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1987 PASTURE ASSESSMENT EARLY WARNING SYSTEM

RESEARCH ON SATELLITE-BASED PASTURE ASSESSMENT IMPLEMENTATION TECHNIQUES

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NIGER INTEGRATED LIVESTOCK PROJECT

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Bruce Wylie
John Harrington, Jr.
Rex Pieper

CENTER FOR INTERNATIONAL PROGRAMS
New Mexico State University
Box 30001, Dept. 3567
Las Cruces, NM 88003
USA

Ali Maman
Issa Denda

REPUBLIC OF NIGER
MINISTRY OF ANIMAL AND WATER RESOURCES
Niamey, Rep. of Niger

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SUMMARY

The objective of this report is to present analysis conducted to determine appropriate and efficient analysis and sampling methods for the development on a cost-effective, timely satellite-based pasture assessment drought early warning system in Niger. Standing herbage estimates were obtained from 23-22 ground control stations (each 100 km^2) in 1986 and 1987. Standing herbage estimates were then combined with NOAA-9 satellite-based LAC NDVI values for the same ground control stations. NDVI composite periods ranging from 2-8 days were generated for the 1986 an 1987 rainy seasons, yielding 12-13 composite periods for each growing season. Two variations of NDVI were evaluated, maximum and integrated NDVI. Integrated NDVI was recommended for standing herbage estimation. The integrated NDVI-standing herbage regression for 1987 was not significantly different between ecological zones. Although there was no significant difference between the integrated NDVI-standing herbage regression among years, degrees of freedom were sufficient to allow 1986 and 1987 to be analyzed separately. Inverse predictions were used to convert or "calibrate" satellite integrated NDVI to standing herbage in 1986 and 1987. Ninety-five percent confidence intervals for inverse predictions of average values indicated that standing herbage classes in increments of about 400 kg/ha were appropriate for NOAA LAC-based average standing herbage estimates.

Integrated NDVI was tested on the 1987 data set using a coarse resolution NDVI, currently used by Niamey's AGRHYMET center. This regression had a lower intercept value than the regression established using LAC data and 10-by-10 km sites.

The effects of a smaller site size on the maximum NDVI-standing herbage regression were evaluated. A site size of 25 km^2 was recommended. This site size would add a small amount of variation to the regression but would allow more sites to be sampled. The advantage of a larger number of sites was hypothesized to more than compensate for the slight inaccuracies associated with the smaller site size. A sampling scheme for the 25 km^2 sites was proposed for the 1988 rainy season.

1. INTRODUCTION

The Niger Integrated Livestock Production Project (NILPP) has been working since 1983 toward the development of a cost effective, Niger-based and operated pasture assessment early warning system. This sustainable system would inform the Government of Niger (GON) of impending forage surpluses and deficits in the pastoral zone of Niger. It would assist the GON in presenting quantified information to prospective donor countries on the magnitude and extent of a drought. An annual timely standing herbage map would serve as a basis for natural resource, management, and policy decisions in good years as well as bad. Standing herbage maps could be combined with other information sources such as market, epidemiology, and human health to assist in decision making processes.

Satellite (NOAA-9) information which displays the geographic variation in standing herbage can be obtained for large areas with minimal costs. Both the satellite-based reflectance data (NDVI) and standing herbage data (kg/ha) are needed from 20-40 sites to merge ground-based standing herbage measurements with satellite values. The relationship between satellite NDVI and standing herbage data established for these sites can then be used to convert or "calibrate" satellite values across the whole region to their equivalent standing herbage.

The pasture assessment early warning system was initially undertaken by the International Livestock Centre for Africa (ILCA). In 1985, ILCA produced the first satellite-based standing herbage map of the project zone. New Mexico State University staff members assisted in ground sampling procedures and implementation. In 1986, contract problems developed with ILCA. GON and NMSU were forced to make the appropriate ground sampling protocol modifications that would allow a satellite-based standing herbage map to be produced for 1986 without the use of the ILCA airplane. Later, NMSU carried out the technical assistance associated with the pasture assessment early warning system for both remote sensing and ground-based data sets.

This 1987 final report presents the results of analysis conducted to determine the most efficient yet reliable means for continuing the pasture assessment program in Niger. After the 1988 rainy season, additional protocol modifications may be recommended in an attempt to further minimize costs after the end of project funding in December 1988. NMSU has proposed project continuation to supply technical support for Niger's fledgling remote sensing capabilities.

2. STANDING HERBAGE

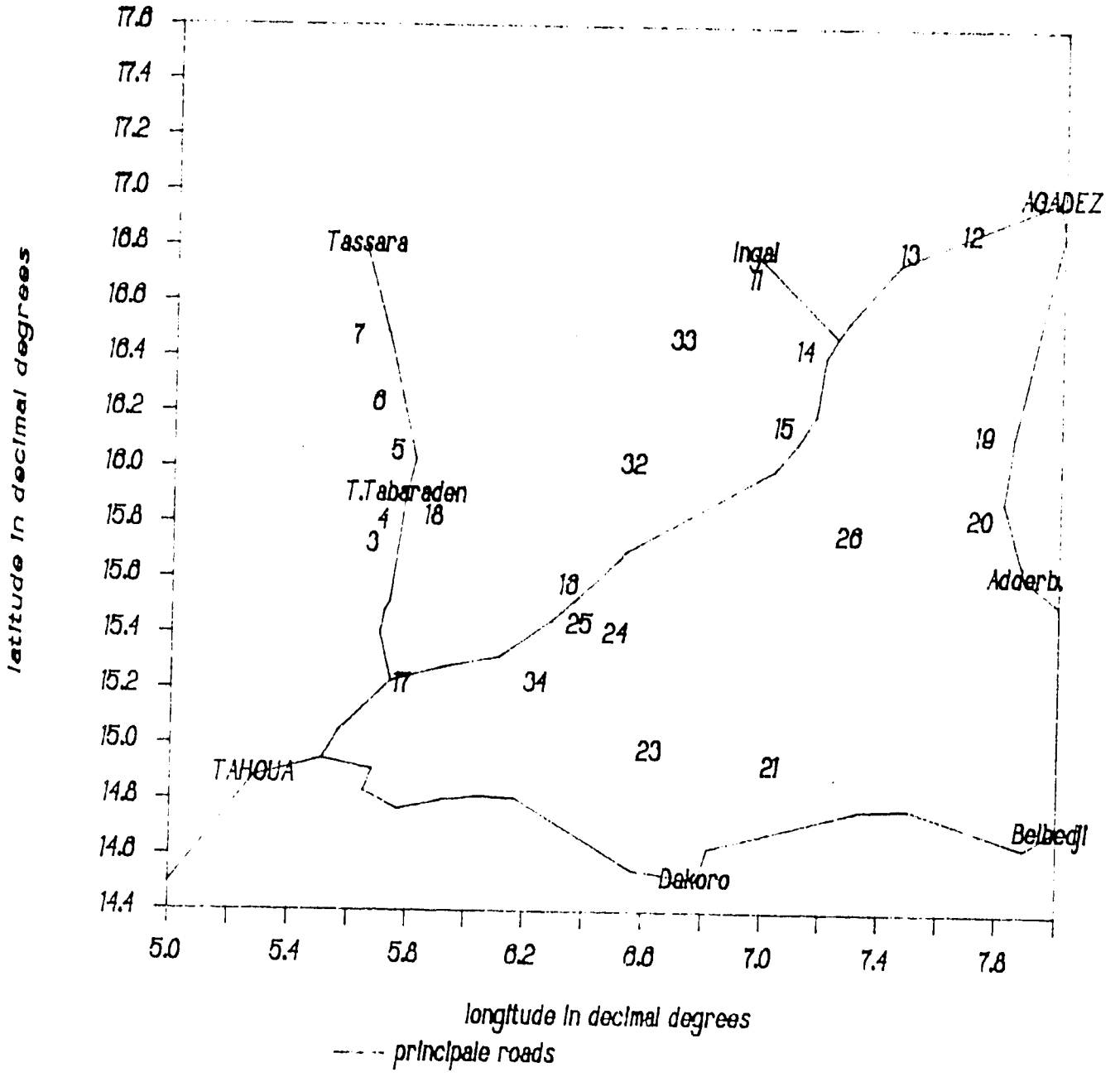
2.1. Methods

The use of regression analysis to establish the relationship between standing herbage and satellite vegetation indices necessitates 20 to 40 different "ground truth" locations where both satellite and standing herbage data are available. The sites within the NILPP zone were established in 1983-1984. These sites were chosen for uniformity and to represent the major range types within the project zone as mapped by Milligan (1982). The site locations within the project zone and the respective site numbers are

displayed in Figure 1.

FIGURE 1

SITE LOCATIONS WITHIN THE PROJECT ZONE



One of the primary goals of a standing herbage early warning system is to predict regional deficits or surpluses in pasture herbage standing crop during the subsequent 9-month dry season. Previous studies have shown that peak herbage standing crop or gross primary production can be correlated to either maximum or integrated vegetation indices[1] (de Wispelaere et al. 1985, Tucker and Sellers 1986, Tucker et al. 1985, Wagenaar and de Ridder 1987). Due to the variability of the rains in the Sahel, the time of actual and anticipated peak standing crop may vary as much as 3-4 weeks. The period when maximum standing herbage occurs on a particular site could be in either August or September, occasionally even in July or October. Ground sampling attempts to document peak standing crop at each site thus, several sampling dates for each site help insure a better estimate of peak standing crop on each site. Two to three sampling trips have traditionally been employed in the NILPP zone covering periods in August, September, and October. In 1986, there were three sampling trips and four in 1987 (Table 1). In 1987, the October sampling was only of selected sites where late rains were anticipated to have caused additional late season pasture growth.

TABLE 1

RAINY SEASON SAMPLING DATES IN 1986 AND 1987

Aug 1-12, 1986	Aug 12-20, 1987
Sep 9-19, 1986	Aug 28-Sep 8, 1987
Oct 14-24, 1986	Sep 18-28, 1987
	Oct 19-23, 1987

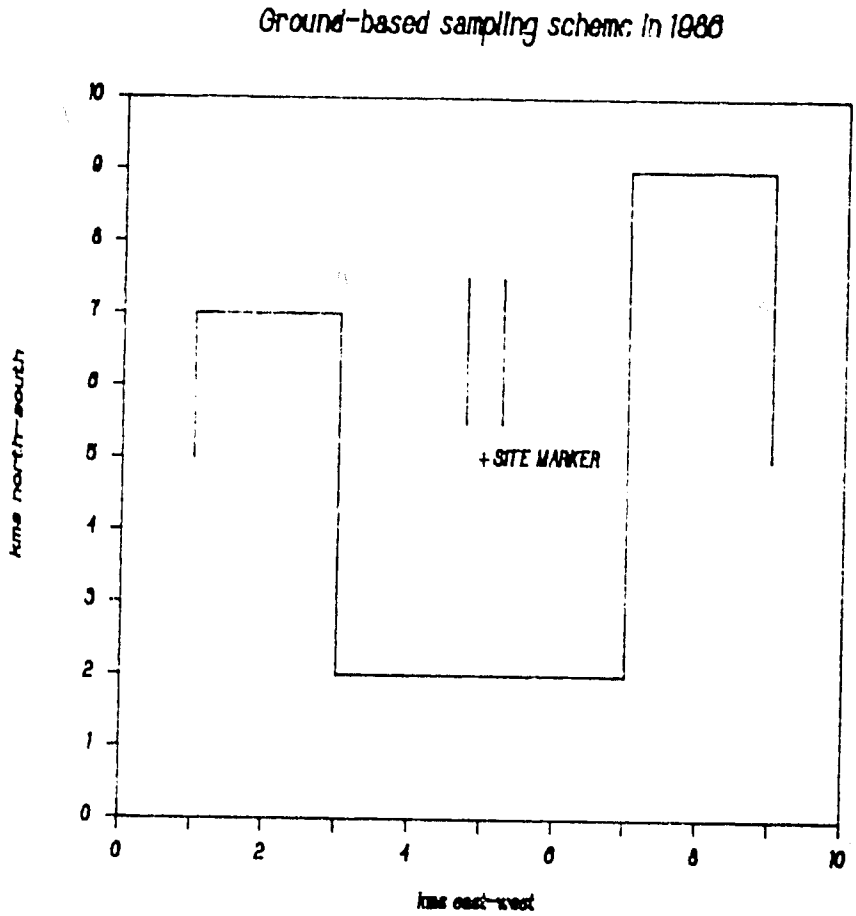
2.1.1. 1986

The 1985 NILPP correlations between standing herbage and satellite reflectance-based vegetation index indicated that a minimum site size of a 100 km^2 was desirable (Wagenaar and de Ridder 1987). Ground standing herbage estimated in the 1986 and 1987 rainy seasons was obtained for 23 sites. Each 100 km^2 site was sampled for standing herbage by sampling quadrates along transects.

In 1986, the sampling scheme involved a 26 km zig-zag transect and two 2 km transects (see Figure 2). The smaller 2 km transects reflected the exact sampling scheme employed in 1985. These were maintained to preserve continuity in the data between 1985 and 1986. These two smaller transects represent the <u>original site</u> and the 26 km zig-zag transect was added to obtain a representative sample from the adjacent area (the <u>adjacent site</u>), insuring that the biomass estimate was representative of the 10-by-10 km site.

[1] Maximum and integrated vegetation indices will be explained in the satellite section of this report.

FIGURE 2


Ground-based sampling scheme in 1988
+ SITE MARKER
kms north-south
kms east-west
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10

2.1.1.1. The original site

The two 2 km transects of the original site had 6 random locations along each of the two transects. At each stop 5 plots (0.5 m^2) were sampled with double sampling[2] which combines ocular estimates with actual measured plot values (usually production). Each plot was ocularly estimated for percent herbaceous cover and herbaceous production in grams[3]. Randomly, 1 out of every 10 plots was clipped and air dry weight was obtained. A linear regression analysis was performed between estimated (independent variable) and actual air dry plot weights (dependent variable) for each estimator in each sampling period. The improvement concept was used to test if the relation between estimated and actual air dry weight was consistent among all sites estimated by the same individual during a sample period. Tests for possible differences among sites included differences in both regression intercepts and slopes. If a site was found to be significantly different, then a separate regression was performed for that site. The mean standing crop for all estimated values for the original site, corrected by their respective regressions, determined the standing herbage estimate for the original site.

2.1.1.2. The adjacent site

Along the 26 km transect, systematic stops were made every 0.3 km and visual estimates of standing herbage were obtained from the vehicle. Vehicle-based estimations were for a 10-by-10 m area on the right side of the vehicle. A randomly selected sub-sample of these vehicle estimates (10% of the vehicle estimates) were sampled with plot placements. If a vehicle estimate was sampled, 9 plots were placed in the 10-by-10 m area from which the vehicle-based estimate was made. Each plot (0.5 m^2) was then sampled using double sampling.

The 26 km transect had a total of 90 vehicle-based estimations, 9 of which were also sampled with plots. The vehicle-based estimations were used to stratify each site into three groups: low, medium, and high production. A frequency analysis of the vehicle-based estimates was used to determine the stratification groups for each site. Roughly 30% of the vehicle-based estimates were assigned to both the low and high production groups while the medium group received the remainder, usually around 40%. The plots associated with the vehicle-based estimates in each stratification group

[2] Double sampling is a technique used in vegetation sampling (Cook and Stubbendieck 1986) which combines visual estimates with actual air dry weights. A larger number of estimated plots are obtained because a minimum of time is required to estimate plot characteristics. All the estimated plot weights can then be corrected to their equivalent air dry weights using regression analysis on the clipped and estimated plot weights.

[3] During the late August or early September sampling period, percent composition by weight of each species in the plot was also estimated in addition to cover and production.

were used to determine production levels for each stratification via double sampling. The overall average production for each adjacent site was an average production across the three stratification groups weighted by the approximate area represented by each stratification group (i.e., the percent of vehicle-based estimates falling in each respective group).

2.1.1.3. Complete site

The original site provided a standing herbage estimate which was considered representative of the 10 km^2 surrounding and north of the original site. The adjacent site provided a standing herbage estimate which represented the remaining 90 km^2. The overall site average standing herbage was the average weighted by areas that the original and adjacent sites represented.

2.1.2. 1987

Due to both the complexity of the analysis and the lack of randomization of the adjacent site's 26 km transect, the 1986 sampling procedures were modified in 1987. After extensive analysis of the 1986 data, a hierarchial randomization of transects was chosen for 1987. The original site was eliminated and the 10 by 10 km site was divided into 4 equal quarters each 5 by 5 km (see Figure 3). Within each quarter a randomly located 5 km north-south transect was located. Along each transect 3 random 1 km^2 areas were chosen which straddled the transect. These 1 km^2 areas were called pixels[4] because they corresponded to the approximate pixel size from the NOAA satellite data sets which were used in this study. Within each pixel there were 15 plots sampled with the double sampling technique[5]. These plots (0.5 m^2) were divided into three groups or clusters of 5 plots each. Thus one site had 4 transects, 3 pixels per transect, 3 clusters per pixel, and 5 plots per cluster giving 180 plots per site.

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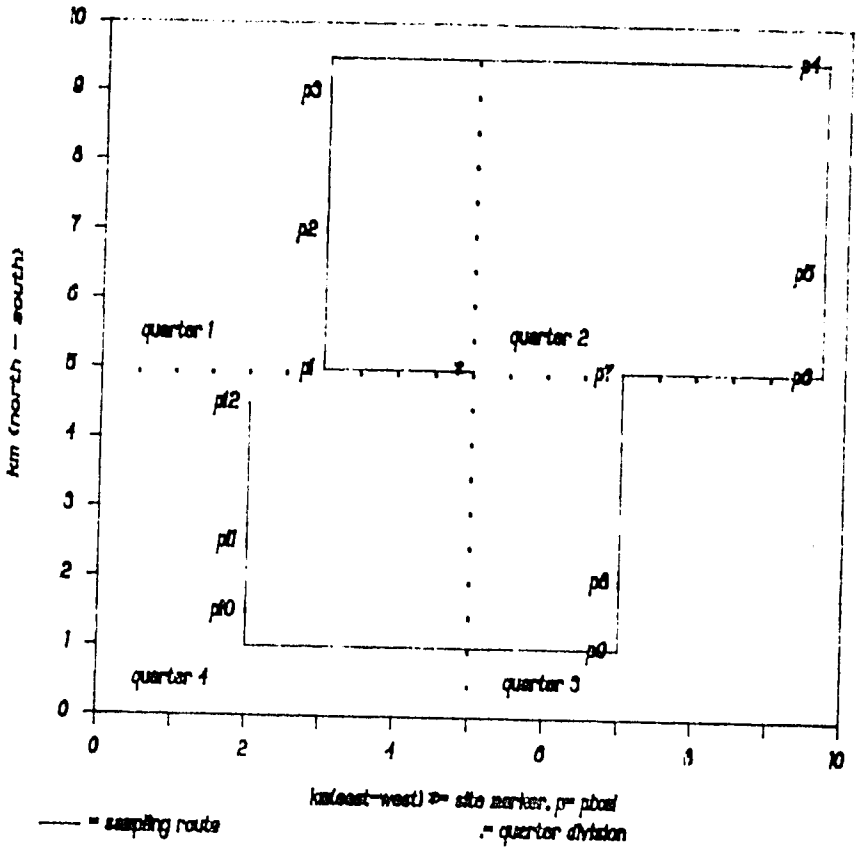
[4] Pixel (or picture element) is the area on the ground (1.1 by 1.1 km) represented by one NOAA satellite data measurement.

[5] The selection of clipped plots was stratified into low and high production. One out of five was clipped from the high production plots and one out of eleven was clipped from the low production plots. This was to insure that clipped plots represented the regression all along the regression line. The division between low and high production was estimated at the beginning of each site so that roughly 30% of the estimated weights would fall in the high production group.

FIGURE 3

1987 SITE SAMPLING SCHEME



2.2. Results

2.2.1. Double Sampling

The double sampling regressions were used to convert the average estimated plot weight for a site to equivalent plot air dry weight. Table 2 and 3 show the adjusted r^2 (the percent of the variation in air dry weights explained by the estimated weights) and the standard error of the regression. The regression statistics presented in table 2 and 3 are from the regression equations used at each respective site for peak standing crop determination.

Weighted least squares were employed in regression calculations due to evidence of heterogeneity of the variance. Generally, plots with high biomass amounts are harder to estimate than plots with low biomass amounts. A weighting term of the reciprocal of the plot estimated weight was used. This made plots with high estimated weights have less weight on the regression than plots with low estimated weights.

TABLE 2

DOUBLE SAMPLING REGRESSION STATISTICS
FOR 1987 PEAK STANDING CROP AT EACH SITE
EXCLUDING OCTOBER SAMPLINGS

REGRESSION	ADJUSTED R^2	$G/0.5m^2$ ST. ERROR	WEIGHTED
Early Sep. 87			
Northern team			
site 13	.77	5.2	no
Southern team			
site 23	.66	2.0	yes
sites 21,24,25,34	.82	1.3	yes
Late Sep. 87			
Northern team			
site 16	.90	1.3	yes
site 26	.86	1.4	yes
site 32	.93	0.5	yes
sites 12,14,15 17,19,20,33	.87	1.4	yes
Southern team			
site 6	.72	0.9	yes
sites 3,4,5,7,18	.82	1.0	yes

TABLE 3

DOUBLE SAMPLING REGRESSION STATISTICS
FOR 1986 PEAK STANDING CROP AT EACH SITE

REGRESSION	ADJUSTED R^2	ST. ERROR	WEIGHTED
Aug.			
northern team			
site 15	.96	6.2	no
site 32	.93	7.7	no
Sept.			
northern team			
site 12	.68	2.7	yes
site 13	.80	1.2	yes
site 17	.77	1.6	yes
site 19	.64	2.1	yes
southern team			
site 4	.53	2.1	yes
site 21	.75	1.9	yes
site 23	.47	3.0	yes
site 34	.75	1.5	yes
sites 3,6,24,25	.75	1.5	yes
Oct.			
northern team			
site 20	.95	1.8	yes
site 26	.58	2.5	yes
sites 11,14,16,33	.81	1.8	yes
southern team			
site 7	.73	3.2	yes
sites 5,28,25	.82	2.1	yes

2.2.2. Standing herbage estimates

The average standing herbage estimates for the sites in 1986 and 1987 are presented in Tables 4 and 5. The 1986 means changed substantially on some sites from the values reported in the 1986 early warning system report (Wylie 1986) because the analysis procedures were different. For the 1986 report, a vehicle-based estimate to cluster average plot weight regression was used. In the 1987 analysis, the vehicle-based estimates were used to stratify each site into three groups. The stratification procedure was generally considered the more appropriate analysis.

These standing herbage estimates were then paired with the respective satellite-based NDVI indices for regression analysis. The next section describes how the satellite-based NDVI indices for each site were computed.

TABLE 4

STANDING HERBAGE ESTIMATES FOR EACH SITE IN 1986*

SITE	AUG 86	SEP 86	OCT 86	PEAK 1986
3	563	816	566	816
4	664	860	467	860
5	283	279	480	480
6	446	545	412	545
7	281	357	370	370
12	62	356	295	356
13	86	267	202	267
14	67	151	245	245
15	629	327	260	629
16	370	424	876	876
17	335	1194	1060	1,194
18	430	885	943	943
19	88	365	365	365
20	506	622	924	924
21	1112	1610	861	1,610
23	746	885	806	885
24	334	771	582	771
25	328	405	460	460
26	1107	611	1162	1,162
32	433	389	346	433
33	580	527	1544	1,544
34	503	1468	843	1,468

TABLE 5

STANDING HERBAGE VALUES* AS THEY CHANGED THROUGHOUT THE 1987 RAINY SEASON

SITE	AUG 87	EARLY SEP 87	LATE SEP 87	OCT 87	PEAK 87
3	34	114	192	318	318
4		33	162	267	267
5	46	60	93	217	217
6	35	92	110	301	301
7	26	27	61	188	188
12	0	7	27		27
13		44	37		44
14	0	7	28		28
15	0	9	50		50
16	42	212	701		701
17	113	474	1,003		1003
18	25	93	240	404	404
19	7	194	323		323
20	64	191	287		287
21	445	916	680		916
23	548	1948	956	1486	1948
24	137	588	273		588
25	116	524	409		524
26	116	109	319		319
32	9	24	143	194	194
33	53	28	69		69
34	202	697	501		697

* Blank values indicate sites which were not sampled.

3. SATELLITE

3.1 Methods

The satellite selected for pasture assessment in the Sahel was the NOAA meteorological satellite. This polar orbiting satellite gives a high temporal frequency of satellite coverage which is needed to monitor the dynamic Sahelian vegetation during the short 3-4 month rainy season. Higher frequency of satellite coverage also allows effective removal of cloud cover by overlaying (compositing) satellite coverage from previous and/or later dates. The NOAA satellite has the Advanced Very High Resolution Radiometer (AVHRR) on board which monitors reflectance in the visible (Channel 1), near-infrared (Channel 2), mid-infrared (Channel 3), and thermal (Channels 4 and 5) bands. The highest resolution provided by AVHRR is Local Area Coverage (LAC) where the instantaneous field of view (pixel) corresponds to

a 1.1 by 1.1 km box on the ground at nadir. This resolution appears to be adequate for a Niger pasture assessment early warning system. This relatively coarse resolution[6] means smaller satellite data sets for a given region, thus making satellite data analysis for the entire country of Niger manageable. The NOAA satellite data sets provide low cost coverage and relatively fast delivery time to the user. A receiving station for the NOAA satellites is being installed at Niamey's AGRHYMET center. This will further facilitate a timely and cost effective satellite data source for Niger and other Sahelian countries.

During the week of February 15th the NMSU technical assistance members visited C.J. Tucker, C.O. Justice, and S.D. Prince at the Laboratory for Terrestrial Physics, NASA/Goddard Space Flight Center, Maryland. The object of this visit was to review NILP project activities, discuss future research objectives, acquire 1986 and 1987 AVHRR data sets for the project zone, and conduct preliminary analysis of the LAC data sets for the NILPP zone.

Based on consultations with Tucker, Justice and Prince, the decision was made to base pastoral assessment on the Normalized Difference Vegetation Index (NDVI). Though our preliminary report (Wylie et al., 1987) proposed the use of a soils background calibration and perpendicular vegetation indices, it was felt that NDVI was reliable, simple, and widely used. Therefore, NDVI appeared to be the most appropriate for an application oriented early warning system.

NDVI, which can be thought of as a "greenness" index, capitalizes on the strong absorption of visible light (particularly light in the red wavelengths) and strong reflectance of light in the near infrared by actively growing vegetation. The formula for NDVI is:

$$\text{NDVI} = \frac{\text{infrared} - \text{visible}}{\text{infrared} + \text{visible}} \quad \text{or NDVI} = \frac{\text{Channel 2} - \text{Channel 1}}{\text{Channel 2} + \text{Channel 1}}$$

NDVI values range from -1 to +1. Clouds and water have negative NDVI values, bare ground and rock have NDVI values near zero, and increasing vegetation gives increasing NDVI over and above zero. NDVI tends to compensate for changing illumination conditions, terrain irregularities, and variation in viewing angles (Matson and Parmenter-Holt 1985).

Research has shown that plant production can be correlated with maximum NDVI (the highest NDVI value found for each pixel location throughout the growing season) and integrated NDVI (averaged NDVI across the growing season weighted by the time interval each NDVI value represents) (Tucker et al. 1985, Wagenaar and de Ridder 1987, Hiernaux and Justice 1986, Goward et al. 1985).

The preliminary analysis of the AVHRR data sets employed a thermal cloud mask (Channel 5) to identify cloud cover. AVHRR data can be matched to ground locations based on satellite tracking data. An individual pixel

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[6] Other satellites such as Landsat TM and Spot have better spatial resolutions; 30 by 30 m and 10 by 10 m respectively.

may be off in actual location by as much as 5-10 kms. Super registration improves this geographic position to within 1-2 kms. After super registration, satellite coverages were composited in 2 - 8 day periods. Compositing selects the highest NDVI value at each pixel location over the composite period. This technique minimizes cloud contamination, shadow effects, off nadir viewing effects, directional reflectance, and aerosol and water-vapor effects (Holben 1986).

A 9 by 9 pixel box (9.9 by 9.9 km) centered on the best estimate of the legal description of each ground truth site or ground data collection site was generated for each composite period. The mean NDVI and the standard deviation were generated for each site and each composite period.

3.2 Results

The dates of the composite periods in 1986 and 1987 are presented in Table 6. October 1986 satellite data were not available due to a malfunction on board the satellite.

TABLE 6

COMPOSITE DATES FOR 1986 AND 1987 SATELLITE DATA SETS

1987	1986
07-Jul - 13-Jul	06-Jul - 09-Jul
15-Jul - 16-Jul	15-Jul - 18-Jul
19-Jul - 25-Jul	23-Jul - 27-Jul
30-Jul - 02-Aug	01-Aug - 05-Aug
08-Aug - 11-Aug	12-Aug - 16-Aug
16-Aug - 22-Aug	20-Aug - 22-Aug
26-Aug - 28-Aug	25-Aug - 26-Aug
06-Sep - 13-Sep	31 Aug - 03-Sep
17-Sep - 19-Sep	12-Sep - 13-Sep
22-Sep - 25-Sep	16-Sep - 19-Sep
02-Oct - 07-Oct	26-Sep - 02-Oct
14-Oct - 21-Oct	02-Nov - 02-Nov
30-Oct - 08-Nov	

Average NDVI values for each 9.9 by 9.9 km site from these composite dates were used to calculate maximum and integrated NDVI. Maximum and integrated NDVI were then used in conjunction with site standing herbage in the following section in an attempt to acquire a calibration formula which would convert NDVI to standing herbage.

Contacts were made with other institutions involved in remote sensing in the Sahel to exchange information concerning activities and objectives. Work accomplished with NASA/Goddard in February consisted of satellite data acquisition, satellite analysis, and project briefing. Collaborative work was also done with NASA/Goddard to compare standing herbage-NDVI relationships throughout the Sahel (Prince 1988a). In March, contact was made with Dr. Charles Hutchinson of the Arizona Remote Sensing Center at the

office of Arid Lands Studies to present the project's early warning system activities for inclusion in technical reviews of Sahelian early warning systems. Dr. Gary Johnson (NOAA/University of Columbia, Mo.) visited NMSU in April to present the remote sensing capabilities at Niamey's regional AGRHYMET center. In May, participant trainees received training using the Earth Resources Data Analysis System (ERDAS) digitizer at the University of Nebraska's Advanced Land Management Information Technologies Department and the geographic location of each Arrondissement boundary location in Niger was saved to diskettes for future project use. Further contact with NASA/Goddard in June allowed additional satellite data acquisition and satellite analysis for the participant trainees.

The ERDAS hardware and software satellite analysis system was selected and acquired for project use. ERDAS is microcomputer-based and has analysis capabilities required for NDVI generation, compositing and registration. In addition, modules for reading of satellite data tapes and color map output were purchased. The remote sensing specialist received a three day training course on the use of ERDAS. The remote sensing specialist subsequently gave a two week training program to the participant trainees on the basic use of ERDAS and the specific tasks required by the project.

4. COMBINING STANDING HERBAGE AND SATELLITE NDVI

4.1. Methods

In the standing herbage section of this report it was stated that the objective of the ground sampling was to obtain an estimate of peak standing crop at each site. This was because maximized or time integrated satellite vegetation indices are functionally related to total standing herbage on a site during the rainy season (Tucker and Sellers 1986). Peak standing crop is our best estimate of total rainy season production at a site. Therefore, the regressions presented here use maximum standing herbage found at each site throughout the rainy season as the standing herbage estimate.

There is some debate among remote sensing scientists as to which variable should be the dependent variable in a regression analysis; the satellite vegetation index or standing herbage (Curran and Hay 1986, Prince 1988b, and Wagenaar and de Ridder 1987). The fact that standing herbage drives or determines the satellite reflectance-based vegetation indices (and not vice-versa) suggests that the satellite vegetation index should be the dependent variable (Southward and Clason 1988[a]). This dependent variable determination via the underlying functional relationship should override dependent variable selection based on merely the magnitude of the errors terms associated with standing herbage and the normalized difference vegetation index values. Currently, work is being conducted to investigate an errors-in-variables regression approach to replace standard regression techniques when using ground-based information to "calibrate" satellite data values (Southward and Clason, 1988[b]). In this report, satellite vegetation indices will be treated as the dependent variable and standing herbage as the independent variable in regression analysis due to their functional relationship. Inverse predictions (Neter et al. 1983, p. 172) from the regression were used to calibrate satellite vegetation indices to standing herbage.

The location of some of the sites were changed between 1986 and 1987. All satellite data values for 1986 and 1987 are for the 1987 site locations. The site location changes were greatest for site 7 and 23 which were moved up to 5 kms. Preliminary analysis of the 1986 data sets showed that site 23 was an outlier, not supporting the trend displayed by the other sites. Thus site 23 was removed from the 1986 analysis until satellite values can be obtained for the 1986 site locations.

4.2. Results

4.2.1. Maximum NDVI

Maximum NDVI, as explained in the satellite section of this report, is the highest NDVI (or "greenness") value recorded for a given location (usually by pixel) over a period of time. The peak NDVI values for each location should be strongly correlated to peak standing herbage. Figures 4 and 5 show the different regressions obtained for maximum NDVI in 1986 and 1987. Table 7 shows the 95% confidence intervals for the regression coefficients and the standard error of the regressions. The y intercept's 95% confidence intervals have considerable overlap but the 95% confidence intervals for the slopes barely overlap. The respective estimates for the slope in 1986 and 1987 do not fall within the 1987 and 1986 confidence intervals. Figures 6 and 7 are color maps of maximum NDVI for the 1986 and 1987 rainy seasons.

FIGURE 4

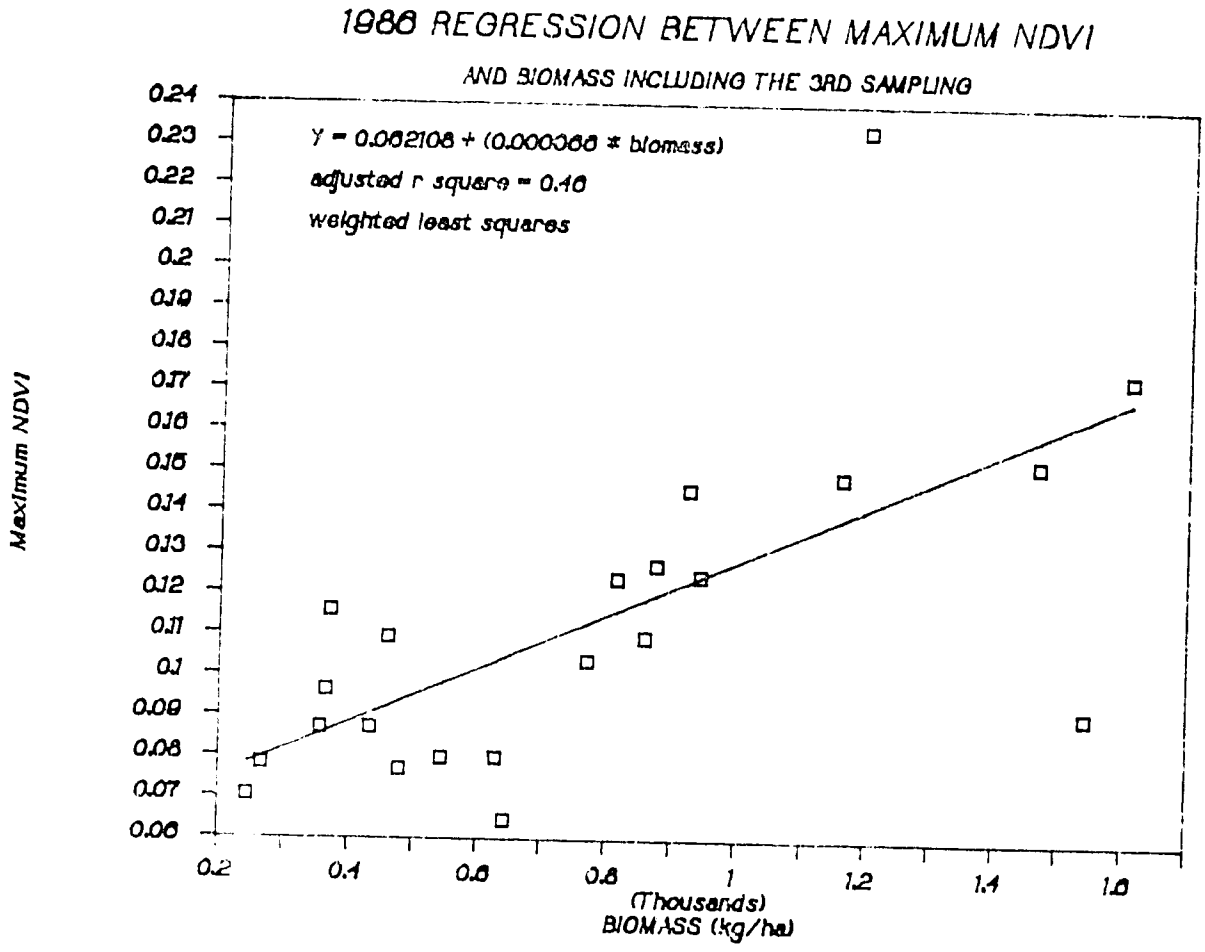


FIGURE 5

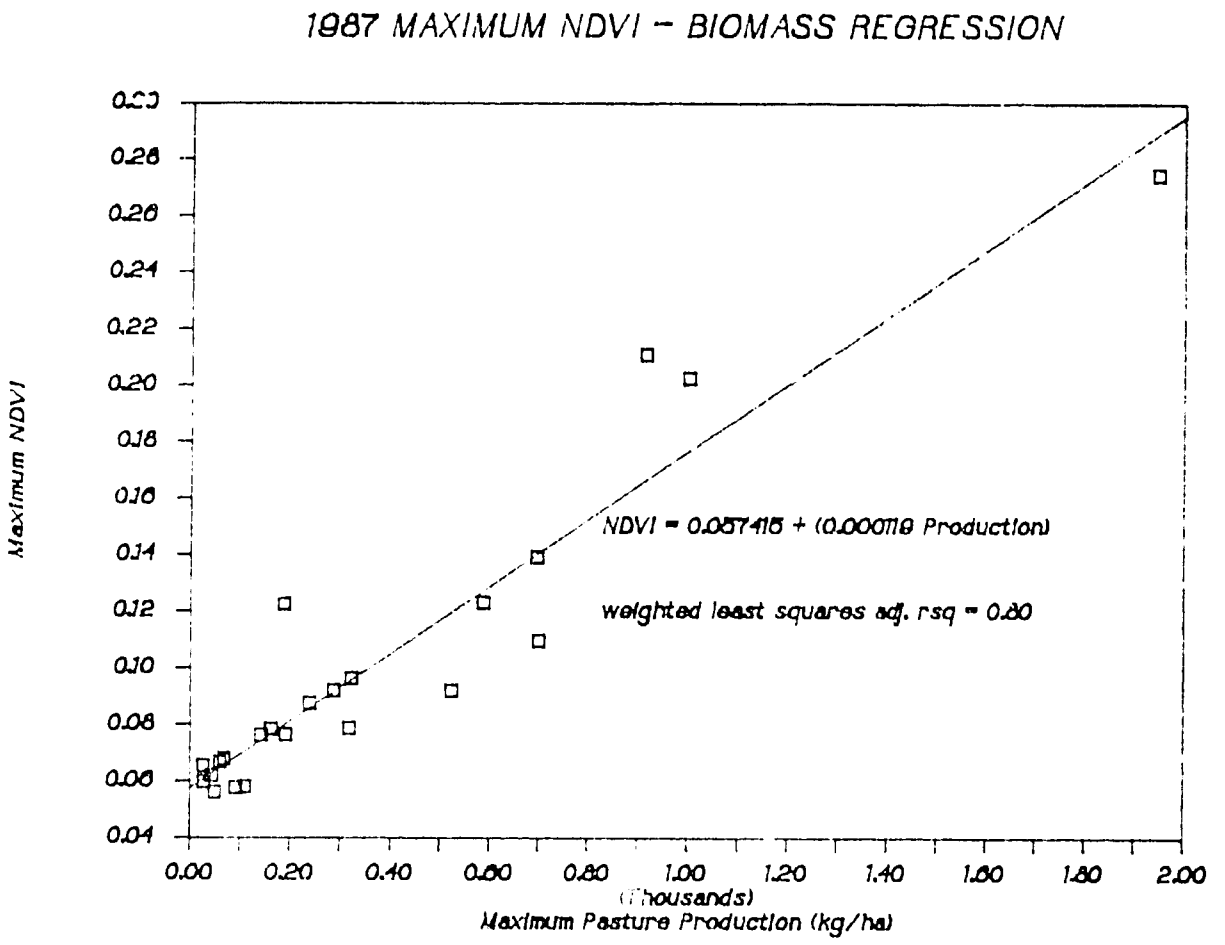


TABLE 7

1986 AND 1987 REGRESSION COEFFICIENTS, 95% CONFIDENCE INTERVALS, AND STANDARD ERRORS OF REGRESSION FOR MAXIMUM NDVI-Standing herbage REGRESSIONS

REGRESSION STATISTIC	YEAR	LOWER LIMIT	ESTIMATE	UPPER LIMIT
Intercept	1986	0.04105	0.06211	0.08317
	1987	0.05203	0.05741	0.06280
Slope	1986	0.00003	0.00007	0.00010
	1987	0.00009	0.00012	0.00015
Standard Error	1986		0.000995	
	1987		0.001009	

Figure 6

Figure 7

4.2.2. Integrated NDVI

The integrated NDVI is the average NDVI for the growing season with each NDVI value throughout the growing season being weighted for the time interval it represents. Integrated NDVI is a time integrated average "greenness" value for the entire growing season which should be strongly correlated with total plant production during the same period. The integration period begins at minimum NDVI. The drop in NDVI in the beginning of the growing season is probably related to an increase in humidity (Holben 1987) but has be assumed to be the time of plant emergence (Chanzy 1987). The termination of the integration was the date the respective site was sampled in late September as NDVI can be artificially high in low humidity conditions in the late rainy season.

The regression equations for integrated NDVI in 1986 and 1987 are presented in Figures 8 and 9. Table 8 presents the 95% confidence intervals for the y intercept and the slopes and the standard error of the regression. Figures 10 and 11 are color maps of the intergrated NDVI for the 1986 and 1987 rainy seasons.

FIGURE 8

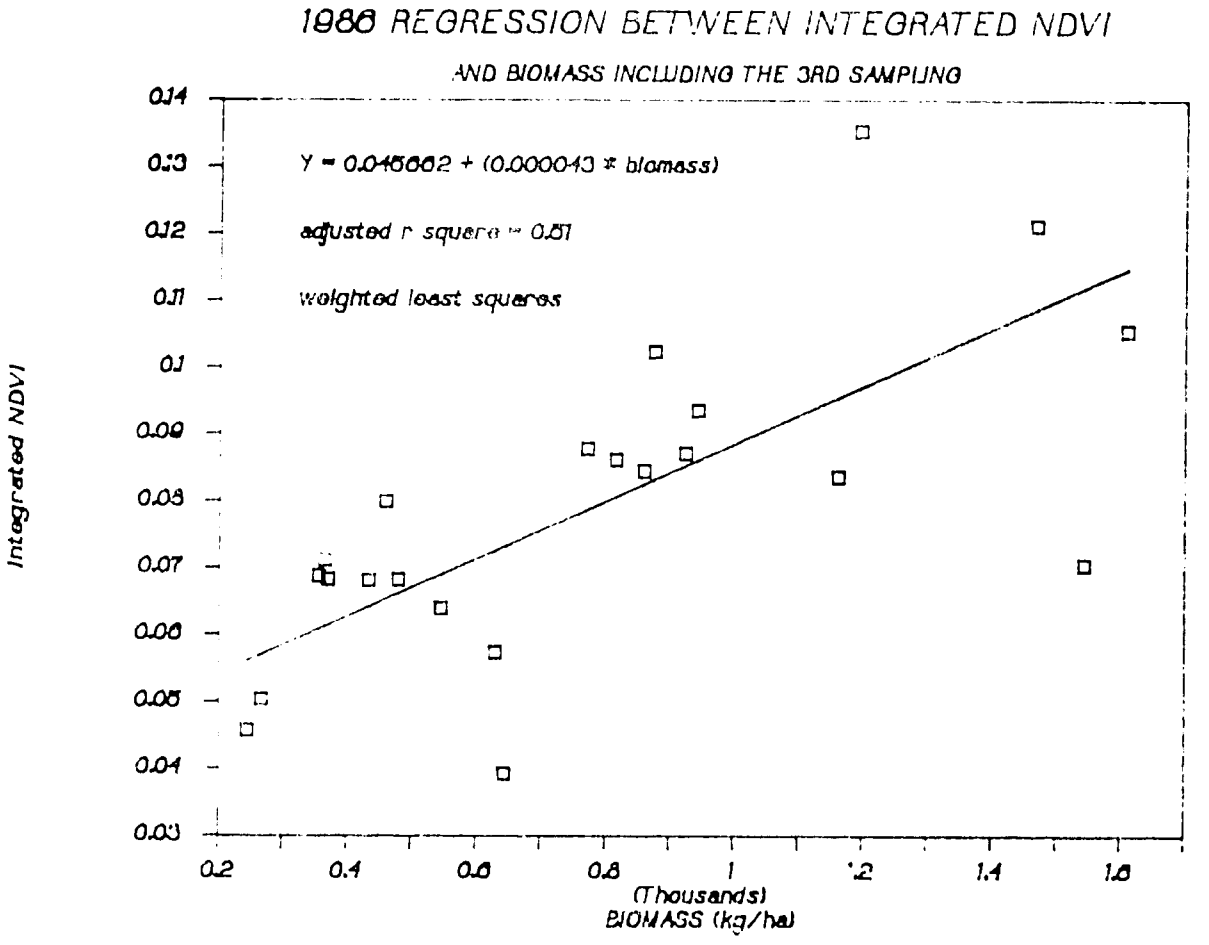


FIGURE 9

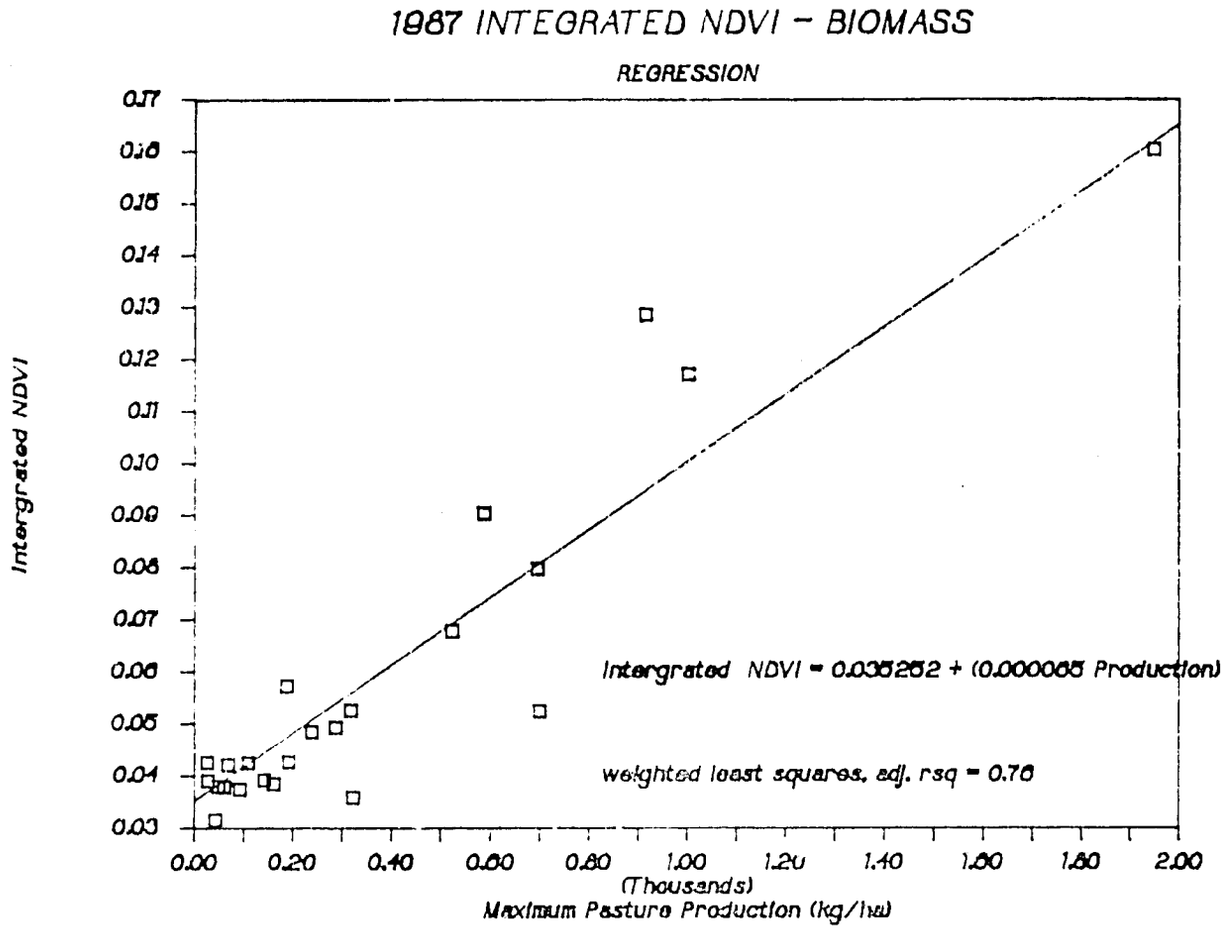


TABLE 8

1986 AND 1987 REGRESSION COEFFICIENTS, 95% CONFIDENCE INTERVALS, AND STANDARD ERRORS OF REGRESSION FOR INTEGRATED NDVI-STANDING HERBAGE REGRESSIONS

REGRESSION STATISTIC	YEAR	LOWER LIMIT	ESTIMATE	UPPER LIMIT
Intercept	1986	0.03300	0.04566	0.05832
	1987	0.03190	0.03525	0.0[illegible]61
Slope	1986	0.00002	0.00004	0.00006
	1987	0.00005	0.00006	0.00008
Standard Error	1986		0.000598	
	1987		0.000629	

Figure 10

22

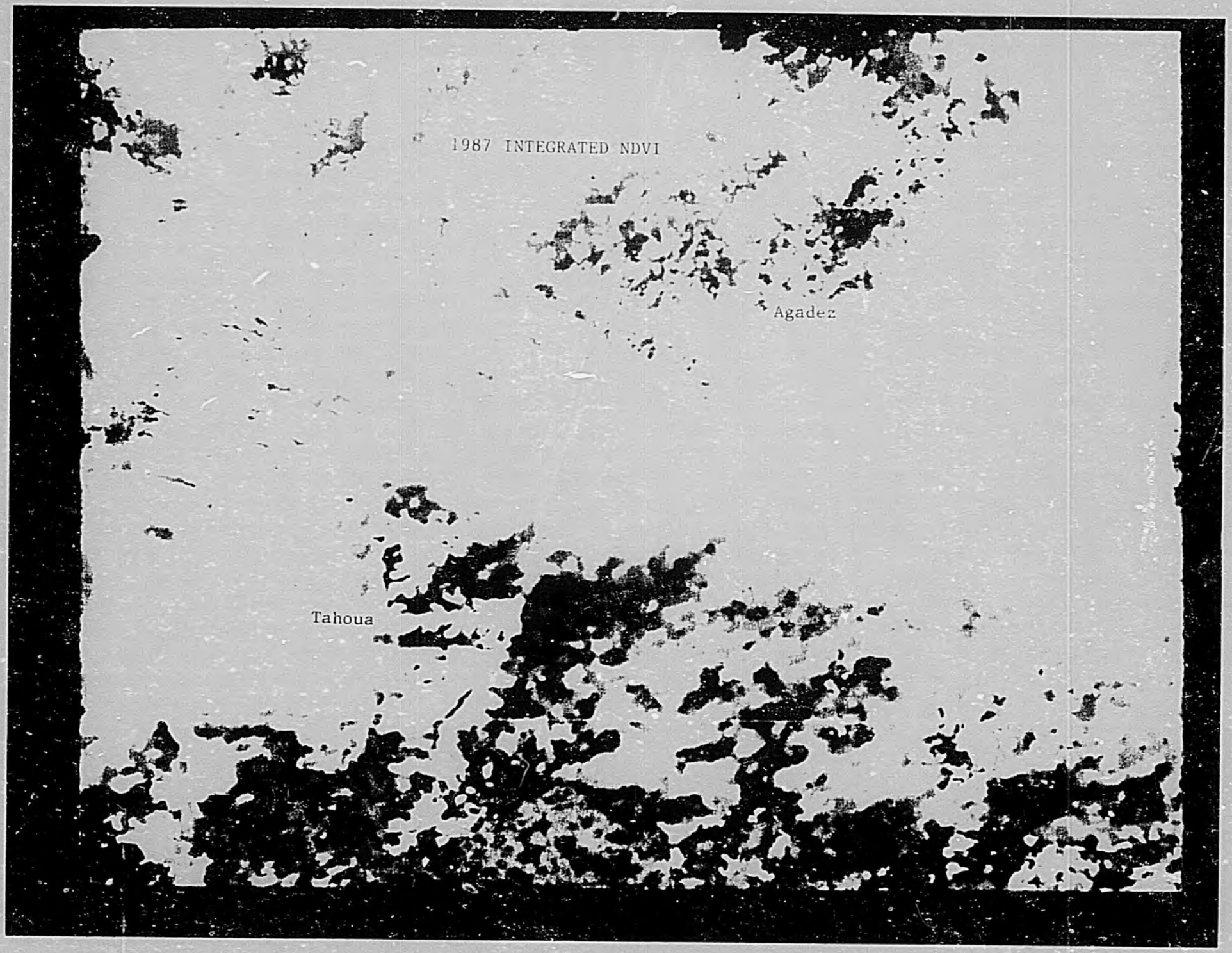


Figure 11

Even though the confidence intervals for y intercepts and the slopes for 1986 and 1987 overlap, this does not necessarily imply that there was no difference between years. A formal statistical test was conducted to test simultaneously for possible differences in the intercepts and slopes among years using the improvement concept. A significance level of 90% was used to avoid making a type II error (i.e., combining or pooling the two regressions when they really were different). The test showed that the difference between years was not significant at the 90% level of confidence and that the regressions could be combined. The pooled regression for 1986 and 1987 was:

integrated NDVI = 0.035965 + (0.000058 * standing herbage)

r^2 = 0.78 standard error = 0.000620 n = 44

However, we were reluctant to combine the regressions. Our consensus was that the 1986 and 1987 regressions had adequate degrees of freedom to establish the relationships each year.

4.3. Discussion

The comparison of the maximum and integrated regressions cannot be done using the adjusted r^2 statistic alone (Figures 4,5,6, and 7). R^2 is the percent of the variability in the dependent variable explained by the regression equation and the independent variable. Adjusted r^2 is merely a correction applied to compensate for a varying number of regressors used in the model. R^2 can give misleading results and should be interpreted with caution. A more reliable comparison statistic would be the standard error of the regression with small standard errors being desirable (Tables 7 and 8). However, since the maximum and integrated vegetation index models use different dependent variables, it is difficult to compare the standard errors of the different regressions. Because maximized variables have peculiar characteristics which often preclude them from a normal distribution, they should be avoided when possible. Thus, average integrated NDVI was the preferred vegetation index when compared with maximum NDVI.

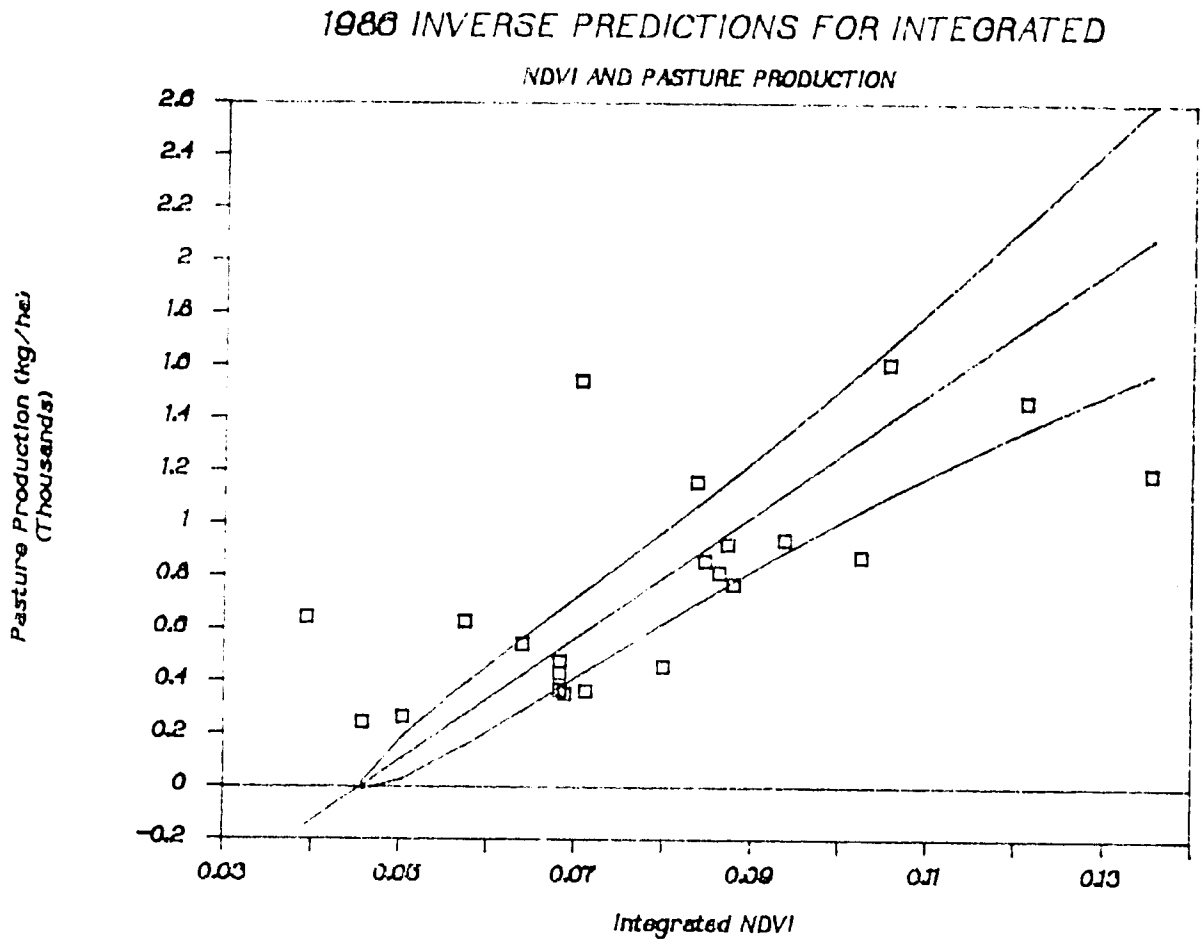
Using the integrated NDVI to standing herbage 1987 regression, we tested for possible differences in regression intercepts and slopes among ecological units. The sites were classified into six different ecological classifications based on landform and soil types:

1=Tchin Tabaradin dunes
2=North stabilized dunes
3=Mixed rocky
4=Tadress plateau
5=Southern stabilized dunes
6=Tadress/stabilized dunes

None of these ecological groups had significantly different slopes or intercepts.

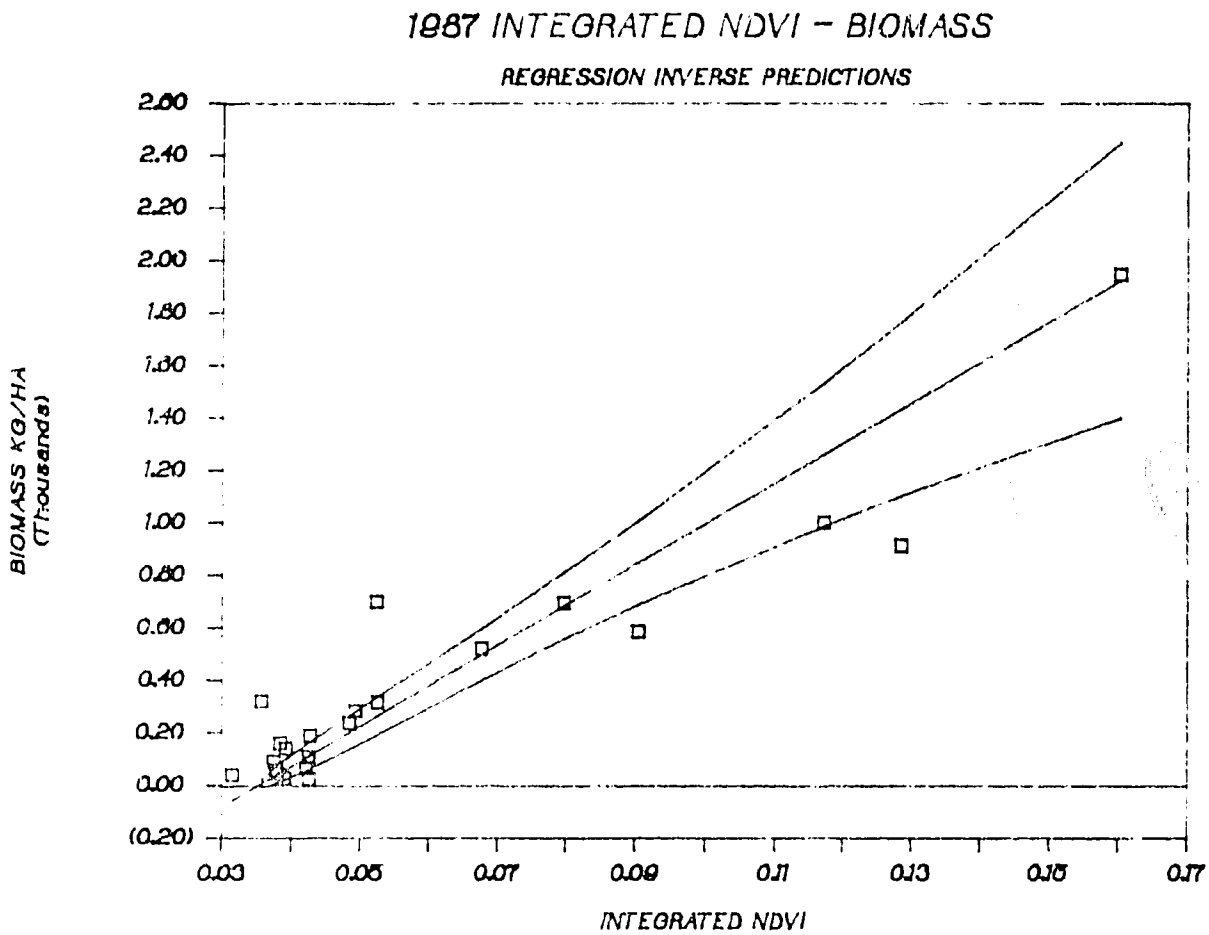
Employing the integrated NDVI as the dependent variable in the regression[7] somewhat complicates the task of "calibrating" the satellite to kg/ha of standing herbage. The task is accomplished via inverse predictions (Neter et al. 1983, p. 172). Figures 12 and 13 show the inverse prediction models for 1986 and 1987 and their approximate 95% confidence intervals for predictions of mean values (e.g., average standing herbage by Arrondissement). These confidence intervals do not take into account error terms associated with the standing herbage estimated at each site but consider these values to be fixed. From Figures 12 and 13 it appears that a satellite standing herbage map could effectively distinguish production classes in increments of about 400 kg/ha.

FIGURE 12



[7] See section 4.1 for an explanation as to why NDVI was selected as the dependent variable.

FIGURE 13



Many individuals in remote sensing have made statements that the reliability of NDVI deteriorates at low standing herbage levels due, in part, to an increase in bare soil reflectance variation (de Wispelaere et al. 1985, Haas 1986, Tucker et al. 1985). However, our regressions showed no visible increase in the point scatter below 300--400 kg/ha. In fact, since we used a weighted least squares analysis we assumed low standing herbage estimates to be more precise than high standing herbage estimates.

If indeed the NDVI-standing herbage relationship was weaker at low standing herbage levels, one would expect variation in intercept coefficients. This was not the case in this study for either maximum or integrated NDVI in 1986 and 1987. There appeared to be more variation in the slopes between years than intercepts. Similar results were found by Prince (1986a) when he compared our results with similar work in Senegal and Mali. This may be indicating that NDVI is an adequate estimator of low

standing herbage levels.

The integrated NDVI-based standing herbage maps for 1986 and 1987 for the project zone were not completed at the time of the writing of this report, though color integrated NDVI maps not calibrated to standing herbage were produced (Figures 10 and 11). Thus, we cannot provided an update of the available pasture at the end of the 1987 and 1986 rainy seasons. This will be accomplished in the near future to improve the between year comparisons that may be made. As pointed out earlier the 1986 standing herbage estimates changed from the estimates provided in the 1986 Early Warning System report (Wylie 1986) because of modifications in the analysis procedures. Table 9 shows comparisons between years in the project zone from 1984-1987 with the modified 1986 values.

TABLE 9

STANDING HERBAGE (kg/ha) AS IT VARIED BETWEEN YEARS IN THE NILPP ZONE

	1984#	1985@	1986#	1987@
North	8	290	523	144
South	32	767	921	613
Average	20	529	722	379

Based on ground sampling only.
@ Based on satellite values calibrated via ground sampling.

4.4. Coarse resolution satellite NDVI

The regional AGRHYMET station in Niamey has been working with the University of Missouri in developing regional NDVI maps for the entire Sahel. Due to the vast region covered, NOAA satellite information was condensed into average values for very coarse resolution product (i.e., 1° longitude and 0.5^{o} latitude). This information is routinely available at AGRHYMET. Through collaborative work with Dr. Gary Johnson (NOAA/University of Missouri-Columbia) we were able to compare average standing herbage in 11 of these cells against integrated NDVI in 1987.

Standing herbage estimates for a particular cell were based on 1 to 3 sites per cell. The NDVI integration period began with minimum weekly NDVI for the respective grid cell and ended during the last week of September. A weighted least squares model was used to conform with previous analyses conducted in this report although the non-weighted model had a higher adjusted r^2. The weighted regression had an adjusted r^2 of 0.55. Other regression statistics are presented in Table 10. The slope and the standard error appear similar to the integrated NDVI-standing herbage regression by site presented in Table 8. However, the intercept appears to be lower when the coarse resolution satellite information is used.

TABLE 10

1987 REGRESSION COEFFICIENTS, 95% CONFIDENCE INTERVALS, AND STANDARD ERRORS OF REGRESSION FOR INTEGRATED NDVI COARSE RESOLUTION-STANDING HERBAGE REGRESSIONS

REGRESSION STATISTIC	YEAR	LOWER LIMIT	ESTIMATE	UPPER LIMIT
Intercept	1987	0.01587	0.02248	0.02909
Slope	1987	0.00001	0.00004	0.00006
Standard Error	1987		0.000656	

5. SAMPLING RECOMMENDATIONS FOR 1988

5.1. Site size

One of the major time and cost factors involved in developing a satellite-based standing herbage map is the collection of standing herbage estimates from 20 or more 100 km^2 sites on the ground several times throughout the rainy season. Previous recommendations for using the NOAA satellites were that the minimum site size needed was 100 km2 (Wagenaar and de Ridder 1987). We designed a study to see if the modification in standing herbage sampling and improved satellite geographic registration would allow a smaller site size.

At the time this study was conducted integrated NDVI had not been selected as the preferred vegetation index. As a consequence, this study was based on maximum NDVI, not integrated NDVI. The NDVI values used in these analyses were NDVI converted to counts[8] so these regressions used a different NDVI scale than the previous analyses. Regression analyses were non-weighted least squares analyses and standing herbage was peak rainy season standing herbage. The use of NDVI counts and non-weighted regressions complicates comparisons with the previous regressions, but comparisons can be made between the various regressions within this study. This study was conducted on the 1987 satellite and standing herbage data sets only.

The 10 by 10 km sites were divided into northern and southern halves, each 5 by 10 kms. Peak standing herbage and maximum NDVI were determined for each half site. The northern and southern half sites were then further divided into quarter sites each, 5 by 5 kms. Due to the hierarchical randomization of the standing herbage (Figure 3) biomass determination for

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[8] A NDVI count is the rescaling of NDVI from -1 to +1 to the rescaled value of 0 to 1024. This rescaling allows more efficient storage on magnetic media.

half and quarter sites was relatively straightforward. The appropriate double sampling regressions were used to convert average estimated plot weights by half and quarter sites to their equivalent air dry weights. The number of estimated 0.5 m^2 plots used in the full, half, and quarter standing herbage estimated average was 180, 90, and 45 respectively.

The maximum NDVI was determined for each site among the composite periods excluding dates after September 30. The satellite data from the date when maximum NDVI occurred on each respective site consisted of a 9 by 9 data matrix with each data value (or pixel) representing 1.1 by 1.1 km on the ground. Thus the satellite sampled a 9.9 by 9.9 km site. The division into half sites was done by discarding the 5th row. Thus half sites were 4 by 9 pixels or 4.4 by 9.9 kms. Similarly, the division into quarters was done by the elimination of the 5th column. This made the quarter sites a 4 by 4 pixel representation or 4.4 by 4.4 km on the ground.

Peak standing herbage for the respective site halves and quarters was paired with respective maximum NDVI values. The site halves were randomly assigned from each site into two groups. Similarly, the site quarters were randomly assigned from each site into four groups.

Separate regressions were then conducted for the full sites and each random site half and quarter groups. Regression statistics for each of these regressions are presented in table 11. The y intercept confidence intervals are in general agreement with the full site confidence intervals. The slope, however, has some variation with smaller site sizes when compared to the slope confidence intervals for the full site. In particular, the quarter randomization one seems low and its confidence interval for the slope does not overlap the confidence interval of the full site slope. This variation in the slope for quarter randomization one may be a factor of the randomization pattern. In general, the slopes appear to be somewhat similar. The standard error of the regression, though smallest for the complete site, was relatively unchanged with variation in site size. Our conclusion was that by reducing the site size to 5-by-5 km we would compromise some of the accuracy in the standing herbage-NDVI relationship. However, the smaller site size will allow more sites to be sampled. We felt the accuracy gained by an increased number of sites was greater than the small amount of accuracy lost by reducing the site size to 5-by-5 kms. Using three ground crews we hope to be able to sample around 36 sites per 10 day sampling period. This would mean that each crew would sample 12 sites in a ten-day period.

TABLE 11

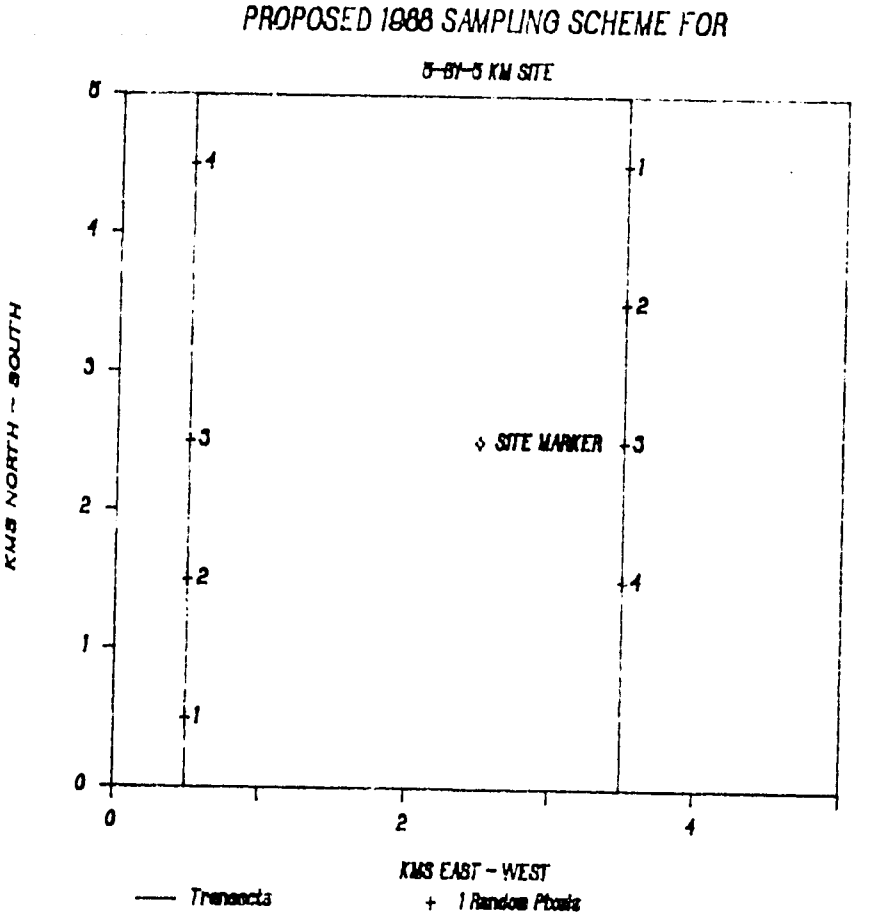
PEAK STANDING HERBAGE-MAXIMUM NDVI
REGRESSION STATISTICS FOR 1987
N=22

SITE SIZE	Y INTERCEPT 95% CONFIDENCE LIMITS	SLOPE 95% CONFIDENCE LIMITS	STANDARD ERROR
FULL	533.9 - 543.5	0.055 - 0.071	8.1
HALF#1	528.5 - 543.4	0.057 - 0.084	11.9
HALF#2	537.7 - 548.0	0.043 - 0.059	9.2
QUARTER#1	538.4 - 554.8	0.026 - 0.049	15.4
QUARTER#2	533.5 - 548.5	0.050 - 0.076	13.0
QUARTER#3	531.1 - 545.6	0.046 - 0.071	11.9
QUARTER#4	530.4 - 546.6	0.057 - 0.086	13.6

5.2. 1988 proposed sampling scheme

Sampling within the 5 by 5 km site has been proposed to consist of two randomly placed north-south transects (figure 10). Along each of the 5 km long north-south transects, four random pixels (roughly 1 km^2 in size) will be sampled. Each pixel will be sampled with two clusters or groups of plots. Each cluster of plots will have five plots. The plot size will be 0.5 m^2 and will be sampled using the double sampling procedure which combines estimated plot values with actual clipped values. The total number of estimated plots per site will be 80. The site size determination standing herbage estimates for the 5 by 5 km areas were based on 45 plots in 1987. We hope to regain some of the accuracy lost by reducing site size by nearly doubling the ground sampling of the smaller sites in 1988.

FIGURE 14



The selection of clipped plots will be similar to the 1987 methods with the addition of the clipping of one randomly chosen cluster of 5 plots. This is needed to determine if the utilization of an errors-in-variable model will improve satellite calibration. The relationship between variation of estimated plots within a cluster and the variation of clipped plots within a cluster has to be documented in order to test the errors-in-variables model. Thus, the total number of clipped plots per site would be:

10% of 80 total plots clipped at random = 8
1 random cluster clipped = 5

total of plots clipped per site = 13

The extension of the standing herbage satellite assessment to a national level will require additional sites to be established both to the east and west of the NILP project zone. Site selection will be for 3-4 northern sites with low standing herbage potentials and the remaining sites would be in high to moderate standing herbage regions. Landsat TM images[9] will be employed in proposing new site locations.

For an assessment of the national pastoral zone, 36 sites have been proposed for the 1988 rainy season. The Niger Centre-Est project zone (NCE) will have 12 sites and the Sud-Temesna project zone will have 3 sites. The remainder of the sites (21) will be in the NILPP zone. These 36 sites will be sampled in 1988 by 3 crews, 2 based in Tahoua and 1 based in Zinder.

[9] The landsat thematic mapper (TM) has a ground resolution of 30 by 30 m. The high resolution and the subsequent high satellite data volumes combined with a lower frequency of passage (every 16 days) make landsat undesirable for a pasture production drought early warning system.

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