EARLY WARNING SYSTEM PRELIMINARY REPORT

PASTURE PRODUCTION IN THE CENTRAL AND EASTERN PASTORAL ZONES OF NIGER

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INTEGRATED LIVESTOCK PRODUCTION PROJECT

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SUMMARY

Extensive ground-based biomass sampling appeared to give representative herbaceous biomass estimates for 22 sites each representing 100 km^2. Ground-based NDVI was not recommended as a necessary component of a cost-effective biomass ground-sampling method. The r^2 of 60% obtained between ground-based biomass and satellite (NOAA 9) NDVI was comparable to other studies in Niger. Satellite-based maps of herbaceous pasture production were produced for the central and eastern pastoral zone of Niger, though ground-based sampling was restricted to the central pastoral zone. Regional statistics of pasture production and carrying capacities were produced for the NILPP zone and comparisons made between years from 1984 to 1987. Further analyses which may improve the pasture production map were identified.

INTRODUCTION

The Niger Integrated Livestock Production Project (NILPP) has been working toward the development of a cost-effective satellite-based (NOAA 9) pasture deficit warning system for the project zone since 1984. This system would inform the Government of Niger and donor countries of impending pasture deficits in Niger's pastoral zone. Originally, this was done in collaboration with the International Livestock Centre for Africa (ILCA). However, contract negotiation problems developed in 1986. New Mexico State University (NMSU), which had provided technical assistance since 1984 for the ground-based pasture production estimates used in the warning system, proposed to conduct the pasture deficit warning system in place of ILCA from 1986 to 1988.

This report provides a map and preliminary analysis of the geographic variation in available biomass throughout the NILPP zone and an additional map of biomass variation in eastern Niger, the Niger Centre-Est Project zone. Digital image processing of data obtained from the Advanced Very High Resolution Radiometer (AVHRR) sensor on the NOAA-9 satellite was used to produce a map of the normalized difference vegetation index (NDVI). Remote sensing researchers have shown a good correlation between NDVI and biomass. Data from ground based sampling of biomass for 22 sites within the NILPP zone were used to calibrate the map. In general, satellite estimates of biomass based on late-August/early-September data indicate marginal production of grass this year. Maximum growth has occurred in the area northwest of Dakoro. However, much of the northern part of the study area (especially areas north of 16°N latitude) has little, if any, vegetation growth. The following sections discuss the steps that were used to create a map of the geographic variation in biomass. Problems associated with this activity that impact on the establishment of an early warning system (EWS) will also be identified. Further work will be done at NMSU this spring, to analyze the satellite data for the entire 1986 and 1987 rainy seasons.

METHODOLOGY

Ground-Based Biomass Estimates

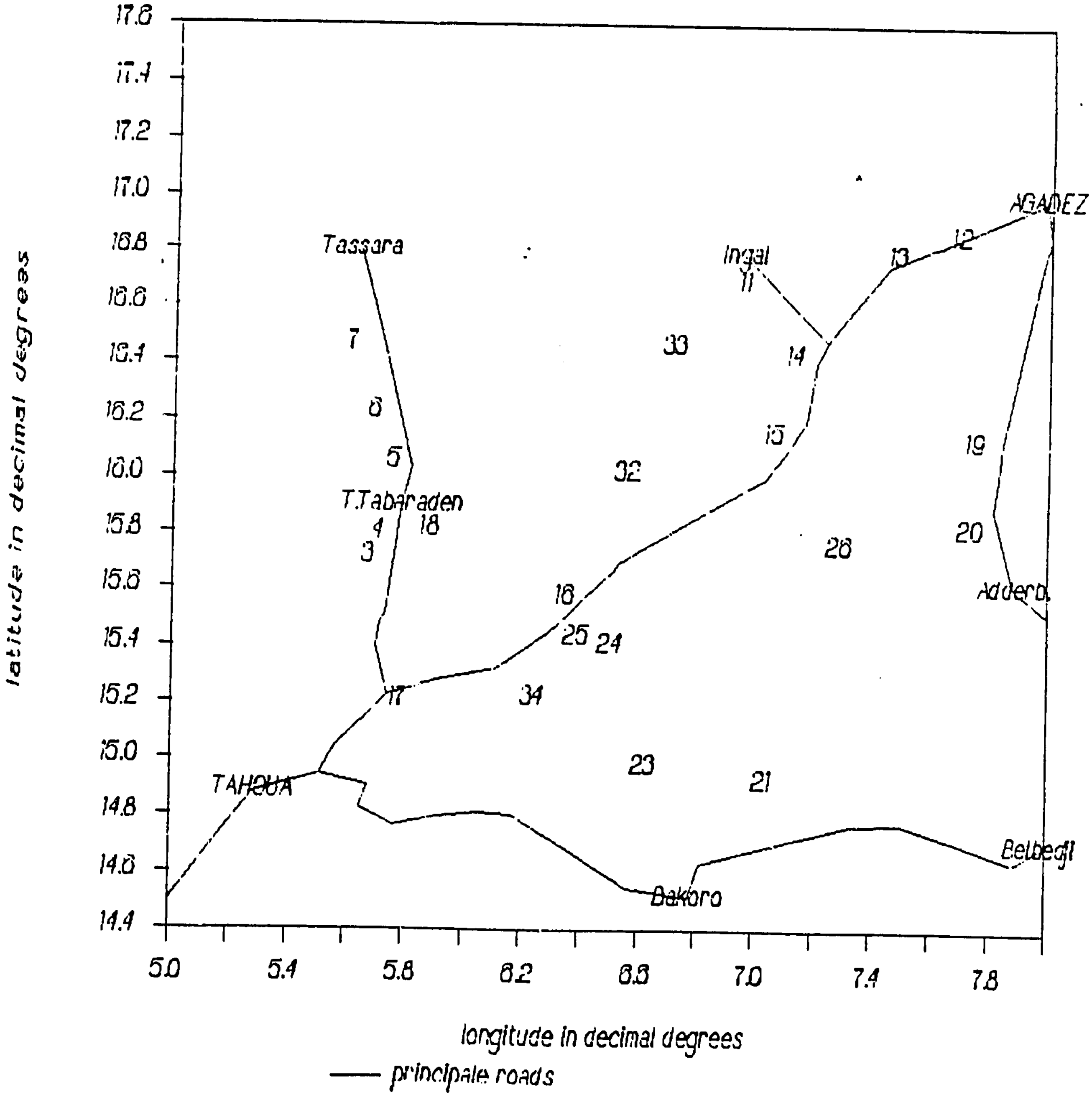
Permanent ground truth sites in the NILPP zone were established in 1983-1984. The sites were chosen to represent the major range types identified by Milligan (1982), for uniformity of the vegetation, and for quick and easy access. The locations of the ground truth stations within the NILPP zone are displayed in Figure 1. Due to the late date (early October 1987) on which the pasture production map was requested for the Centre-Est project, no ground truth sites were established in its project zone during the 1987 rainy season. It was felt that the correlation between biomass and satellite NDVI would be similar for the two project zones. However, ground truth sites should be established in the Centre-Est project zone for the 1988 rainy season.

Wagenaar and De Ridder (1985) recommended that when using National Oceanic and Atmospheric Administration (NOAA) satellite data sets with the higher resolution setting, local area coverage (LAC), the minimum area needed for a ground truth site was about 10 by 10 kms. This was largely due to the inherent error of up to 3 km in identifying the satellite pixels accurately with actual locations on the ground. Using a larger ground truth site increases the size of the target area and the number of pixels on the satellite data set which will represent the ground truth site. Thus, there is a greater likelihood that a substantial percentage of the ground truth site will be represented by the appropriate corresponding satellite pixels.

In order to acquire a biomass estimate that is representative of a large area, in 1985 ILCA used reflectance data acquired from an airplane. Reflectance data was used to extrapolate the ground-based biomass estimate obtained on one km^2 to the adjacent 13 by 13 km area (Wagenaar and DeRidder 1987).

Figure 1

Ground truth site locations within the NILP project zone



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In 1986, after a breakdown in ILCA contract negotiations, NMSU and NILPP staff members proposed a modified ground-based biomass sampling scheme (Denda et al. 1986). This sampling scheme allowed the collection of a biomass estimate representative of a 10 by 10 km area or ground truth site (GTS), through the use of four-wheel-drive vehicles. This ground-based sampling method was modified again in 1987 after extensive consultations with NMSU statisticians and the modified field procedures were described (Pase 1987).

The 1987 methodology divides the 10 by 10 km square for each site into four equal quarters. Within each quarter are four randomly located north-south transects (see Figure 2). Each of these transects contains three randomly chosen points or pixels, giving a total of 12 random pixel (or point) locations per site (p1, p2, etc. in Figure 2). Five different random patterns were drawn up and assigned permanently to the different ground truth sites at random.

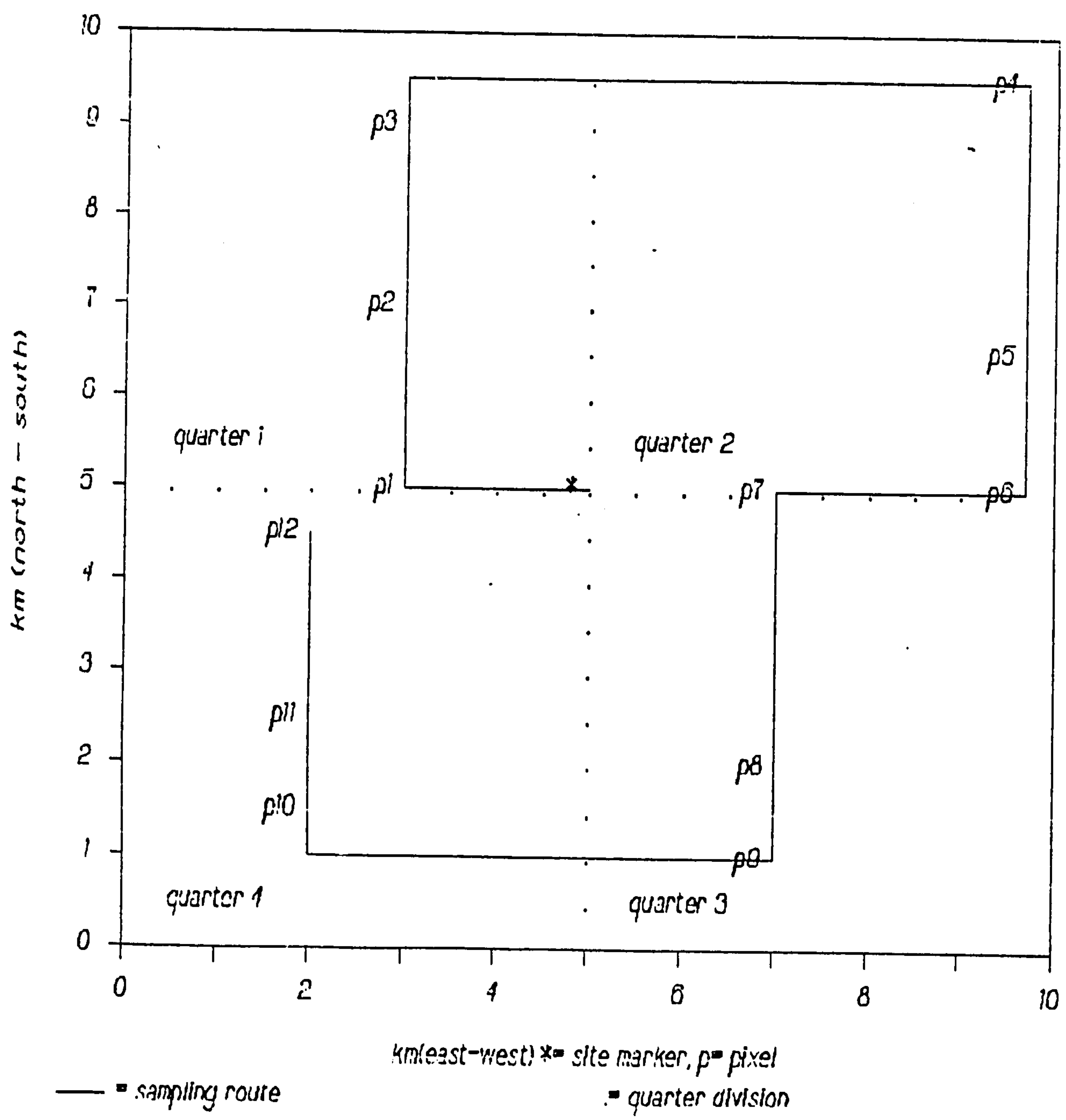
Each pixel (or random point) on the ground represents a one square km block and was sampled with three systematically placed quadrat clusters. Each quadrat cluster consists of five systematic quadrat placements. The half meter square quadrat was sampled for herbaceous biomass using the "double sampling" technique. This sampling scheme used 15 quadrat estimates and roughly 1 - 2 clipped quadrats at each of the 12 random pixel locations. This gave a total of 180 quadrat estimated weights and 15 -18 clipped quadrat weights per site.

Usually a full day was required to finish a site. Currently in the NILPP zone there are 23 ground truth sites. Thus, two ground-based sampling teams were employed, a northern team and a southern team, allowing all sites to be sampled in the 10 to 11 day periods of August 12 - 20, August 28 - September 8, September 18 - 28, and October 19 - 23, respectively .

The "double sampling" technique involved obtaining a large population of estimated quadrat weights and/or percent herbaceous cover which were later corrected to actual air-dried weight using a smaller random sub-sample of the estimated quadrats which were also clipped. The clipped quadrats were weighed in the field (green weight) and later air-dried and reweighed (air dried weights). A regression was then formed for each estimator on each sampling trip to convert estimated weights to equivalent actual air-dried weight. This regression formula was used to convert the average estimated weight per site to equivalent air-dried weight.

Figure 2

Ground biomass sampling random pattern #1



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The 1986 double sampling regressions showed a deficit in clipped quadrats with high biomass production. NMSU statisticians recommended stratifying the clipped quadrats in 1987 to insure that an adequate number of the clipped quadrats with larger biomass amounts were obtained for each regression. This, in essence, was to insure that an adequate number of actual air-dried weights represented the regression in its entirety.

The estimator, upon arriving at the ground truth site, estimated the quadrat weight which roughly 30% of the quadrats would exceed. This served as the cut-off point between "heavy" quadrats and "light" quadrats. If his estimation for a particular quadrat fell in the "light" quadrat group, after recording his estimate, he drew from a pocket containing 11 marbles, one of which was off color. If he drew the off color marble, the quadrat was clipped. If not, he continued on to the next quadrat. After a marble was drawn, it was placed in another pocket (sampling without replacement). When all 11 marbles were drawn, they were returned to the original pocket and drawing continued.

If, on the other hand, the quadrat estimated was a "heavy" quadrat, the drawing was from a separate pocket containing 4 marbles with one off color marble. Drawing again was without replacement. This gave "heavy" quadrats a higher probability of being clipped than "light" quadrats, 1 out of 4 and 1 out of 11, respectively.

Each regression equation was evaluated for heterogeneity of the variance. Generally, quadrats with large amounts of biomass were harder to estimate than the quadrats with smaller amounts of biomass. If this was true, then the variance was not constant along the regression and a weighted least squares regression was employed. All regression models were also tested for possible differences between sites for both slopes and intercepts.

During the time of anticipated peak standing crop, the August 28 - September 8 sampling trip, in addition to quadrat weight and percent cover, percent composition by weight was also estimated for each herbaceous species within the quadrat. From this, species composition was calculated for each site by calculating the approximate weight of each species in each quadrat. Total weights for each species were calculated for each site and then converted to percentage composition by weight. These computations insured that each quadrat's species composition was weighted by its appropriate total quadrat weight.

For the October 19 - 23 sampling, in addition to standing herbage estimates and clipped weights, separate estimates and clipped weights were also obtained for litter of the year. This was done within the same quadrat using the "double sampling" method described above.

Reflectance Data

The amount and type of light reflected from a region can be used to estimate actively growing vegetation production levels. This is possible because actively growing vegetation strongly absorbs light in the visible wavelengths (particularly the red wavelengths) and strongly reflects light in the near infrared wavelengths (NOAA 1986). Vegetation indexes calculated from reflectance data primarily use this phenomeonon to estimate vegetation production levels on the ground (Wylie 1987, Weiser et al. 1986, and Perry and Lautenschlager 1984). One of the most widely used indexes is the Normalized Difference Vegetation Index or NDVI. NDVI is essentially a ratio of the difference between the near-infrared and the visible (or red) reflectances and the sum of the near-infrared and the visible reflectances:

$$NDVI = \frac{(INFRARED - VISIBLE)}{(INFRARED + VISIBLE)}$$

This tends to minimize differences caused by differential illumination, variation in viewing angles, and terrain irregularities (Matson and Parmenter-Holt 1985) because both factors, visible and near-infrared reflectance, are present in both the numerator and the denominator. NDVI values for water are negative because the visible reflectance exceeds the near-infrared reflectance. Rock and bare soil tend to have NDVI values that are close to zero because the visible and near-infrared reflectances are about equal. NDVI values for actively growing vegetation range from 0.1 to 0.6, with the higher NDVI values associated with the higher biomass values.

However, NDVI loses its accuracy when estimating low plant cover, low biomass, or low leaf area indexes. This is in part due to the increased background effect of bare soil (Miller et al. 1984 and Musick 1984). Minimum vegetation parameters that can be effectively estimated with NDVI range from 250 to 500 kg/ha (de Wispelaere et al. 1985, Haas 1986, and Tucker et al. 1985b) or about 30% cover (Musick 1984).

Ground-Based Reflectance

The primary objective of collecting ground-based reflectance was to:

1) allow comparisons between satellite NDVI and ground-based NDVI and

2) determine if ground-based reflectance was a more efficient and precise estimator of biomass than visual estimations.

Ground-based reflectance was collected on the first three sampling dates (mid August, early September, and late September) using a hand held radiometer[1]. The radiometer was connected to a Polycorder field data logger[2] allowing the needed reflectance bands to be read simultaneously from the radiometer and automatic storage of the data. Wagenaar and De Ridder (1987) recommended simultaneous radiometer readings to minimize the effect of differential illumination between the different band readings. The radiometer used Thermatic Mapper (TM) filters[3] which gave the first four channels the following bandpasses:

channel	bandpass (um)
TM1	0.45 - 0.52
TM2	0.52 - 0.60
TM3	0.63 - 0.69
TM4	0.76 - 0.90

The NOAA 9 satellite, employed for this study, has the Advanced Very High Resolution Radiometer (AVHRR) on board. The AVHRR has somewhat different bandpass ranges than TM for the visible and infra-red regions of the spectrum:

channel	bandpass (um)
AVHRR1	0.55 - 0.68
AVHRR2	0.73 - 1.10

To have comparable NDVI values with the NOAA 9 satellite values, TM channels 2 and 3 should be averaged. This would be roughly equivalent to AVHRR channel 1. AVHRR2 is roughly equivalent to TM channel 4.

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[1] The radiometer used was an EXOTECH 4 channel 100 BX with 15° field of view lenses.

[2] The data logger was an Ominidata Model 516C-32-A.

[3] The Thermatic Mapper (TM) is one of the radiometers mounted on Landsats 4 and 5. It has a spatial resolution of 30 m and seven spectral bands.

The quadrats sampled with the radiometer were a subsample of the quadrats estimated using the "double sampling" technique, one out of every five quadrats estimated was sampled with the radiometer, including all quadrats which were clipped. Each quadrat sampled with the radiometer had three hand-held radiometer readings representing 48% of the quadrat's surface. Because radiometer measurements were only accurate between 9:00 AM and 4:00 PM due to the angle of the sun, quadrats which were sampled outside these time limits were sampled with the "double sampling" technique only and radiometer sampling was forgone. This was to insure that all the sites would be completed in a minimum of time. The reflectance data (total visual and total infrared reflectance) were read from the data logger and copied onto the "double sampling" field data sheets daily to avoid possible loss of the data.

Satellite-Based Reflectance

In May of 1987 NMSU reguested the high resolution setting, local area coverage (LAC), for the NOAA 9 satellite data sets for the entire rainy season from July 8 to October 30. Satellite data sets for this preliminary report were selected for the period of anticipated peak herbaceous production, the second sampling period (28 August and September 8). On 11 September 1987, an order was placed with the Satellite Data Services Division of NOAA for the NOAA AVHRR data for the period 28 August through 8 September. Indications at that time suggested that the data would be available in three weeks. The data finally arrived on 28 October; several phone calls were necessary to prompt delivery and to convey the need for timely delivery.

The data that were finally delivered were for 5 of the 12 days during the period of interest. Specific dates available for this analysis were: AUG 28, AUG 29, SEP 2, SEP 3, and SEP 6. Data for the SEP 3 date was limited to eastern Niger, in areas outside the NILPP zone. Thus, four dates were used for analysis of biomass variation in the NILPP zone and five dates were used for production of the map for eastern Niger.

The delay of over 45 days from date of order to delivery underscores the importance of an on-line ground receiving station at Regional Agrhymet in Niamey. If the technology associated with this project is to be transferred successfully to an operational EWS in Niger, then remote sensing data must be available in near real-time.

Computer software for analysis of the NOAA AVHRR satellite data was obtained from the NOAA sponsored Climate Applications Branch in Columbia, Missouri. The software is designed for operation on a VAX computer operating under the VMS operating system. Additional PC-based software and hardware is required for display of a color coded map of the data. This hardware, operating system, and software are all available at Regional Agrhymet in Niamey. The NOAA/VAX software and PC-based software will be installed on the necessary computer hardware at New Mexico State University (NMSU) for remote sensing analysis and instruction in 1988.

Contacts had been made with the AGRYHMET station in Niamey in 1986 to insure compatibility with other early warning systems and to conduct the analysis of the 1987 satellite data sets in Niger on the AGRHYMET computer. Unfortunately, the NOAA satellite data analysis software had not been installed on the AGRYHMET computer when the satellite data sets were received. In order to insure the timely production of a preliminary biomass map for the 1987 growing season, the decision was made to process the data at the University of Nebraska's Center for Advanced Land Management Information Technologies (CALMIT). Resources available at CALMIT include a VAX computer, the PC-based ERDAS data management and display system, and individuals with several years of experience in processing satellite data. The NOAA/VAX software was installed on the VAX at CALMIT. Initial processing was accomplished with the NOAA/VAX software. The tasks included: 1) unpacking each date of data with the routine LACUNPK, 2) registering the data to the Plate Carrie geographic projection with the routine LACXY, 3) compositing or merging the data for all available dates using XYCOMP (the Old NVI Method which bases decisions on the maximum vegetation index from the dates in question was used), and 4) filling in any missing information using the procedure NEWXYFILLER (the Surrounding Pixel Averaging method was used). The net result of these four steps was the production of a data matrix for the study area that provided the best indication of maximum vegetation index for each pixel.

Due to the unavailability of several necessary data analysis procedures within the NOAA software programs, the data were transferred to the ERDAS system for additional analysis. Specific capabilities provided by the ERDAS system that were not available in the NOAA software include color hardcopy output and the ability to identify summary statistics for a subset of the data matrix. The latter utility was necessary for identification of mean NDVI for each ground data collection site.

Currently, the NOAA software is primarily designed to prepare the satellite data for display on a color monitor. If quantitative analysis of the satellite data is needed, or if hardcopy output of a map is desired, then additional software development and testing must occur.

Separate analyses were done for the NILPP zone and for eastern Niger. The boundaries used for the NILPP zone were 5°E to 8°E longitude and 14°N to 18°N latitude. The boundaries used in the analysis for eastern Niger were 8°E to 14°E longitude and 13.5°N to 17.5°N latitude.

The NDVI statistic was calculated for each pixel using the standard equation: NDVI = (100)(channel 2 - channel 1) / (channel 2 + channel 1). The multiplication factor of 100 was used to change the ratio percentage into an integer value.

A simple regression was used to correct the satellite maximum NDVI values by site to biomass equivalents using biomass as the dependent variable and satellite NDVI as the independent variable. This regression was then used to convert all the maximum NDVI values across the two project zones to their biomass equivalents.

RESULTS AND DISCUSSION

Ground Based Biomass Estimates

The regression statistics for the double sampling regressions for each sampling team and sampling period are presented in Table 1. The regressions were for standing herbaceous crop of the year except for the October 19-23 regressions which were for litter and standing herbage combined. Generally, a weighted least square regression was employed. A regression with none of the sites being significantly different would have one intercept and one slope. Each significantly different site could add an additional intercept, slope, or both. The r^2 presented here, or the percentage of the variability accounted for by the regression, is the adjusted r^2 which compensates for varying degrees of freedom in the model. The standard errors of the regression were usually less than 50 kg/ha.

Table 1

Double sampling regression statistics

DATE	LOCATION	REG TYPE	NUMBER OF INTERCEPTS	NUMBER OF SLOPES	r^2 (adj)	St. Er (kg/ha)
AUG 12-20						
	NORTHERN	SIMPLE	1	2	90%	59
	SOUTHERN	WEIGHTED	1	1	80%	19
AUG 28-SEP 8						
	NORTHERN	WEIGHTED	2	4	81%	17
	SOUTHERN	WEIGHTED	2	2	83%	28
SEP 18-28						
	NORTHERN	WEIGHTED	2	3	87%	26
	SOUTHERN	WEIGHTED	4	4	84%	28
OCT 19-23						
	NORTHERN	WEIGHTED	2	1	75%	50
	SOUTHERN	WEIGHTED	1	1	73%	41

The regression models were then used to correct the site averages of the 180 estimated quadrat weights for each site to their equivalent air-dried weights. The corrected average kg/ha found on each of the sites on each of the sampling dates is presented in table 2. The actual sample dates were August 12 to 18; August 28 - September 8; September 18 - September 28; and October 10 - 23 and are represented in Table 2 by an intermediary date within each sample period. All the biomass values represent standing crop of the year except the October 20th sample date which included both standing and litter of the year for the sites where litter was evident. The October 20th sampling was, with the exception of site 23, of selected sites on which additional growth was anticipated after the September 22nd sampling.

Table 2
Biomass (kg/ha) values as they changed throughout the 1987 rainy season

SITE	AUG15,87	SEP1,87	SEP22,87	OCT20,87	PEAK87
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	-	1,003
18	25	93	240	404	404
19	7	194	323	-	323
20	64	191	287	-	287
21	445	916	680	-	916
23	548	1,948	956	1,486	1,948
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

- represents sites that contained herbaceous production but were not sampled.

Peak biomass in 1987 reflects the maximum biomass values found on each site throughout the rainy season. After plant maturation, decreases in standing herbage levels occur as on site 23 from September 1 to September 22. This was probably mostly a transfer of biomass from standing herbage to litter brought on by seed dispersal and leaf shattering combined with sampling errors. These processes can be accelerated by late rains and/or strong winds. However, biomass transferred to the litter layer is not necessarily lost to herbivores as litter is an important dry season fodder source. Thus, dry season pasture availability may best be represented by peak rainy season production because of inaccuracies involved in sampling litter of the year. These inaccuracies include incomplete collection of litter of the year when clipping due to seed dispersal and leaf shattering, wind removal of litter as the quadrat is being clipped, difficulties in separating litter of the year from less palatable and lower quality litter of previous years, and difficulty in estimating litter because of reduced visibility for the lower herbaceous layers.

Tables 3 and 4 present the results of percent species composition by weight for the northern and southern sampling teams during the second sampling period (August 23 - September 8). Species which had percent compositions that were consistently less than 5% were not displayed.

Table 3
Percent composition by weight
for the northern sampling team

	sites											
Species*	11	12	13	14	15	16	17	19	20	26	32	33
Ar spp	1%	41%	12%	0%	0%	6%	8%	18%	5%	5%	3%	23%
Bo er	11%	3%	25%	16%	0%	0%	1%	9%	1%	0%	2%	14%
Br spp	0%	0%	8%	0%	0%	2%	4%	0%	0%	0%	1%	1%
Ce bi	1%	0%	1%	1%	99%	71%	63%	8%	52%	77%	23%	38%
Cy spp	0%	9%	4%	10%	0%	1%	0%	0%	0%	0%	0%	0%
Er spp	0%	0%	0%	0%	0%	1%	1%	0%	1%	0%	8%	0%
Gi ph	1%	0%	6%	6%	0%	2%	1%	36%	5%	0%	3%	3%
In spp	0%	25%	0%	13%	0%	0%	1%	16%	18%	0%	0%	0%
Li vi	0%	0%	0%	14%	0%	0%	0%	0%	0%	0%	0%	0%
Pa tu	77%	21%	18%	10%	0%	0%	0%	0%	0%	0%	0%	1%
Tr spp	2%	0%	2%	0%	0%	13%	16%	1%	3%	7%	17%	5%
Tr te	5%	1%	12%	21%	1%	0%	0%	10%	11%	5%	37%	12%

Table 4
Percent composition by weight
for the southern sampling team

Species*	3	4	5	6	7	18	21	23	24	25	34
Ar spp	0%	0%	2%	1%	80%	0%	7%	0%	2%	3%	2%
Bo er	5%	10%	3%	42%	10%	3%	0%	0%	0%	3%	7%
Br xa	2%	8%	1%	14%	0%	9%	0%	0%	3%	1%	0%
Ce bi	75%	74%	22%	10%	1%	56%	66%	46%	40%	34%	44%
Ci co	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%
Da ae	3%	0%	3%	0%	0%	7%	8%	3%	14%	33%	3%
Gi ph	2%	2%	5%	22%	3%	2%	0%	2%	1%	1%	0%
Pa tr	0%	0%	25%	2%	0%	9%	0%	0%	0%	0%	0%
Pa tu	0%	0%	29%	6%	0%	0%	0%	0%	0%	0%	0%
Tr spp	3%	0%	1%	2%	1%	2%	9%	20%	35%	19%	14%
Tr te	3%	2%	10%	1%	4%	3%	1%	14%	1%	2%	22%

* The abreviated species names are presented here. Below are the names of the abreviated species.

Ar spp	*Aristida* species
Bo er	*Boerhavia* species
Br spp	*Brachiaria* species
Br xa	*Brachiaria xantholeuca*
Ce bi	*Cenchrus biflorus*
Ci co	*Citrullus colocynthis*
Cy spp	*Cyperus* species
Er spp	*Eragrostis* species
Gi ph	*Gisekia pharnaciodes*
In spp	*Indigofera* species
Li vi	*Limeum viscosum*
Pa tr	*Pancratium trianthum*
Pa tu	*Panicum turgidum*
Tr spp	*Tragus* species
Tr te	*Tribulus terrestris*

Ground-Based NDVI

The gound-based NDVI data were poorly correlated with herbaceous biomass. This was largely due to a programming error in the data logger program. The program totalled the three values for each quadrat for each of the TM channels 1, 2, and 3. The total values for TM channels 1 and 2 for each quadrat were averaged and stored along with the TM channel 3 data. Unfortunately, the TM channels which should have been used were the average of the TM channels 2 and 3 to simulate the AVHRR channel 1 and TM channel 4 to simulate the AVHRR channel 2. The possibility of using only the red reflectance (TM channel 3) to estimate biomass will be investigated but because of this error it is doubtful that these data will be of any use.

However, the ground-based NDVI to biomass regression generated by ILCA in 1985 considered by quadrat had a r^2 of only 52% (Wagenaar and De Ridder 1987). In comparison to the "double sampling" regressions considered by quadrat for 1985 and 1987, this is a low r^2 (Wagenaar and De Ridder 1987 and table 5). Variation in percent dry matter of the vegetaion probably contributes to the low r^2 values for ground-based NDVI by quadrats.

TABLE 5

Comparison of r^2 values between double sampling and ground-based NDVI by quadrat

Ground-based NDVI 1985	Double sampling 1985*	Double sampling 1987
52%	55% - 83%	73% - 90%

* Data from Wagenaar and De Ridder (1987) and did not test for possible differences between sites and heterogeneity of the variance which may have improved the relationship.

This relative inaccuracy when compared with double sampling, the high cost associated with ground-based reflectance equipment ($10,000 per sampling team) and the time constraints for sampling (9:00 AM to 4:00 PM), make ground-based NDVI an unattractive option for ground-biomass estimation for an operational cost-effective pasture deficit early warning system. Ground-based NDVI may be an interesting research tool but Wagennaar and De Ridder (1987) found it a reliable tool only for estimating biomass for large areas (ie. averaged by clusters or sites, but not by quadrat).

Satellite-Based NDVI

Values of the maximum NDVI were extracted and averaged for the location of each of the ground data collection sites (Table 6). A simple linear regression was performed on the NDVI statistics and corresponding biomass data. Output from this analysis indicates an r^2 value of 60% (n = 22) for the equation:

$$biomass = (119)(NDVI) - 377$$

This correlation is comparable to Wagenaar and De Ridder's regression (1987) for the same sites in 1985 where the regression between aerial NDVI (from the airplane) and AVHRR NDVI had a r^2 of 55% (n = 25). Wispelaere et al. (1985) found a somewhat higher r^2 (70%) using AVHRR NDVI in the Sud-Tamesna project zone. However, this was with a slightly limited sample size of only 10. The 1987 regression may be further improved during the final analysis to be conducted at NMSU this spring.

Table 6

Biomass* and normalized difference vegetation index (NDVI) data for each of the study sites.

Site	Biomass	NDVI
	August 28 to September 8 sampling	
3	118	4.86
4	40	3.59
5	66	3.41
6	97	3.77
7	34	3.53
11	13	2.51
12	7	2.72
13	44	2.32
14	7	2.14
15	9	1.65
16	212	8.28
17	474	16.4
18	98	4.25
19	194	.91
20	191	.67
21	898	5.0
23	2,024	18.8
24	579	9.12
25	517	.00
26	-	
32	24	2.90
33	28	3.23
34	685	9.96

* Biomass values as of Nov 87 which were later slightly modified after minor corrections and are presented in table 2.

\- Data unavailable at NMSU at the time of analysis (Nov 87).

This relationship between biomass and NDVI and summary statistics concerning the statistical distribution of NDVI values were used to produce estimates of percent aerial coverage for five subjectively determined biomass categories (Table 7). The class breaks for the biomass/NDVI categories used in Table 7 were based on the distribution of and range in biomass values that were determined on the second sampling period.

Table 7
NILPP zone aerial coverage statistics of NDVI computed estimates of biomass.

NDVI Range	Biomass Range (kg/hectare)	% Aerial Coverage	Square Kilometers
0 - 5	0 - 200	63.8	93,120
6 - 10	200 - 800	18.6	27,170
11 - 15	800 - 1400	11.9	17,300
16 - 20	1400 - 2000	4.5	6,620
20 - 31	2000 +	1.1	1,650

The class breaks used in Table 7 were also used to determine the break points for a level slice (or density slice) of the NDVI statistics. A color coded level slice of NDVI variation within the NILPP zone (Figure 3) was produced using the ERDAS software available at CALMIT. On this map, light brown areas indicate areas of little or no vegetation based on the NDVI whereas areas in orange have the greatest standing biomass (Table 8). Interpretation of the map patterns suggests that maximum growth has occurred in the area northwest of Dakoro centered around 6.5°E longitude and 14.8°N latitude. However, much of the northern part of the study area (especially areas north of 16°N latitude) has little, if any, vegetation growth with the exceptions of the Teguiddan-Adrar and Tchighazerine regions. Areas shown in white correspond with either 1) a road overlay that was created using the ERDAS system or 2) areas that were covered by clouds on all four dates and which were composited to produce the final map.

Figure 3

Herbaceous biomass production in the NILPP zone

(A = Agadez   T = Tahoua   D = Dakoro)

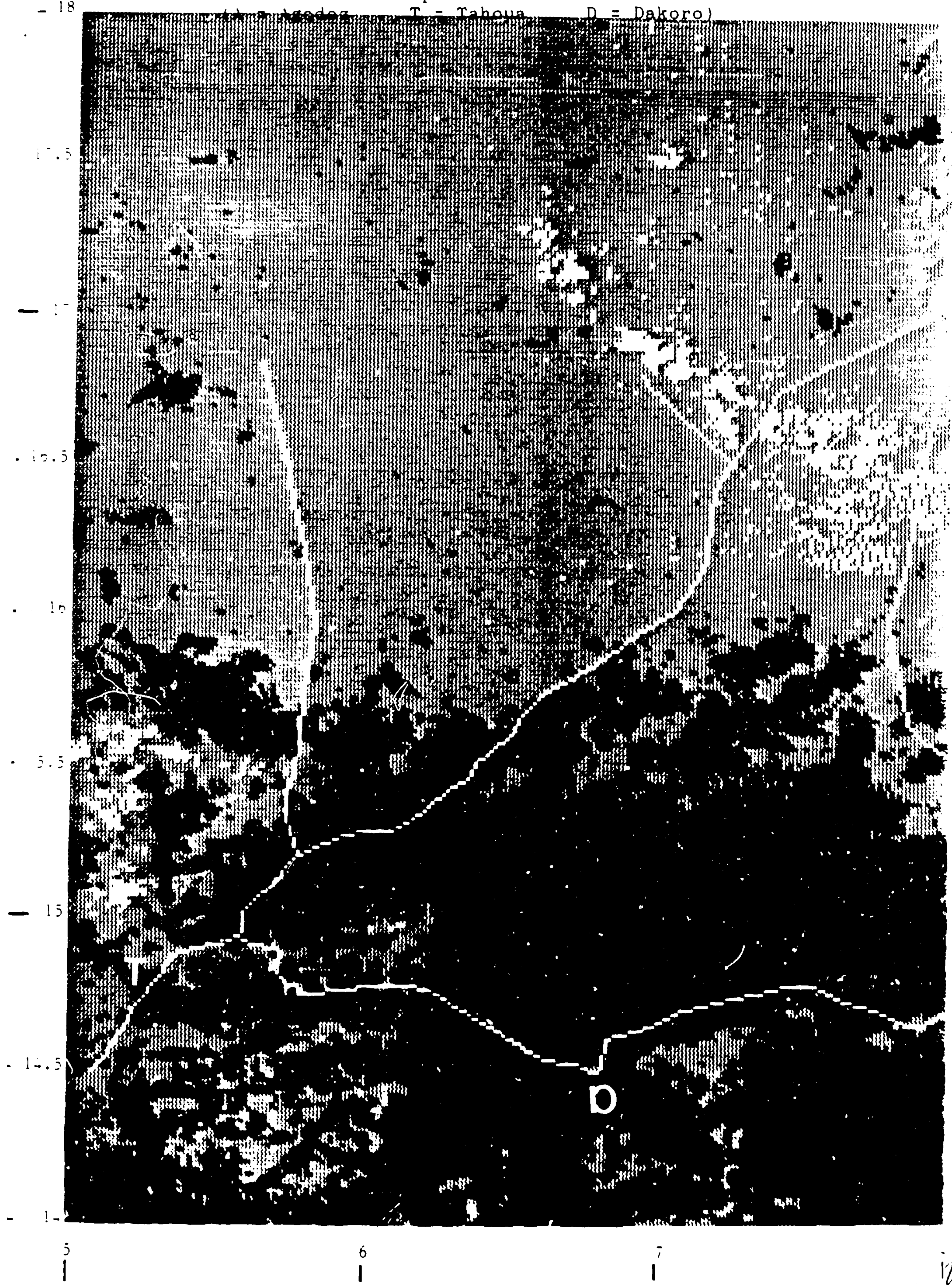


Table 8
Color codes, associated range in NDVI, and NDVI computed estimates of biomass.

Color	NDVI Range	Biomass Range (kg/hectare)
White	0	clouds, cloud shadows, and roads
Tan	1 - 5	0 - 200
Brown	6 - 10	200 - 800
Dark Green	11 - 15	800 - 1400
Light Green	16 - 20	1400 - 2000
Orange	20 - 31	2000 +

A similar color coded map of the NDVI statistic for the eastern section of Niger was also produced (Figure 4). The color scheme (Table 8) used in producing this level slice was the same as that used for the map of the NILPP zone. Highest satellite derived estimates of biomass occurred in southern sections but many of these areas are not in the pastoral zone. Throughout most of the pastoral zone in eastern Niger, the available biomass as of 6 SEP 1987 was quite low. Only in the area to the east-northeast of Goure (centered at 11.2°E, 14.2°N) were relatively high levels of biomass indicated by analysis of the satellite data.

The costs associated with the acquisition and analysis of the August 28 to September 8 satellite data sets were only around $2,000.

Regional statistics were generated from the biomass map for the NILPP zone and are presented in Table 9. Generally, the northern part of the NILPP zone had poor pasture production (100 kg/ha) and the southern part had good production (700 kg/ha). This gave an overall average production for the NILPP zone of 390 kg/ha.

Figure 4
Herbaceous biomass production in the NCE zone
(Z = Zinder G = Gouré N = N'Guigmi)

Table 9

Herbaceous biomass production levels in different classified regions within the NILPP zone

region	biomass (kg/ha
NILPP zone@	390
NILPP zone north of 16° north latitude	100
NILPP zone south of 16° north latitude@	700
Agadez department within NILPP zone	140
Tahoua department within NILPP zone	410
Maradi department within NILPP zone	1,800
Zinder department within NILPP zone	1,100

@ The southern limit of the pastoral zone was 15° N LAT

Subsequent sampling of the sites after the dates used to construct the satellite map (late August to early September) showed that significant plant growth did occur afterward (see table 2). Therefore, a more accurate pasture production map will be obtained once the satellite data sets for the complete rainy season have been analyzed.

Using the pasture production estimates currently available, comparisons were made between years (table 10). Pasture production was virtually nonexistent in 1984. Production levels for the NILPP zone in 1985 to 1986 were fairly constant at about 500 kg/ha. However, in 1985 production was high in the southern half while in 1986 production was high in the northern half. Production in the project zone in 1987 was somewhat lower, being 73% of the 1985 - 1986 average production in the NILPP zone. This was primarily due to low production levels in the north.

Table 10

Comparison of pasture production levels in the NILPP zone since 1984

	1984 sites#	1985 satellite+	1986 sites#	1987 satellite+
NILPP zone	21	486	588	390
North half	8	198	388	100
South half	32	816	676	700

Pasture production estimates based solely on ground-based sampling.

+ Pasture production estimates based on satellite-based information corrected to pasture production via ground-based sampling.

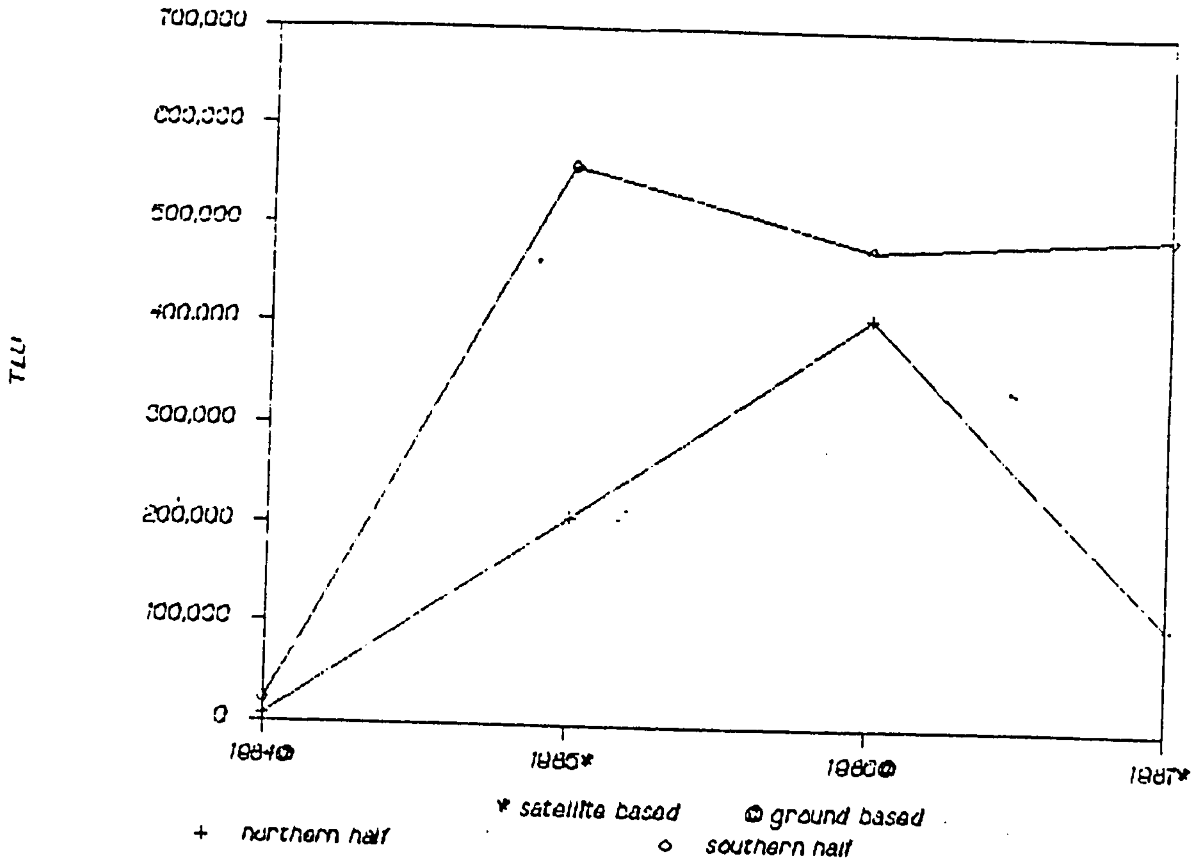
Carrying Capacity

Using the pasture production estimates for the NILPP zone, the number of tropical livestock (TLU) equivalents that could be maintained in the project zone during the nine-month dry season were estimated. Currently the Nigerien livestock school in Kollo uses the IEMVT method for calculating the carrying capacity. This method assumes that a TLU consumes 6.25 kg of dry matter per day and that one third of the available forage is available to grazing, the remaining two thirds being lost to trampling, natural decomposition, and site preservation.

Figure 5 shows the estimated IEMVT carrying capacities as they changed in the northern and southern halves of the NILPP zone[4]. Carrying capacity was fairly constant at around 500,000 TLUs for the southern half of the zone in the years 1985 - 1987 with peak southern carrying capacity occuring in 1985. The carrying capacity in the northern half of the zone showed a lot a variablility between years with peak carrying capacity occurring in 1986. Northern carrying capacities for 1987 are lower than the previous two years.

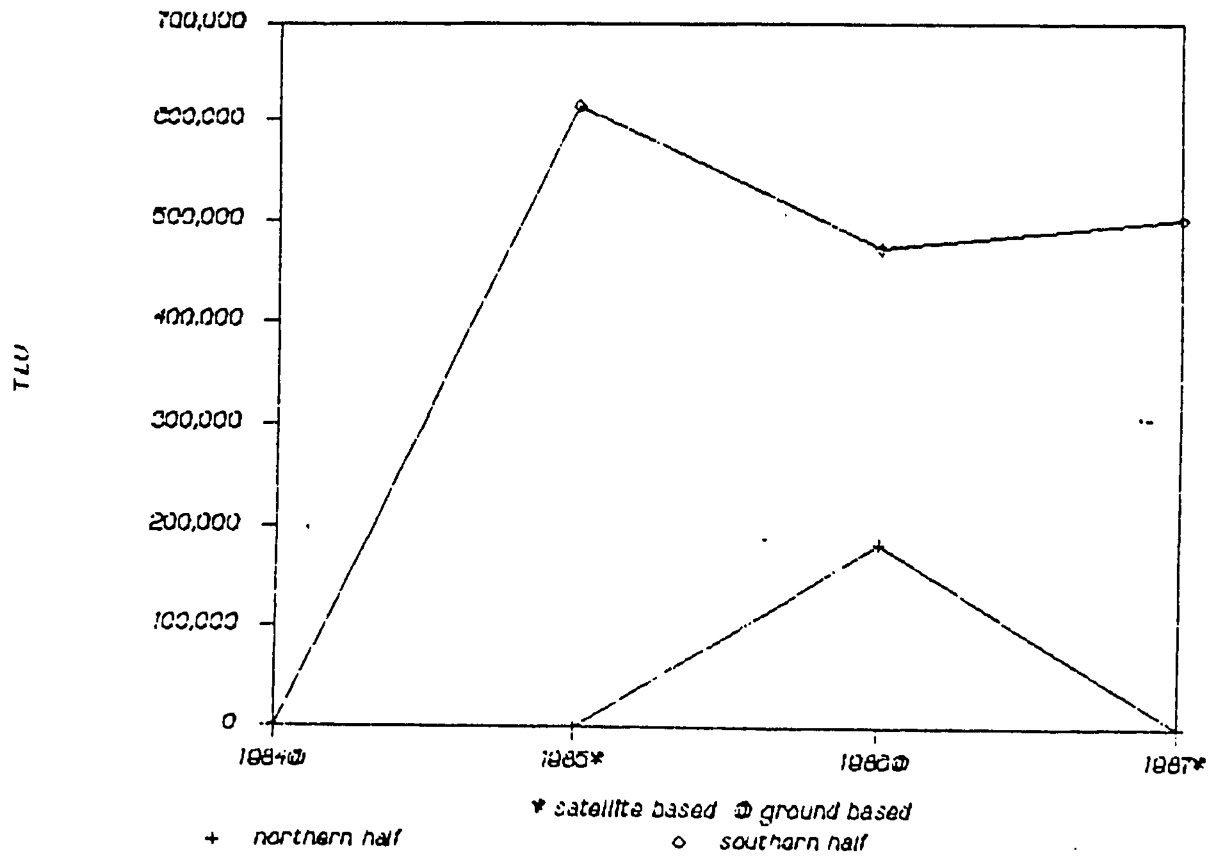
[4] The NILPP zone was 89,064 sq km from 17.5° N LAT to 15° N LAT and from 5° E LON to 8° E LON. This is somewhat smaller than the area mapped in figure 3 but more accurately represents the pastoral zone. This includes an area in the northwest which was not included in the project zone in previous reports.

Figure 5
Carrying capacities (TLU) for the NILPP zone
using the IEMVT method



Research conducted during the Niger Range and Livestock Project (NRL), predecessor to NILPP, showed that animal weight gain tended to drop dramatically when residual forage levels dropped below 200 to 300 kg/ha (Wylie et al. 1983). Leaving 200 to 300 kg/ha after grazing also promotes site maintenance or improvement by minimizing wind erosion, soil moisture evaporation, soil temperature, and increasing soil organic matter. Carrying capacities were estimated to leave 200 kg/ha at the end of the nine month dry season, taking into account consumption of 3% of body weight per day and natural decomposition at 4% per month (Pase 1985). Figure 6 shows carrying capacity estimates from the NRL method for the northern and southern halves of the NILPP zone since 1984. As with the IEMVT method, carrying capacities in the south, excluding 1984, were fairly constant at about 500,000 TLUs, peaking in 1985 with about 600,000 TLUs. Carrying capacity in the north was nil except in 1986. These calculations were based on the average forage production for the region. In the north there were pockets of forage production greater than 200 kg/ha in 1987 and 1985 but on the average forage production was less than 200 (table 10).

Figure 6
Carrying capacities (TLU) for the NILPP zone using the NRL method



With the exeption of 1984, variablility between years in the carrying capacity (using the NRL method) was about 100,000 TLUs in both the northern and southern halves of the zone. Table 11 showes the long-term carrying capacities (using the NRL method) of the NILPP zone including and excluding the 1984 drought.

Table 11

Long-term dry season carrying capacities for the northern and southern halves of the NILPP zone

	north		south	
	TLU	TLU/KM²	TLU	TLU/KM²
average 85-87	60,525	1.14	530,610	14.84
average 84-87	45,394	0.85	397,957	11.13

NMSU Analysis in 1988

The satellite data for a ten-day period in early June were ordered from NOAA to serve as soils reflectance baseline data. These are now at NMSU and will be employed in the final analysis this spring during testing of other vegetation indices.

The 1986 ground-based pasture production estimates will be correlated against the 1986 satellite values in the spring of 1988. The approval of the NMSU contract in late spring 1987 did not permit the purchasing and analysis of the 1986 satellite data sets before the 1987 rainy season.

Analysis to be done at NMSU on the 1986 and 1987 data sets this spring will use geographic reference points from within the two project zones in an attempt to further minimize errors in pixel locations. Further analysis to be done at NMSU includes: treating NDVI as the dependent variable and biomass as the independent variable, addressing possible heterogeneity of the variance, testing the significance of a "phenology" index[5], testing other vegetation indexes that maybe more appropriate for low biomass estimations, testing an integrated NDVI across the complete growing season, and testing for possible differences in the NDVI regression between major ecological zones.

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[5] The "phenology" index as proposed by Wylie (1987) was merely the number of days that each pixel exceeded a minimun NDVI value. This would roughly correspond to the age of the vegetaion and thus, its phenological stage. This variable will be tested as a possible covariate with vegetation indexes. It may not add significantly to the model because of possible colinearity with maximum NDVI.

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