings. Carneggie and DeGloria (1974) have shown that the repetitive coverage and synoptic view of LANDSAT can be a valuable tool for evaluating rangeland resources in California. Deering et al. (1975) developed a green vegetation estimation model using LANDSAT data that can be used as an indicator of rangeland vegetation conditions in the Great Plains. Maxwell (1976) described how LANDSAT data can provide range managers with maps and tables giving standing herbaceous biomass for selected range types in northwestern Colorado. Thompson (1975) has shown that LANDSAT imagery can provide frequent estimates of rangelands in western Canada where estimate intervals now are 6 to 10 years apart.

Our objective was to investigate eight spectral vegetation indices that can be determined from LANDSAT multispectral scanner (MSS) digital data (Richardson and Wiegand, 1977) to determine their usefulness to range managers for estimating animal harvestable forage in open rangeland areas of south Texas.

EXPERIMENTAL PROCEDURES

Study Area and Field Methods

The specific study area is located between 26°28' and 26°42' north latitude and 97°25' and 97°49' west longitude, and includes about 81,000 ha in Kenedy and Willacy Counties, in south Texas (Everitt et al., 1979). It is a transition zone between the Texas Coastal Prairies and the South Texas Plains vegetational regions (Gould, 1975). The Gulf of Mexico borders the area on the east.

The topography is flat to gently sloping with elevations ranging from sea level to 15 m above sea level (U.S. Geological Survey 7.5 Minute Topographic Maps).

The climate is mild, with short winters and relatively warm temperatures throughout the year. The average growing season exceeds 325 days (Texas Almanac, 1975). The 30 year average annual rainfall is 660 mm (Potter, 1976). Heaviest rains fall in May and September.

Herbaceous production of primary interest to range managers relates to total standing herbaceous biomass available for grazing, without deleteriously affecting vegetation. Therefore, total standing herbaceous biomass samples were obtained, at or near the time of LANDSAT-2 clear overpasses from five different rangeland sites within the 81,000 ha study area. Since the LANDSAT MSS digital data is expected to be sensitive only to the total standing green herbaceous biomass, it should yield best estimates of total standing herbage production when standing green herbage predominates over standing brown herbage (Tucker, 1977). The five rangeland sites used were:

1. Tight sandy loam (improved grasses). The brush had been controlled and the range reseeded with buffel grass (*Cenchrus ciliaris* L.). Native grasses have reestablished themselves. At the time of the study this was a highly productive grassland site.
2. Tight sandy loam (alicia grass). The brush had been controlled and the site has been improved by reseeding with alicia grass (*Cynodon* spp.). At the time of the study, this was a highly productive grassland site.
3. Coastal sand (native grass). This native grassland site had few woody plants (less than 5%) other than an occasional mott of mesquite (*Prosopis glandulosa* Torr.) or live oak trees (*Quercus virginiana* Mill.). At the time of the study, this was a moderately productive coastal grassland site.
4. Deep sand (improved grasses). The brush had been controlled and native grasses and herbs were reestablished. At the time of the study this was a moderately productive grassland site.
5. Salty Flat (native grass). A few salt tolerant herbaceous species, but no woody plant species were present at the time of the study and productivity was low.

We determined total standing herbaceous biomass production for each rangeland site by clipping all standing vegetation 2 cm above ground level in 20 quadrats (each 50 cm x 50 cm) (Stewart and Hutchins, 1936) once a month during the 1975 and 1976 range growing seasons. Percent canopy cover of woody vegetation was determined by the line-intercept method (Canfield, 1941). Besides these five rangeland sites in the study area, three other bare soil sites that were used are:

6. Tidal Flats. This site occurs on nearly level areas along the coast only a few feet above the mean high tide and has large bare soil areas or salt slicks.
7. Cropland. These are blocks of cultivated land located in the southern part of the study area. Nonirrigated grain sorghum and cotton row crops are grown in the late spring and summer.
8. Sand Dunes. These are coastal areas of deep unstable sand usually bare of vegetation, except for vegetation around their outer perimeter.

These three bare soil sites (6 to 8) were not sampled for biomass measurements. For each of these sites, we assumed biomass was zero for regression analysis studies to relate biomass to LANDSAT spectral data. On July 31, 1976, the cropland site was planted to sorghum and so we did not use it for the regression analysis on this date.

Although sandy mound live oak brush, deep sand mesquite brush, and tight sandy loam mixed brush rangeland sites were present in the study area (Everitt et al., 1979), they were not used in regression analysis studies because their woody canopies obscured the herbaceous biomass. Lagunas were not used in the study because their signature varied from wet to dry seasons.

LANDSAT Digital Data

We used MSS computer compatible tapes (CCT) and corresponding color images (1:1,000,000 scale) for four LANDSAT-2 overpasses. All four of the LANDSAT MSS bands were used, covering the 0.5- to 1.1-μm spectral region. These overpasses provided digital counts for a 185- by 185-km scene that included the 81,000 ha rangeland study area in Kenedy and Willacy Counties in south Texas. Four cloud-free LANDSAT-2 overpass dates were chosen to relate satellite data to herbage production. An October 17, 1975 overpass (scene ID 2268-16190) provided an image of the area when most vegetation was in late season growth. A December 10, 1975 overpass (scene ID 2322-16183) provided an image of the area when it was seasonally dormant; near freezing air temperatures and a radiational frost had occurred about a month earlier. The July 31, 1976 overpass (scene ID 2556-16125) provided an image of the area when the vegetation was at peak growth after heavy rains in June and early July. The September 23, 1976 overpass (scene ID 2610-16112) provided a second data set comparable to the October 17, 1975 overpass.

A supervised analysis was used with the MSS data that consisted of acquiring over 650 training pixels (picture element) from 15 training sites within the 81,000 ha rangeland study area (1.0% of total area) that intensive ground observations indicated were representative of the five rangeland and three bare soil sites previously described. The mean digital count for each spectral band of each site was used to calculate eight spectral vegetation index (VI) models, as described by Richardson and Wiegand (1977). Training sites were identified on gray scale maps of the study area, from which record and pixel coordinates were determined. The same training sites were used for all four LANDSAT overpass dates. Regression analysis was used to test the ability of each of the eight VI models to estimate total herbaceous biomass production previously determined for each of the five rangeland types. The regression model used is as follows:

$$\text{BIOMASS (kg/ha)} = a_0 + a_1 \text{ VI}, \tag{1}$$

where VI is any one of eight vegetation index models.

<u>Vegetation Index Models</u>

The same vegetation indices, used by Richardson and Wiegand (1977) to characterize the seasonal development of grain sorghum, were used in this study to quantify seasonal grassland changes. All models use LANDSAT digital data. A sun angle cosine correction factor (F) was used to correct for the seasonal sun zenith angle effects as follows (Deering et al., 1975; Richardson and Wiegand, 1977):

$$F = \cos\emptyset \,/\, \cos\theta, \tag{2}$$

where $\emptyset$ = 39°, median sun zenith angle, and θ is the zenith angle of the LANDSAT overpass being processed. The raw LANDSAT CCT digital data were multiplied by F before the VI's were calculated.

The following formulas define the eight VI models:

Transformed Vegetation Index Model (TVI),

$$\text{TVI} = ((\text{MSS7}-\text{MSS5})/(\text{MSS7}+\text{MSS5}) + 0.5)^{\frac{1}{2}}. \tag{3}$$

Transformed Vegetation Index Six Model (TVI6),

$$\text{TVI6} = ((\text{MSS6}-\text{MSS5})/(\text{MSS6}+\text{MSS5}) + 0.5)^{\frac{1}{2}}. \tag{4}$$

Ratio Vegetation Index Model (RVI),

$$RVI = MSS5 / MSS7. \qquad (5)$$

Perpendicular Vegetation Index Model (PVI),

$$PVI = ((Rgg5 - Rp5)^2 + (Rgg7 - Rp7)^2)^{\frac{1}{2}}. \qquad (6)$$

where Rgg5 = 0.851Rp5 + 0.355Rp7; Rgg7 = 0.355Rp5 + 0.148Rp7; Rp5 = MSS5; and Rp7 = MSS7.

Perpendicular Vegetation Index Six Model (PVI6),

$$PVI6 = ((Rgg5 - Rp5)^2 + (Rgg6 - Rp6)^2)^{\frac{1}{2}}. \qquad (7)$$

where Rgg5 = -.498 + 0.543Rp5 + 0.498Rp6; Rgg6 = 2.734 + 0.498Rp5 + 0.457Rp6; Rp5 = MSS5; and Rp6 = MSS6.

Difference Vegetation Index Model (DVI),

$$DVI = 2.4MSS7 - MSS5. \qquad (8)$$

Soil Brightness Index Model (SBI),

$$SBI = 0.433MSS4 + 0.632MSS5 + 0.586MSS6 + 0.264MSS7. \qquad (9)$$

Green Vegetation Index Model (GVI),

$$GVI = -0.290MSS4 - 0.562MSS5 + 0.600MSS6 + 0.491MSS7. \qquad (10)$$

The TVI, TVI6, and RVI models were used by Texas A&M University personnel as indicators of the amount and condition of rangeland vegetation (Deering et al., 1975). The PVI, PVI6, and DVI models were developed by Richardson and Wiegand (1977) at Weslaco, Texas, for spectral monitoring of sorghum plant growth. The SBI and GVI models (Kauth and Thomas, 1976) were used in the Large Area Crop Inventory Experiment (LACIE) at the Johnson Spacecraft Center, Houston, Texas, for describing soil background reflectance and crop development, respectively.

RESULTS AND DISCUSSION

Vegetation Index Models

The results of the regression analysis that tested (equation 1) the ability of each of the eight VI models for estimating herbaceous biomass are given in Tables 1 through 4 along with the LANDSAT and ground observation data collected for each range site on each of the four sampling dates (October 17 and December 10, 1975; July 31 and September 23, 1976). All VI models yielded significant correlations with herbaceous biomass although the PVI and DVI models seemed to have generally higher correlation coefficients for all four dates. As expected, the soil brightness index (SBI), a measure of soil background reflectance, was negatively (but insignificantly) correlated with biomass for any date. Since the individual LANDSAT band digital counts were not significantly correlated with biomass, the VI models are a considerable improvement for characterizing rangeland herbage production.

Regression coefficients (r), relating total herbaceous biomass with PVI for each of the four LANDSAT overpass dates individually using open grass and bare soil range sites for all four dates, ranged from 0.74 to 0.97 (Table 5). The regression slopes and intercepts indicated that the biomass and PVI data follow about the same linear line for all four dates. Thus, the data for open range grass sites and bare soil for all four dates were combined into one regression, as shown in Table 5 and Figure 1. The regression coefficient was significant ($r = 0.90^{**}$) indicating that this single relation could be used to estimate standing herbaceous biomass production of open range from PVI at any time of the growing season for either year even though the standard error of estimate, 722 kg/ha, is larger than reported by Deering et al. (1977) and Harlan et. al. (1979) of 250 kg/ha for estimating natural vegetation.

Phenological Variation of Rangeland Biomass

The relative proportions of standing green, standing brown, and heads and stems biomass components constituting the total amount of biomass measured for the moderately productive coastal sand native grass rangeland site (site 3) for the 1976 growing season are shown in Figure 2. Standing green biomass accounted for the large increase in total biomass starting in June and ending about October. The increase in heads and stem biomass from March through October, with an inexplainable dip in September, is consistent with the known phenology of grass growth. The amount of biomass for standing brown was unexplainably variable throughout the growing season.

The seasonal changes in amounts of total herbaceous biomass for the moderately productive coastal sand native grass (site 3) and the less productive deep sand improved grass (site 4) rangeland sites are shown in Figure 3. Total herbaceous biomass for both sites was about the same until July and August, when the coastal sand site produced more green biomass, and therefore, more total biomass than did the deep sand site.

SUMMARY AND CONCLUSIONS

Our results showed that LANDSAT data are significantly correlated with total standing herbaceous biomass. In the study it was not possible to test the combined ability of LANDSAT and weather data to estimate biomass conditions, because cloudy weather prevented LANDSAT coverage on all, except 2 of the 8 biomass collection dates, in both 1975 and 1976 resulting in insufficient data. However, weather information has been shown to be a good estimator of herbaceous biomass (Deering et al., 1975), thus it seems likely that the combined use of LANDSAT and weather data would improve the reliability of herbaceous biomass production estimates.

Everitt et al. (1979) showed that it is possible to distinguish among open grasslands, mixed brush, and live oak rangeland types. Thus, once the areal extent of open grasslands have been remotely inventoried, using LANDSAT MSS data, then the relations developed in this paper could be used to estimate the herbage production of these areas. For areas that are largely open grassland, like those studied by Carneggie and DeGloria (1974) and Maxwell (1976), these procedures could be used directly. Therefore, it seems likely that this information could be displayed as computer generated maps and tables for use by range managers for estimating herbage production of open rangeland.

ACKNOWLEDGEMENTS

We gratefully acknowledge the data processing work of N. S. Caskey and R. W. Schwab, and the field data collection efforts of A. H. Gerbermann and M. A. Alaniz, who helped make this study possible.

REFERENCES

Canfield, R. H. 1941. Application of the line interception method in range vegetation. J. Forest. 39:388-394.

Carneggie, D. M., and S. D. DeGloria. 1974. Determining range condition and forage production potential in California from ERTS-1 imagery. Proc. of the 9th Int. Symp. on Remote Sens. of Environ. April 15-19. II:1051-1059.

Dallas Morning News, The. 1974-1975. The Texas Almanac. Dallas. 704 pp.

Deering, D. W., J. W. Rouse, R. H. Haas, and J. A. Schell. 1975. Measuring "forage production" of grazing units from LANDSAT MSS data. Proc. of the 10th Int. Symp. on Remote Sens. of Environ. October 6-10. II:1169-1178.

Deering, D. W., J. W. Rouse, R. H. Haas, R. I. Welch, J. C. Harlan, and P. R. Whitney. 1977. Final Type III Report (RSC 3018-6) for period February 1975 to December 1976. 220 pp.

Everitt, J. H., A. J. Richardson, A. H. Gerbermann, C. L. Wiegand, and M. A. Alaniz. 1979. Utilization of satellite data for inventorying rangelands in south Texas. Machine Processing of Remotely Sensed Data. 6/27 - 29, LARS, Purdue, IEEE Cat. No. 79, CH 1430-8 MPRSD. p 132-141.

Gould, F. W. 1975. Texas plants--A checklist and ecological summary. Tex. Agric. Exp. Stn., Texas A&M Univ., College Station. MP-585. 121 pp.

Harlan, J. C., D. W. Deering, R. H. Haas, and W. E. Boyd. 1979. Determination of range biomass using LANDSAT. Proc. of the 13th Int. Symp. on Remote Sens. of Environ. II:659-673.

Kauth, R. J., and G. S. Thomas. 1976. The tasselled cap--A graphic description of the spectral-temporal development of agricultural crops as seen by LANDSAT. Proc. Symp. Machine Proc. of Remote Sens. Data, 6/29 - 7/2, LARS, Purdue, IEEE Cat. No. 76, Ch. 1103-1 MPRSD. 4B:41-51.

Maxwell, E. L. 1976. A remote rangeland analysis system. J. Range Manage. 29(1):66-73.

Potter, T. D. 1976. Climatological Data--Texas Annual Summary 1975. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Vol. 80, No. 13. 31 pp.

Richardson, A. J., and C. L. Wiegand. 1977. Distinguishing vegetation from soil background information. Photogrammetric Engineering and Remote Sensing. 43(12):1541-1552.

Stewart, G., and S. S. Hutchings. 1936. The point observation-plot (square foot density) method of vegetation survey. Agron. J. 28:714-726.

Thompson, M. D. 1975. Remote sensing of rangeland in Western Canada. Fall Convention of the Am. Soc. of Photogramm. Phoenix, AZ. October 26-31. 19 pp.

Tucker, C. J. 1977. Spectral estimation of grass canopy variables. Remote Sensing of Environment. 6(1):11-26.

ORIGINAL PAGE IS
OF POOR QUALITY

Table 1. October 17, 1975, LANDSAT digital data, vegetation indices, and sampled herbaceous biomass for 8 sites within a 81,000 ha rangeland study area. Sun elevation was 44 and sun azimuth was 137; digital data were corrected for sun angle before calculation of vegetation indices. Estimated herbaceous biomass was calculated using BIOMASS = -297 + 253PVI. Negative biomass estimates were entered as zero.

Rangeland Site	Site Number	LANDSAT MSS BANDS				VEGETATION INDICES								Herbaceous Biomass Production	
		MSS4	MSS5	MSS6	MSS7	TVI	TVI6	RVI	PVI	PVI6	DVI	SBI	GVI	SAMPLED	ESTIMATED
		- -Digital Counts- -												- -kg/ha- -	
Tight Sandy Loam															
Improved Grass	(1)	20	21	51	27	0.79	0.96	0.78	17	21	44	59	26	4752	4004
Alicia Grass	(2)	18	19	47	25	0.80	0.97	0.75	16	20	42	54	25	3730	3751
Coastal Sand															
Native Grass	(3)	22	25	42	20	0.63	0.87	1.24	9	12	23	55	15	2922	1980
Deep Sand															
Improved Grass	(4)	20	25	43	22	0.66	0.88	1.14	11	13	27	56	17	1884	2486
Salty Flat															
Native Grass	(5)	39	51	59	25	0.38	0.76	2.10	3	7	8	91	7	660	462
Soils															
Tidal Flats	(6)	47	62	66	28	0.35	0.73	2.20	2	5	5	105	5	0	209
Cropland	(7)	24	30	33	14	0.37	0.73	2.15	1	2	4	52	3	0	0
Sand Dune	(8)	49	71	79	32	0.35	0.74	2.23	2	8	5	120	9	0	209
SIMPLE CORRELATION WITH BIOMASS (r)		-0.74*	-0.77*	-0.37	0.02	.96**	.97**	-.96**	.97**	.95**	.97**	-.63	.95**		

** Significant at the 0.01 probability level.

Table 2. December 10, 1975, LANDSAT digital data, vegetation indices, and sampled herbaceous biomass for 8 sites within a 81,000 ha rangeland study area. Sun elevation was 32 and sun azimuth was 145; digital data were corrected for sun angle before calculation of vegetation indices. Estimated herbaceous biomass was calculated using BIOMASS = -297 + 253PVI. Negative biomass estimates were entered as zero.

Rangeland Site	Site Number	LANDSAT MSS BANDS				VEGETATION INDICES								Herbaceous Biomass Production	
		MSS4	MSS5	MSS6	MSS7	TVI	TVI6	RVI	PVI	PVI6	DVI	SBI	GVI	SAMPLED	ESTIMATED
		- -Digital Counts- -												- -kg/ha- -	
Tight Sandy Loam															
Improved Grass	(1)	21	27	39	20	0.59	0.83	1.35	8	8	21	54	12	2100	1727
Alicia Grass	(2)	24	33	45	22	0.54	0.80	1.52	7	8	19	64	12	1632	1474
Coastal Sand															
Native Grass	(3)	20	24	36	18	0.58	0.83	1.38	7	8	18	50	11	1664	1474
Deep Sand															
Improved Grasses	(4)	23	31	42	21	0.55	0.81	1.49	7	8	19	59	12	--	1474
Salty Flat															
Native Grasses	(5)	22	25	42	20	0.63	0.86	1.24	9	12	24	56	14	414	1980
Soils															
Tidal Flats	(6)	36	44	50	21	0.37	0.75	2.13	2	5	6	79	5	0	209
Cropland	(7)	21	27	28	12	0.34	0.72	2.26	1	2	2	45	1	0	0
Sand Dunes	(8)	63	95	100	40	0.29	0.72	2.41	0	7	0	156	7	0	0
SIMPLE CORRELATION WITH BIOMASS (r)		-0.53	-0.47	-0.37	-0.22	.74*	.67	-.76*	.74**	.39*	.73**	-.44	.67**		

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Table 3. July 31, 1976, LANDSAT digital data, vegetation indices, and sampled herbaceous biomass for 8 sites within a 81,000 ha rangeland study area. Sun elevation was 55 and sun azimuth was 95; digital data were corrected for sun angle before calculation of vegetation indices. Estimated herbaceous biomass was calculated using BIOMASS = -297 + 253PVI. Negative biomass estimates were entered as zero.

Rangeland Site	Site Number	LANDSAT MSS BANDS				VEGETATION INDICES								Herbaceous Biomass Production	
		MSS4	MSS5	MSS6	MSS7	TVI	TVI6	RVI	PVI	PVI6	DVI	SBI	GVI	SAMPLED	ESTIMATED
		- -Digital Counts- -												- -kg/ha- -	
Tight Sandy Loam															
Improved Grass	(1)	21	19	57	28	0.84	1.00	0.66	19	27	49	62	31	4720	4510
Alicia Grass	(2)	24	25	53	25	0.71	0.92	1.00	14	20	36	64	23	4414	3245
Coastal Sand															
Native Grass	(3)	26	30	46	21	0.56	0.84	1.47	7	11	19	63	13	2422	1474
Deep Sand															
Improved Grass	(4)	25	27	50	23	0.64	0.89	1.19	11	16	28	64	19	1926	2486
Salty Flat															
Native Grass	(5)	27	28	48	21	0.60	0.87	1.33	9	14	23	63	15	487	1980
Soils															
Tidal Flat	(6)	37	45	55	22	0.40	0.77	2.02	3	8	9	83	9	0	462
Cropland[1]	(7)	23	24	55	26	0.73	0.94	0.92	15	22	39	64	26	--	--
Sand Dunes	(8)	56	81	84	32	0.26	0.72	2.53	-2	-5	-4	134	4	0	0
SIMPLE CORRELATION WITH BIOMASS (r)		-0.70	-0.67	-0.33	-0.10	.86*	.86*	-.84*	.87*	.82*	.88*	-.57	.89*		

[1] For this date, sorghum was still present in the training sites for cropland.

* Significant at the 0.05 probability level.

Table 4. September 23, 1976, LANDSAT digital data, vegetation indices, and sampled herbaceous biomass for 8 sites within a 81,000 ha rangeland study area. Sun elevation was 48 and sun azimuth was 124; digital data were corrected for sun angle before calculation of vegetation indices. Estimated herbaceous biomass was calculated using BIOMASS = -297 + 253PVI. Negative biomass estimates were entered as zero.

Rangeland Site	Site Number	LANDSAT MSS BANDS				VEGETATION INDICES								Herbaceous Biomass Production	
		MSS4	MSS5	MSS6	MSS7	TVI	TVI6	RVI	PVI	PVI6	DVI	SBI	GVI	SAMPLED	ESTIMATED
		- -Digital Counts- -												- -kg/ha- -	
Tight Sandy Loam															
Improved Grass	(1)	22	22	51	25	0.74	0.94	0.91	14	20	37	60	24	4336	3245
Alicia Grass	(2)	25	27	50	24	0.67	0.90	1.10	12	16	32	63	20	2140	2739
Coastal Sand															
Native Grass	(3)	25	29	44	20	0.57	0.85	1.42	8	11	20	60	13	1434	1727
Deep Sand															
Improved Grass	(4)	24	27	44	20	0.60	0.87	1.32	8	12	22	58	15	1306	1727
Salty Flat															
Native Grass	(5)	25	26	44	20	0.60	0.87	1.34	8	13	21	58	14	678	1727
Soils															
Tidal Flat	(6)	37	45	52	19	0.31	0.75	2.36	0	5	1	80	4	0	0
Cropland	(7)	27	33	41	17	0.44	0.78	1.88	4	6	9	61	7	0	715
Sand Dunes	(8)	56	82	85	32	0.26	0.72	2.53	-2	-5	-4	135	5	0	0
SIMPLE CORRELATION WITH BIOMASS (r)		-0.55	-0.55	-0.20	0.19	.83*	.86*	-.81*	.86*	.81*	.87*	-.42	.93*		

* Significant at the 0.05 probability level.

ORIGINAL PAGE IS OF POOR QUALITY

Table 5. Regression analysis of total standing herbaceous biomass (BIOMASS) with the perpendicular vegetation index (PVI) determined from LANDSAT MSS bands 5 and 7 for four LANDSAT overpass dates individually and all dates combined.

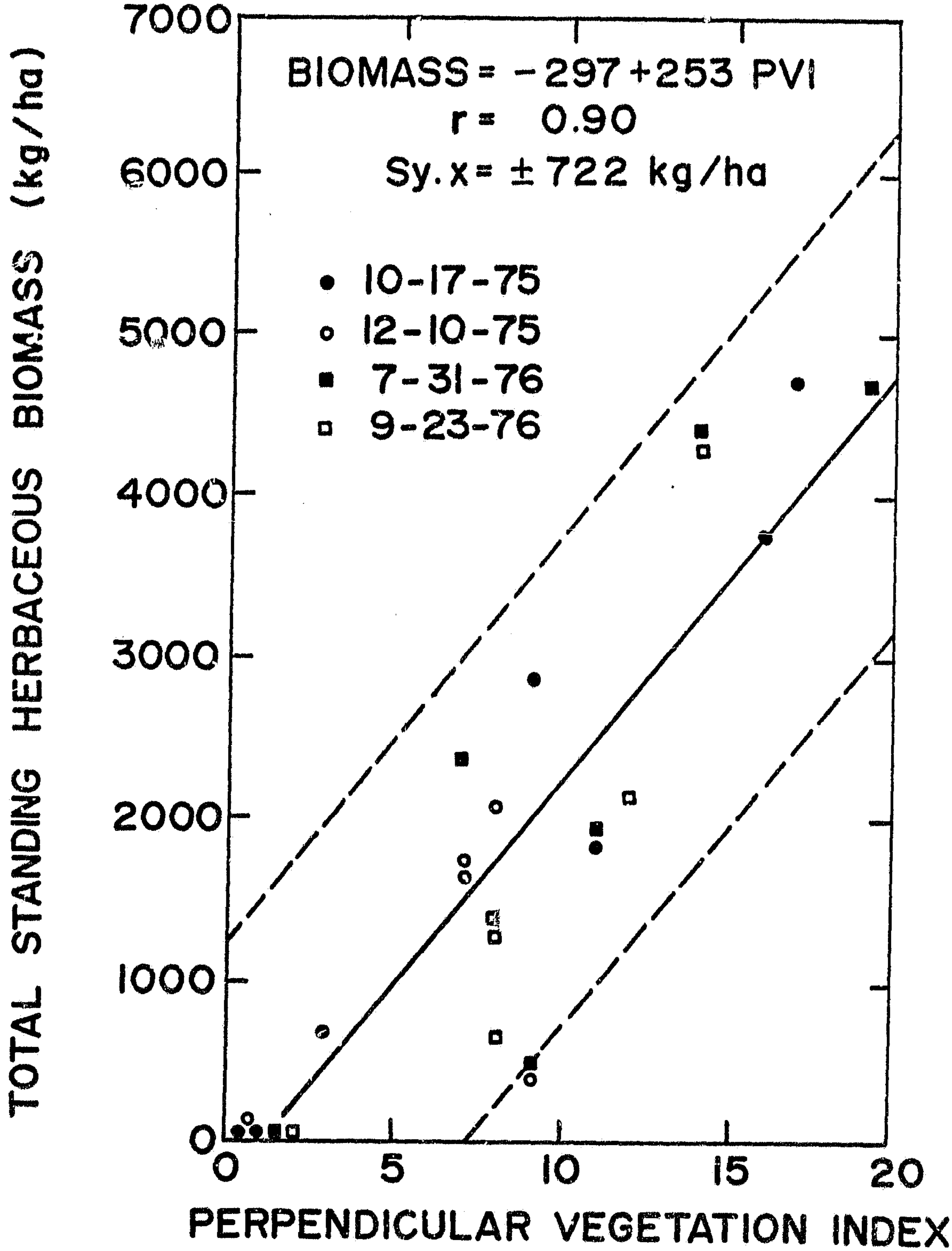
LANDSAT OVERPASS DATE	LINEAR REGRESSION EQUATION	r	Sy.x (kg/ha)
10/17/75	BIOMASS = -370 + 277 PVI	0.97	527
12/10/75	BIOMASS = -71 + 186 PVI	0.74	684
7/31/76	BIOMASS = -180 + 250 PVI	0.87	1063
9/23/76	BIOMASS = -264 + 231 PVI	0.86	812
ALL DATES COMBINED	BIOMASS = -297 + 253 PVI	0.90	722

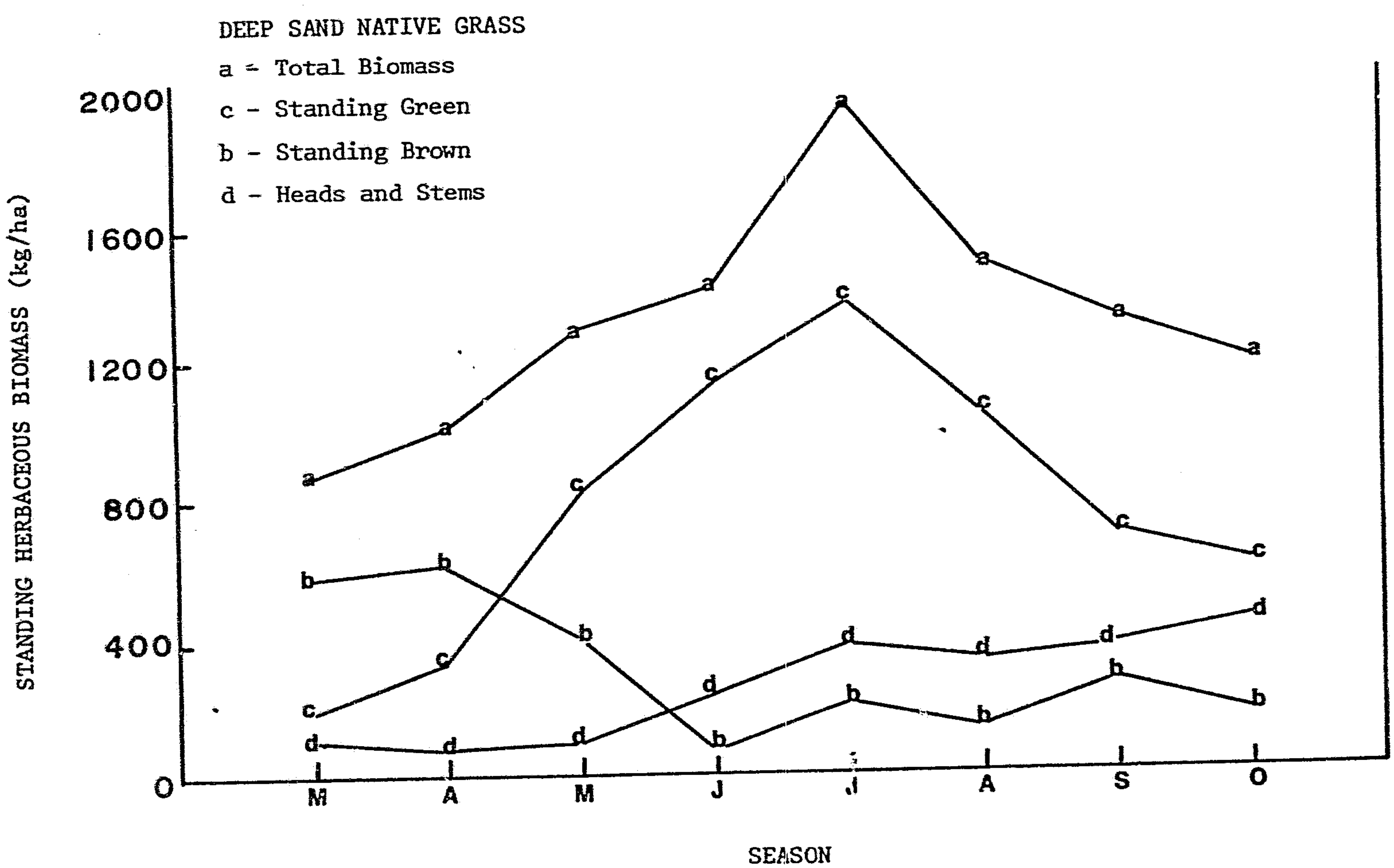
FIGURE CAPTIONS

Figure 1. Overall regression (solid line) of total standing herbaceous biomass collected on October 17 and December 10, 1975, and July 31 and September 23, 1976, with the perpendicular vegetation index determined from LANDSAT MSS bands 5 and 7.

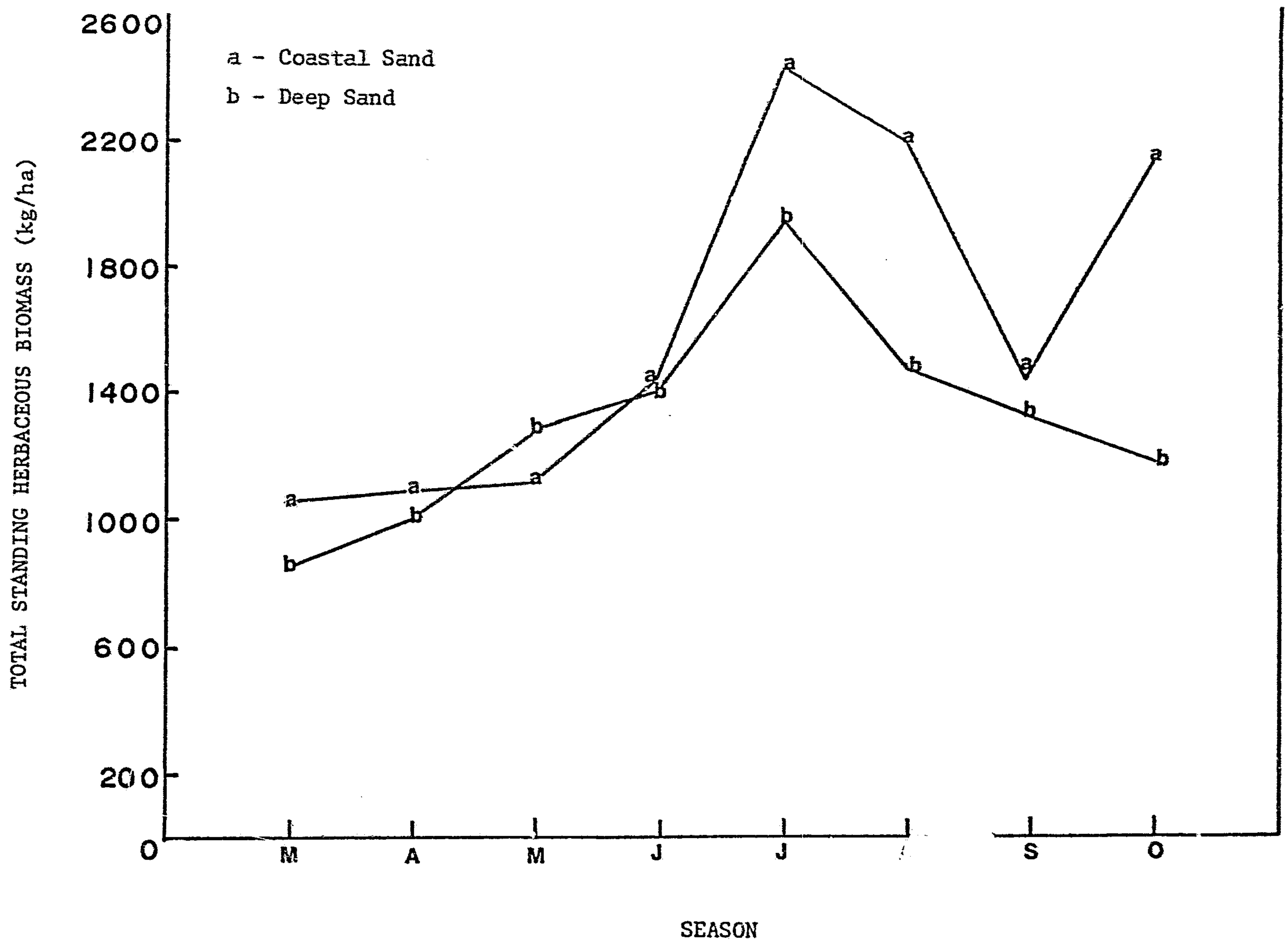
Figure 2. Temporal plot of total, standing green, standing brown, and heads and stem herbaceous biomass collected for a coastal sand native grass range site, located in south Texas, for the 1976 growing season.

Figure 3. Temporal plot of total standing herbaceous biomass for medium (coastal sand native grass) and low (deep sand improved grass) productive forage range sites in south Texas for the 1976 growing season.


BIOMASS = -297 + 253 PVI
r = 0.90
Sy.x = ± 722 kg/ha
10-17-75
12-10-75
7-31-76
9-23-76
TOTAL STANDING HERBACEOUS BIOMASS (kg/ha)
PERPENDICULAR VEGETATION INDEX
0
1000
2000
3000
4000
5000
6000
7000
0
5
10
15
20



DEEP SAND NATIVE GRASS
a = Total Biomass
c - Standing Green
b - Standing Brown
d - Heads and Stems
STANDING HERBACEOUS BIOMASS (kg/ha)
2000
1600
1200
800
400
0
M
A
M
J
J
A
S
O
SEASON



a - Coastal Sand
b - Deep Sand
TOTAL STANDING HERBACEOUS BIOMASS (kg/ha)
2600
2200
1800
1400
1000
600
200
0
M
A
M
J
J
S
O
SEASON