

**GEORGE HANUSCHAR'S**

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# LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)



NASA NOAA USDA

## FEASIBILITY OF ASSESSING CROP CONDITION AND YIELD FROM LANDSAT DATA

**NASA**

National Aeronautics and  
Space Administration

Lyndon B. Johnson Space Center  
Houston, Texas 77058

MARCH 1978

## PREFACE

A 1-day set of briefings on the feasibility of assessing crop condition and yield from Landsat data was given at NASA Headquarters on September 27, 1977, to allow an assessment of the technical status and remaining technical issues on this important topic. It allowed an update on the Landsat aspect of yield from the earlier 1974 NASA JSC Wheat-Yield Conference (NASA TM X-58158, JSC-09256, April 1975).

Approved

*Jon D. Erickson*  
Jon D. Erickson

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## SECTION 1

### INTRODUCTION AND SUMMARY

By

Jon D. Erickson and Richard G. Stuff

The purpose of the briefings was to:

- Present the technical status of key investigations in the assessment of crop condition and yield using Landsat data.
- Identify the technical issues that are currently limiting the research progress or applications of Landsat to yield estimation.
- Provide briefing charts and sufficient textural material to publish a readable report documenting the technical status and issues.

The briefing agenda consisted of the same order of subjects and speakers as given in the table of contents.

The objective of yield modeling for crop production estimation is to derive a means of predicting the within-a-year yield and the year-to-year variability of yield over some fixed or randomly located unit of area. Yield prediction models have traditionally been empirical functions of weather variables (1) or in-season sampling of crop dry matter and stand parameters (2). The need for improved yield models incorporating satellite data was described for the Large Area Crop Inventory Experiment (2-4)\* and by USDA personnel attending the briefings. In addition to better yield predictions for their component role in production, they can also contribute to crop identification and area determination by remote sensing since expected values of yield indicate the condition of a standing crop and the probability that an area or portion thereof will not be harvested can be computed. Preliminary studies indicate that the requirements for interpreting Landsat data for yield may be sufficiently similar to those of signature extension that it is feasible to investigate the automated estimation of production (4-24).

The model approaches proposed for estimating yield from Landsat data are based on the explicit or implicit use of crop condition variables. Although crop condition and Landsat data may be analyzed separately, it should be recognized that the ultimate function is to employ the results in yield or production prediction. A preferable method for describing or quantifying crop condition is in terms of expected yield per unit area and conversely, expected yield relative to normal should provide the best available quantification of crop condition.

To date, none of the crop condition indicators described in the briefings have been functionally related to yield in a tested model. Some of the crop condition indicators used in the described Landsat-yield studies are detrac-  
tant cause (3-16), percent green cover (4-11), redness in Landsat color  
composites (5-4), threshold index of transformed Landsat data (5-7), stand  
quality (5-28), two or three classes of stress estimated at 12.5 x 12.5 n.m.  
coordinates on Landsat images (7-2), and LAI at given growth stages (6-7).  
A correlation between percent green cover and yields was indicated for

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\*Number-numbers in parentheses refer to pages in this report.

observations from a LACIE test site (4-11). Also the correlations between leaf area duration and yield as reported by Welbank et al. are frequently cited (3-1) even though these correlations were insignificantly low or negative for winter wheat. In other cases the field measured crop condition-yield comparison is omitted (6-7). The lack of yield models based on ground observed crop condition variables could be considered one of the voids in the technology for estimating yields from Landsat.

The main potential or feasibility indicators for using Landsat data to estimate yield are the spot correlations (not models) between MSS data and crop condition or yield. Where the same data are used in both cases, the correlation between yield and spectral data appears to be as high as that between crop condition and the spectral data (4-11 to 13, 5-28). This similarity suggests that the spectral data may contain more yield "information" than the individual crop condition parameters. Analytical definitions or statistical proofs of the crop condition parameters which are actually "viewed" by Landsat data apparently are not available, and more than one crop feature may be associated with the yield effects. The yield-Landsat indicator correlations also show changes with crop calendar (3-3, 5-27) with the peak correlation apparently near heading. Thus seasonal, geographical, and culturally induced variability in crop calendars must somehow be taken into account in yield models using Landsat.

The concept of an advanced yield model consisting of both spectral and meteorological components was endorsed (2-17, 4-25, 5-22, 8-4). Rationale for using meteorological parameters originates from known between season and near harvest dynamics in crop environmental-condition-yield relationships. On the other hand, MSS spectral components could both simplify and make advanced yield models more accurate by accounting for the multitude of yield affecting factors integrated by the crop up to the reflectance observation time. Studies with the infrared bands planned for Landsat C and Landsat D indicate that they will provide even more crop condition and yield information than the current Landsat data (3-4).

As interim or alternatives to the direct use of Landsat data in yield models, the briefings presented two indirect approaches where Landsat data is used in conjunction with available yield models. Procedures indicating some feasibility were those where Landsat estimated LAI is input to ET or Growth Models (6-13), Landsat interpreted overrides to crop diagnostic submodels (7-2), and monitoring the areal extent of drought (5-1 to 9). The improvement relative to the equivalents of these procedures without Landsat data has not been experimentally (statistically) evaluated.

An initial list of technical issues relating to the development of advanced yield models was presented (2-18), and several new ones were identified during the briefings:

- Obtaining or identifying accurate estimates of true yields for specific fields (4-14, 5-22, and 8-4).
- Accounting for within field variability of crop condition, yield, or soil moisture for associated Landsat or thermal data (3-6 and 5-22).
- Separation of crop development stage effects from crop condition variability in model development.

The lack of definition of crop condition or features sensed by MSS data and models relating ground observations of these variables to yield could also be considered a technical issue.

Thus technical rationale and indicators (spot correlations) are the principal criteria demonstrating the feasibility of using Landsat data for yield estimation. To quantitatively assess the feasibility relative to conventional methods of estimating yield still requires a considerable amount of model development and testing on independent data.

References:

1. Baier, W. 1977. Note on terminology of crop-weather models.  
WMO expert meeting on Crop-Weather Models, Ottawa, October 11-13.
2. USDA Statistical Reporting Service. Weather Objective Yield Survey -  
Enumerator Manual, annual.



SECTION 2

LACIE EXPERIENCE AND OVERVIEW  
OF JSC YIELD PROGRAM

J. D. Erickson

LACIE PHASE I AND II ACCURACY SUMMARY

PRODUCTION

- WINTER WHEAT
  - U.S. AND USSR ESTIMATES SUPPORTED 90/90 AT-HARVEST CRITERION
- SPRING WHEAT
  - TENDENCY TO UNDERESTIMATE DUE TO ACREAGE UNDERESTIMATION IN U.S. AND CANADA
  - UNDERESTIMATE NOT OBSERVED IN USSR

YIELD

- SUPPORTED 90/90 CRITERION IN PHASE I AND II OPERATIONS
  - LOCAL PROBLEMS OBSERVED IN AREAS OF EXTREME WEATHER TESTS
- 10-YEAR TESTS INDICATED PERFORMANCE marginally supported 90/90 IN USGP

## TECHNICAL MODIFICATIONS IN YIELD FOR PHASE III

- INITIALLY, PHASE II TECHNOLOGY WAS USED
  - CCEA I YIELD MODELS ARE IN PHASE II
- YIELD
  - MODIFICATION OF CCEA I MODELS - IMPLEMENTED APRIL 77
    - EXPANDED TO PREVIOUSLY UNMODELED AREAS IN U.S., USSR
    - REDEFINED MODEL BOUNDARIES IN U.S. TO ELIMINATE BIASES DUE TO OVERLAP
  - EVALUATION OF SECOND GENERATION YIELD MODELS IN LIMITED AREAS
    - KANSAS, NORTH DAKOTA, 1 USSR WW AND 1 USSR SW OBLAST
- PRODUCTION
  - INCORPORATED GENERAL ASSESSMENT OF CROP CONDITION BASED ON CLIMATIC AND LANDSAT DATA INTO REPORTS

## LACIE PHASE III RESULTS-TO-DATE SUMMARY

### ESTIMATE ACCURACIES

IN THREE GLOBAL CROP YEARS, LACIE CROP SURVEY TECHNOLOGY HAS PRODUCED SIGNIFICANTLY IMPROVED WHEAT PRODUCTION INFORMATION

- U.S. AND USSR WINTER WHEAT SURVEY ESTIMATES SUPPORTIVE OF 90/90 CRITERION 1-1/2 - 2 MONTHS PRIOR TO HARVEST
- PHASE III MODIFICATIONS PRODUCED SIGNIFICANTLY IMPROVED EARLY SEASON SPRING WHEAT ESTIMATE IN COMPARISON TO PHASE II - HOWEVER, KEY TECHNICAL ISSUES REMAIN WITH SMALL FIELDS/REGISTRATION
- YIELD ESTIMATES SUPPORTIVE OF 90/90 - TEST AND EVALUATION OF MODELS MODELS PLUS POOR PERFORMANCE IN OTHER-THAN-NORMAL WEATHER CONDITIONS INDICATES NEED FOR FURTHER IMPROVEMENT

## NASA/JSC YIELD R&D OBJECTIVES

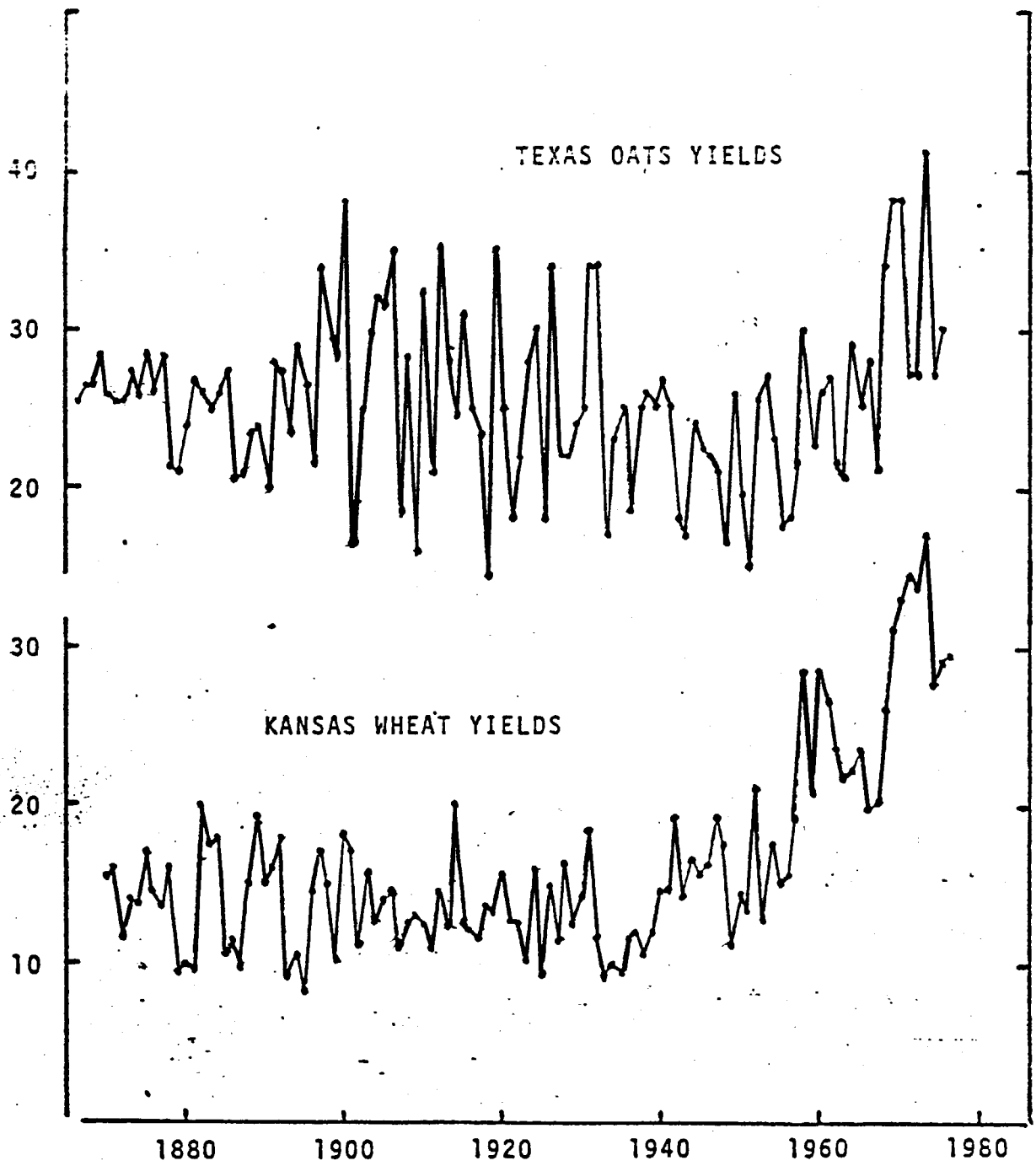
GENERAL - DEVELOP IMPROVED TECHNOLOGY TO PREDICT MORE ACCURATELY AND WITH KNOWN CERTAINTY, VALUE OF YIELD PER HARVESTED ACRE WHICH CAN BE USED IN PRODUCTION FORECASTING FOR LARGE U.S. AND FOREIGN REGIONS AT REGULAR INTERVALS PRIOR TO HARVEST

SPECIFIC - OBTAIN MODELS WHICH:

- ARE UNIVERSAL IN APPLICABILITY WITH A MINIMUM OF ANCILLARY DATA
- ARE MORE RESPONSIVE TO WEATHER -- ESPECIALLY ABNORMAL AND EPISODIC WEATHER
- INCORPORATE DIRECT OBSERVATION OF CROPS, WEATHER, SOILS, AND SOIL MOISTURE FROM SATELLITES
- SUPPORT THE IDENTIFICATION OF PARTICULAR CROP IN REMOTE SENSING PROCEDURES
- FLEXIBLE AND EFFICIENT TO OPERATE AND UPGRADE

FY78 YIELD-RELATED SUPPORT & RESEARCH & TECHNOLOGY

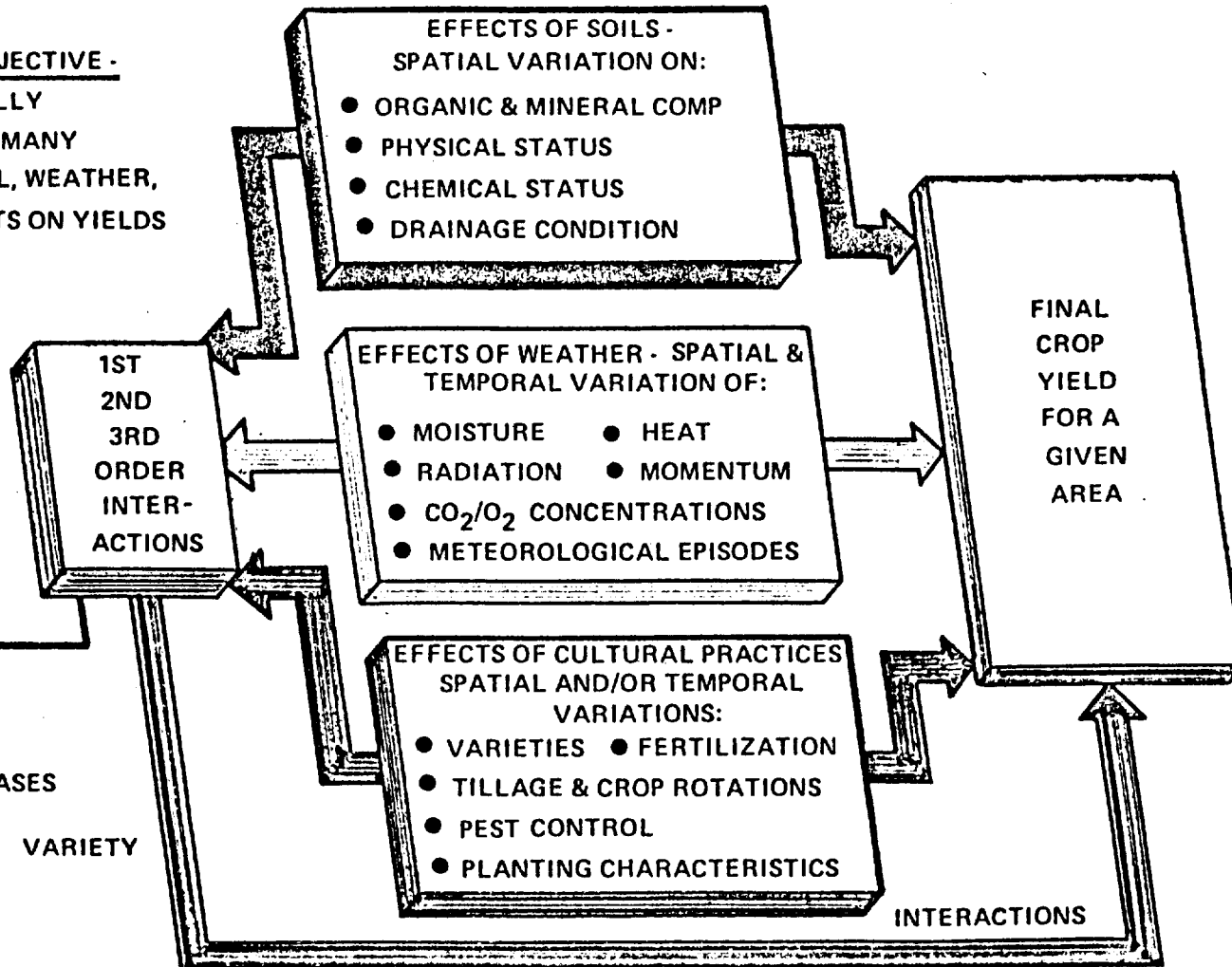
- KSU - FEYERHERM  
CONTINUE DEVELOPMENT AND TESTING OF KSU YIELD MODEL
- KSU - KANEMASU  
CONTINUE DEVELOPMENT AND TESTING OF KANEMASU GROWTH AND YIELD MODELS
- USDA/ARS - WHEAT YIELD MODELING TEAM  
COLLECT DATA AND DEVELOP AN ADVANCED WHEAT YIELD MODEL
- USDA/ARS - BLACK (FY77)  
DEVELOP A MODEL OF WINTERKILL PERCENT
- DPRA (FY77)  
DEVELOP A WINTER WHEAT STARTER MODEL AND IMPROVED CROP CALENDAR MODEL
- RFP  
DEVELOP IMPROVED TECHNIQUES FOR USING METSAT INFORMATION TO INTERPOLATE PRECIPITATION AMONG FIRST ORDER STATIONS AND DERIVE SOLAR RADIATION ESTIMATES: PROVIDE IN A FORMAT WHICH NOAA CAN IMMEDIATELY USE
- RFP  
DEVELOP A HYBRID YIELD MODEL BASED, PERHAPS ON THE FEYERHERM AGROMET MODEL AND INCORPORATING LANDSAT - DERIVED (ET/ETP) OVERRIDES
- RFP  
DEVELOP A MET-BASED MODEL WHICH PREDICTS CROP LANDSAT SPECTRAL APPEARANCE ON ANY CALENDAR DATE



EXAMPLES OF YEAR-TO-YEAR VARIABILITY IN LARGE AREA CROP YIELDS

# YIELDS ARE DETERMINED BY THE INTEGRATED EFFECTS OF BASIC SOILS, CLIMATE AND CULTURAL FACTORS BY CROPS

YIELD MODELLING OBJECTIVE -  
MATHEMATICALLY  
ACCOUNT FOR AS MANY  
AS POSSIBLE OF THE SOIL, WEATHER,  
AND CULTURAL EFFECTS ON YIELDS

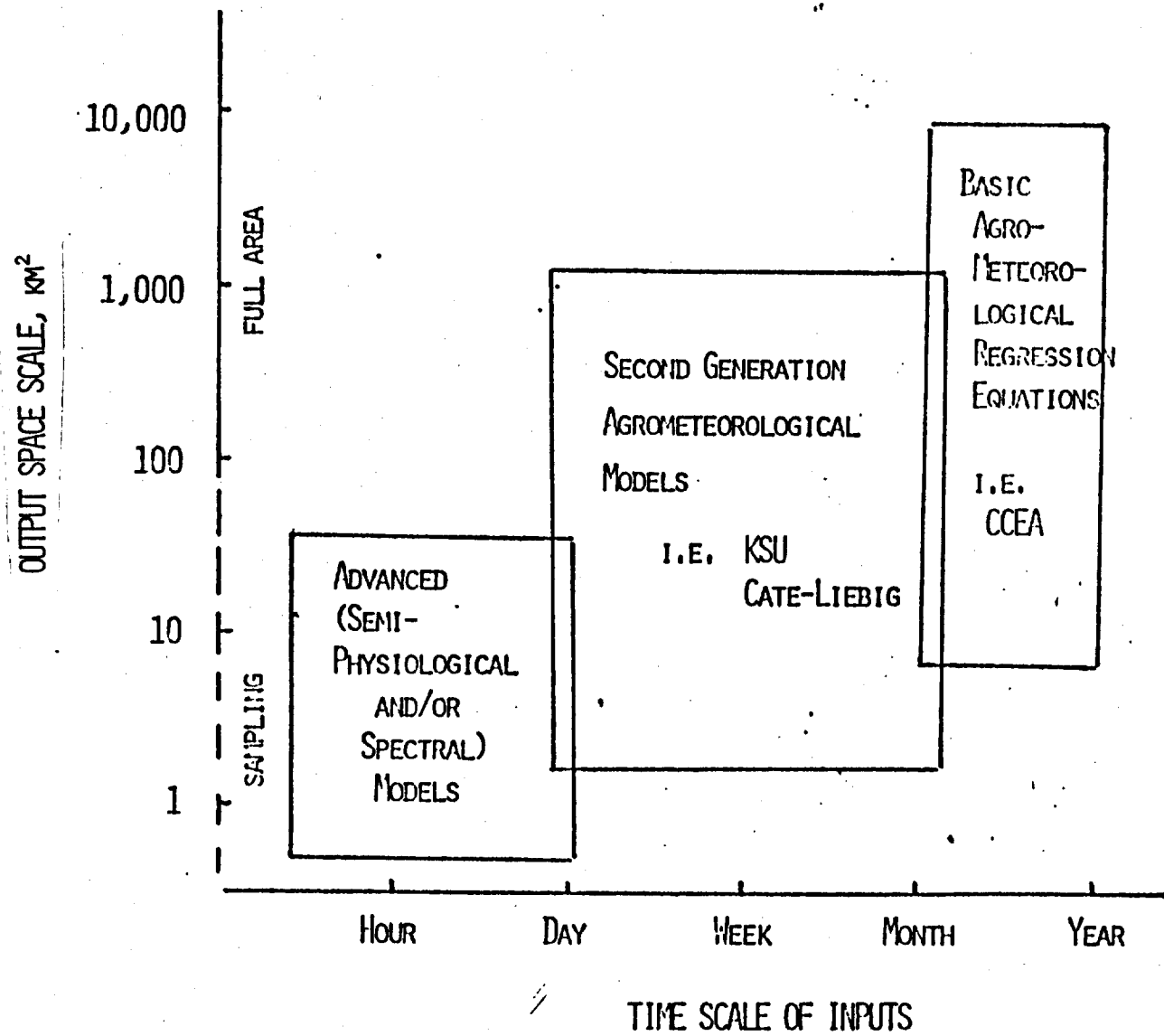


FOR EXAMPLE:

- CROP CALENDER x DISEASES
- SOIL FERTILITY x SOIL MOISTURE x VARIETY

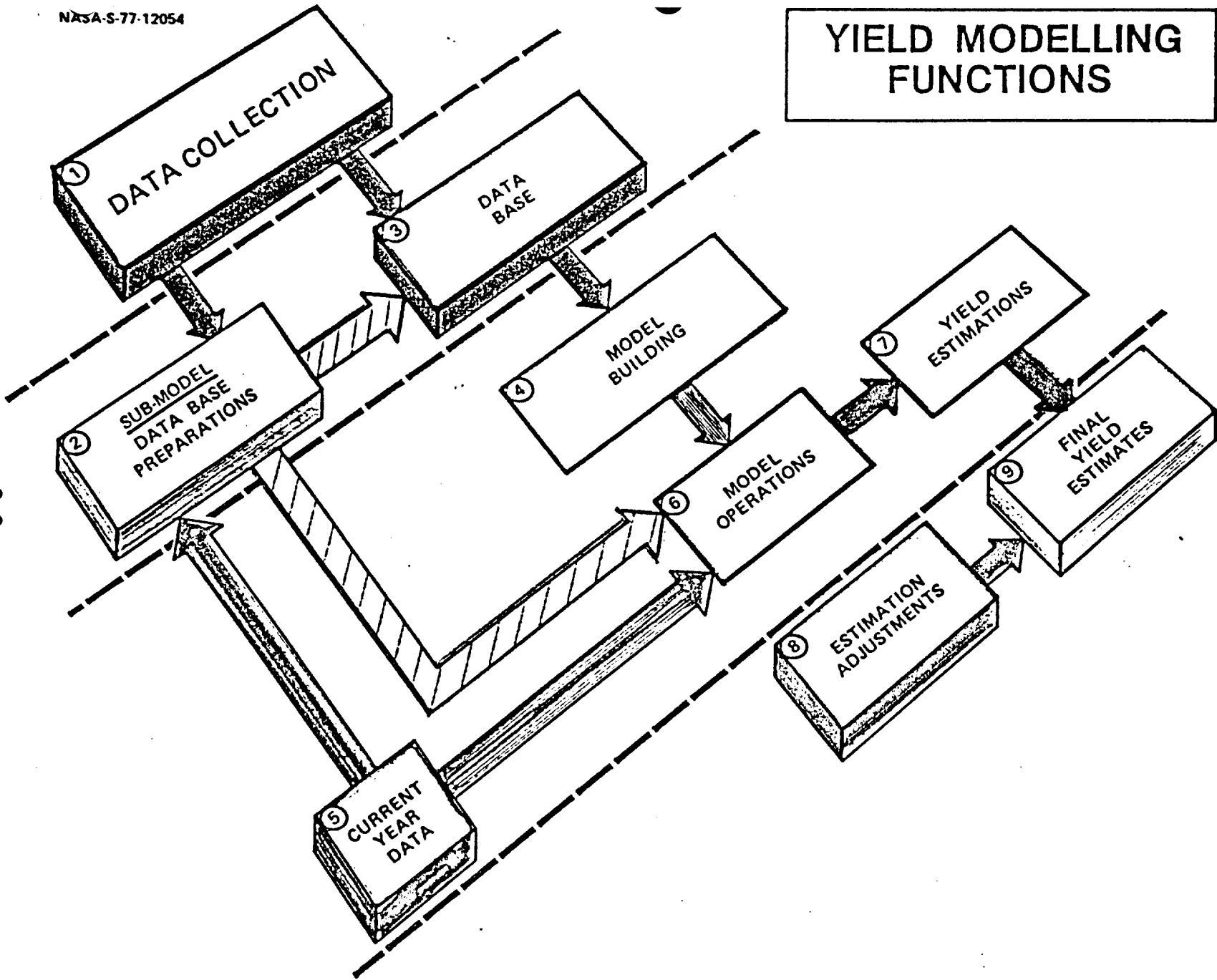


# YIELD MODEL TYPES

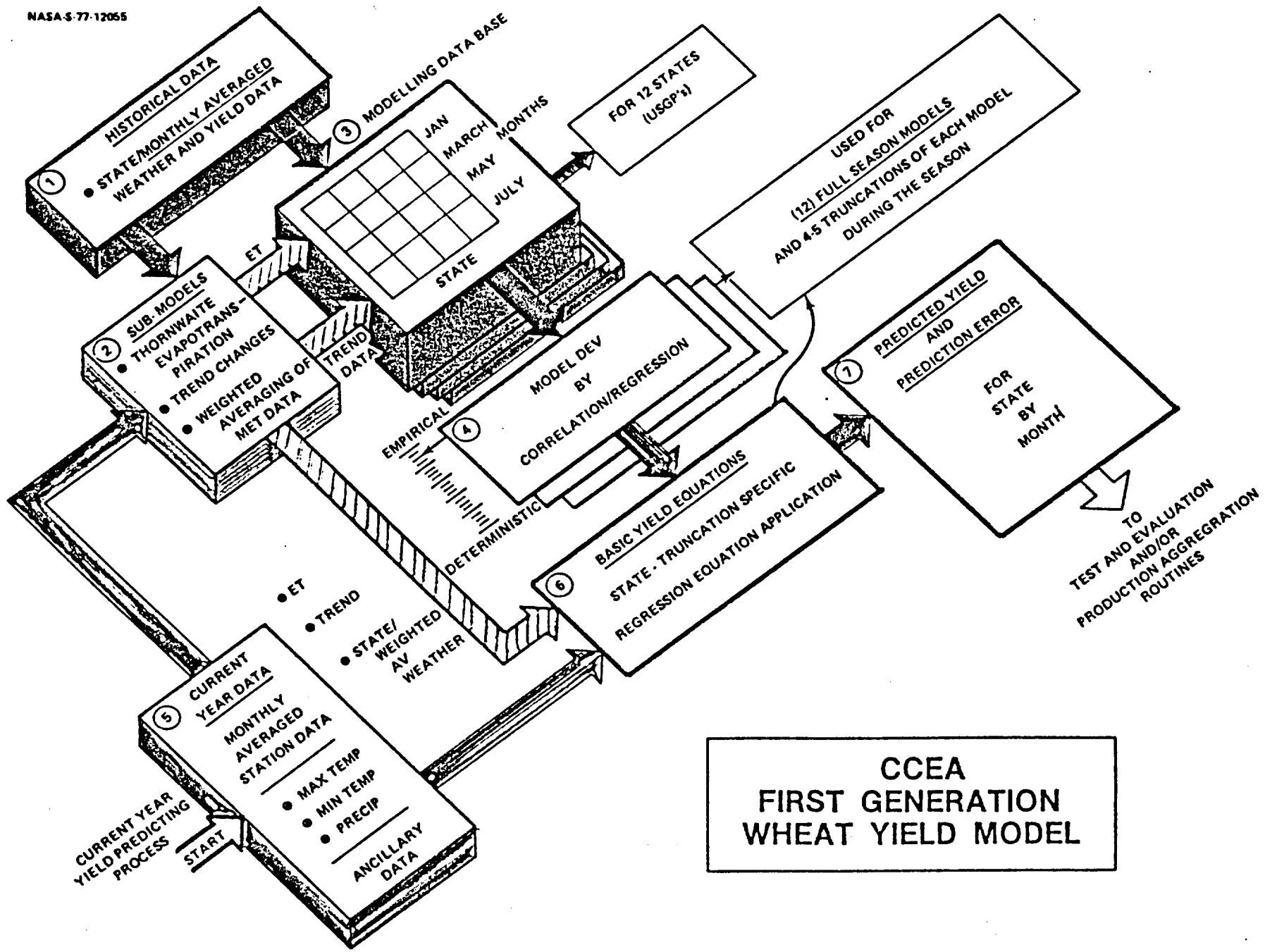


# YIELD MODELLING FUNCTIONS

2-9



2-10



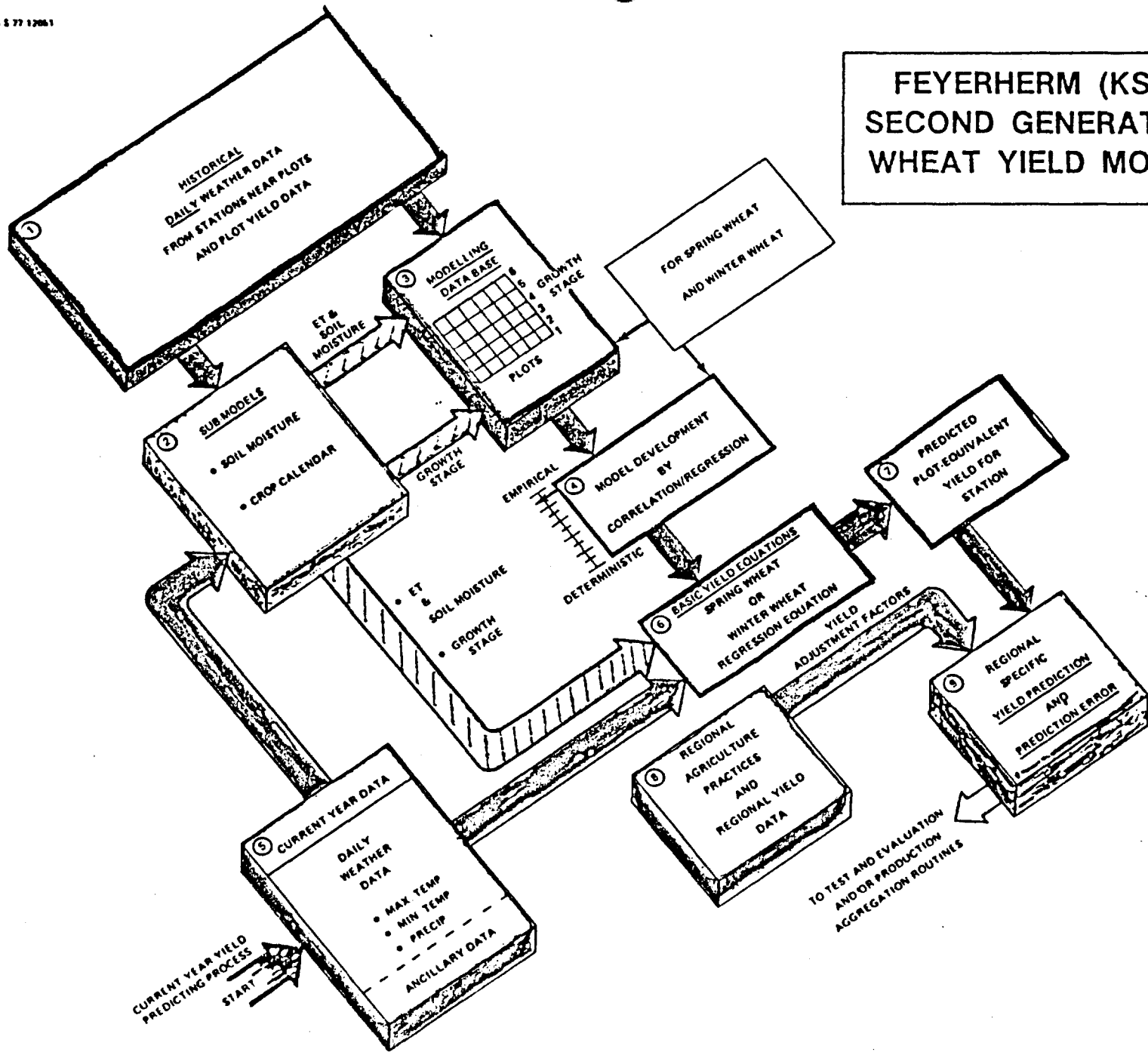
CCEA FIRST GENERATION WHEAT YIELD MODEL

TEST AND EVALUATION RESULTS - SUMMARY TO DATE

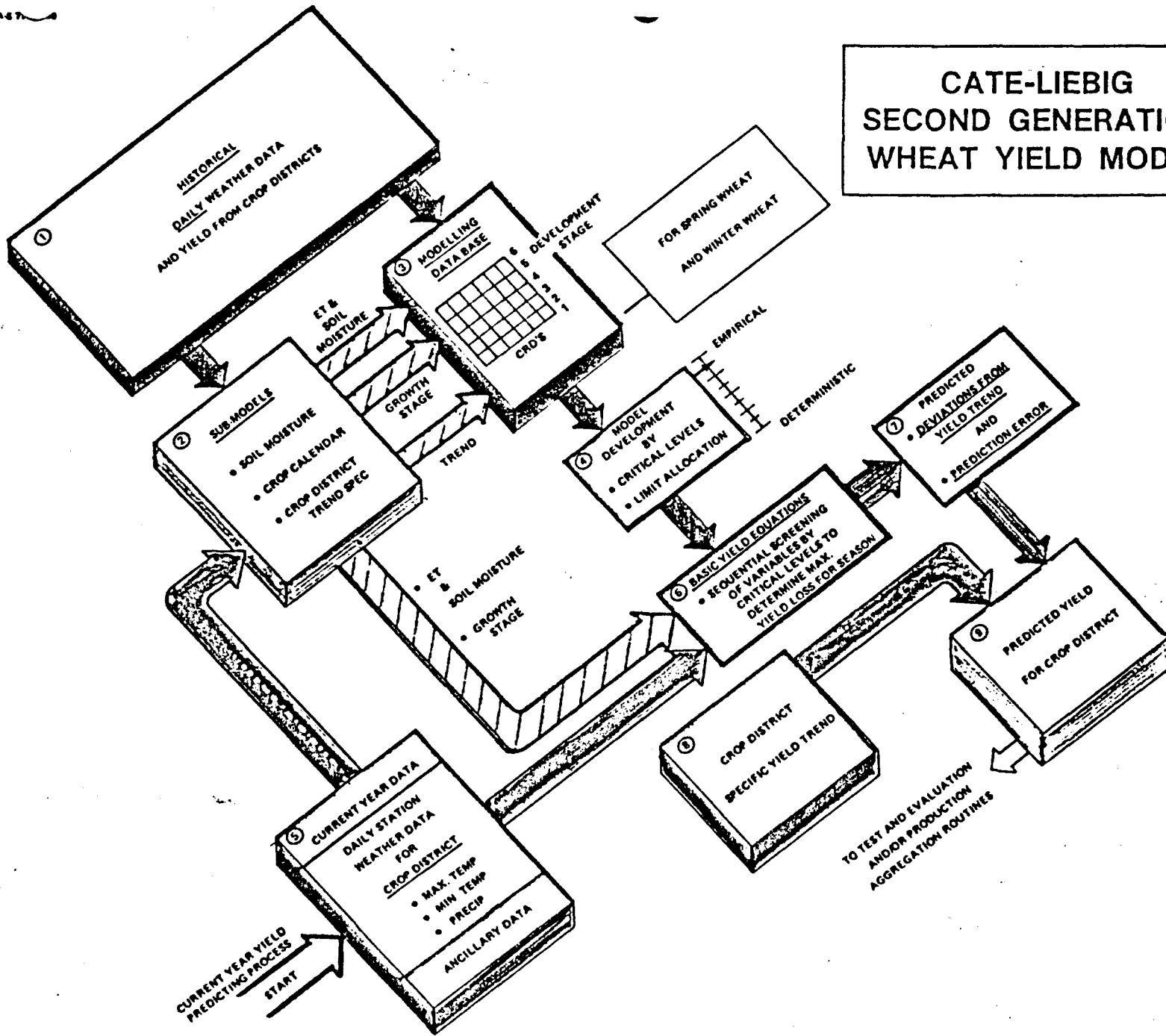
- BASIC AGROMET REGRESSION MODELS (CCEA) CONDITIONALLY MEET 90/90 HYPOTHESIS
  - POWER OF 10-YEAR TEST RELATIVELY LOW AND INDEPENDENCE OF SAMPLE RESTRICTED
  - OBSERVED AMPLITUDE ABOUT MEANS OF PREDICTED YIELDS IS SMALL COMPARED TO ACTUALS
  - CASES OF BIAS OBSERVED IN INDIVIDUAL MODEL REGIONS
  - CASES OF LARGE SINGLE YEAR ERRORS IN INDIVIDUAL STRATA ARE OBSERVED
  - VARIANCE COMPUTATIONS VALID
- POTENTIAL IMPROVEMENT BY SECOND GENERATION MODELS INDICATED BUT NOT YET DEMONSTRATED ON FULL REGION (90/90) CRITERIA

**FEYERHERM (KSU)  
SECOND GENERATION  
WHEAT YIELD MODEL**

2-12

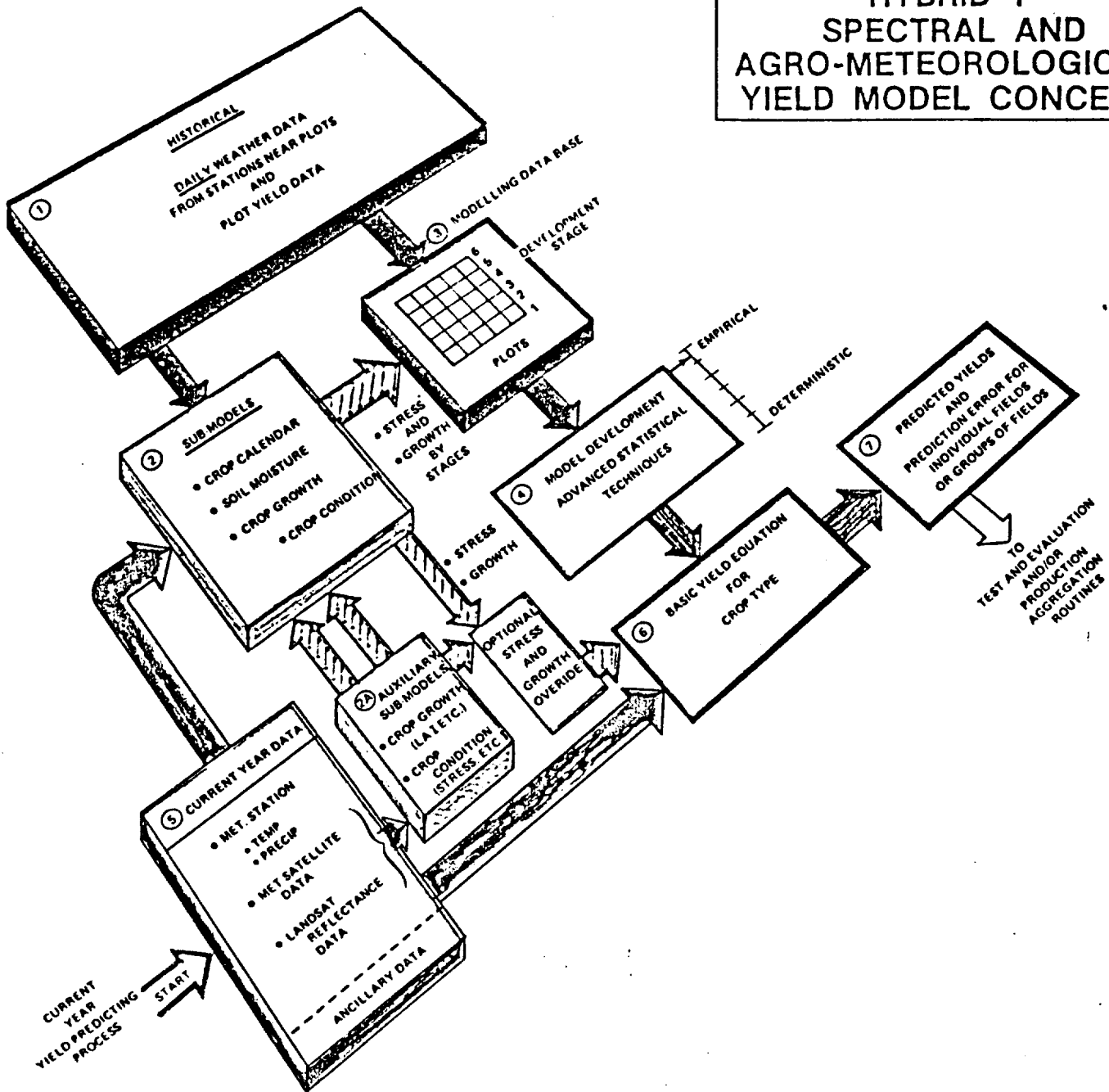


# CATE-LIEBIG SECOND GENERATION WHEAT YIELD MODEL



# HYBRID 1 SPECTRAL AND AGRO-METEOROLOGICAL YIELD MODEL CONCEPT

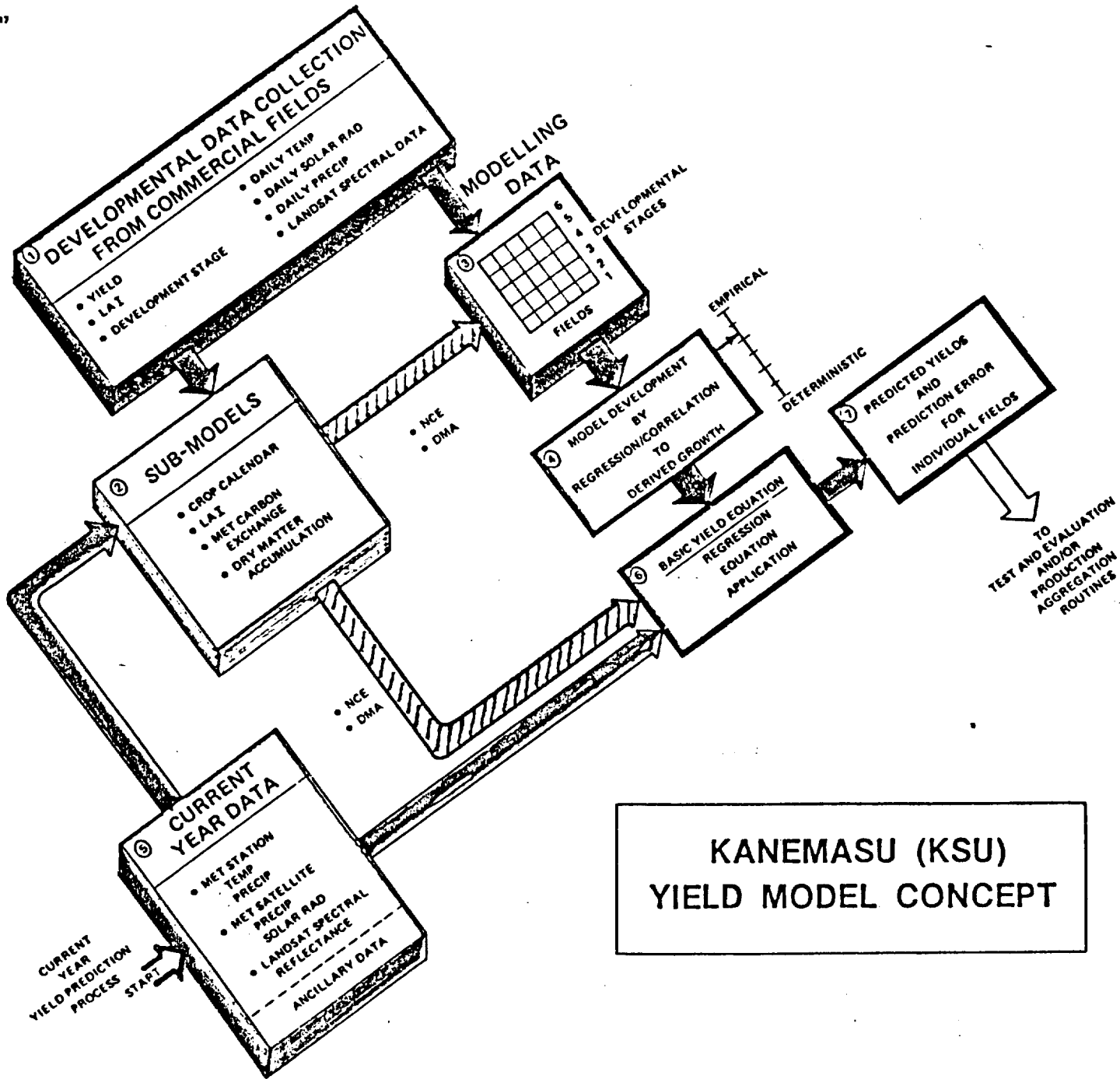
2-14



CURRENT YEAR PREDICTING PROCESS START

TO TEST AND EVALUATION AND/OR PRODUCTION AGGREGATION ROUTINES

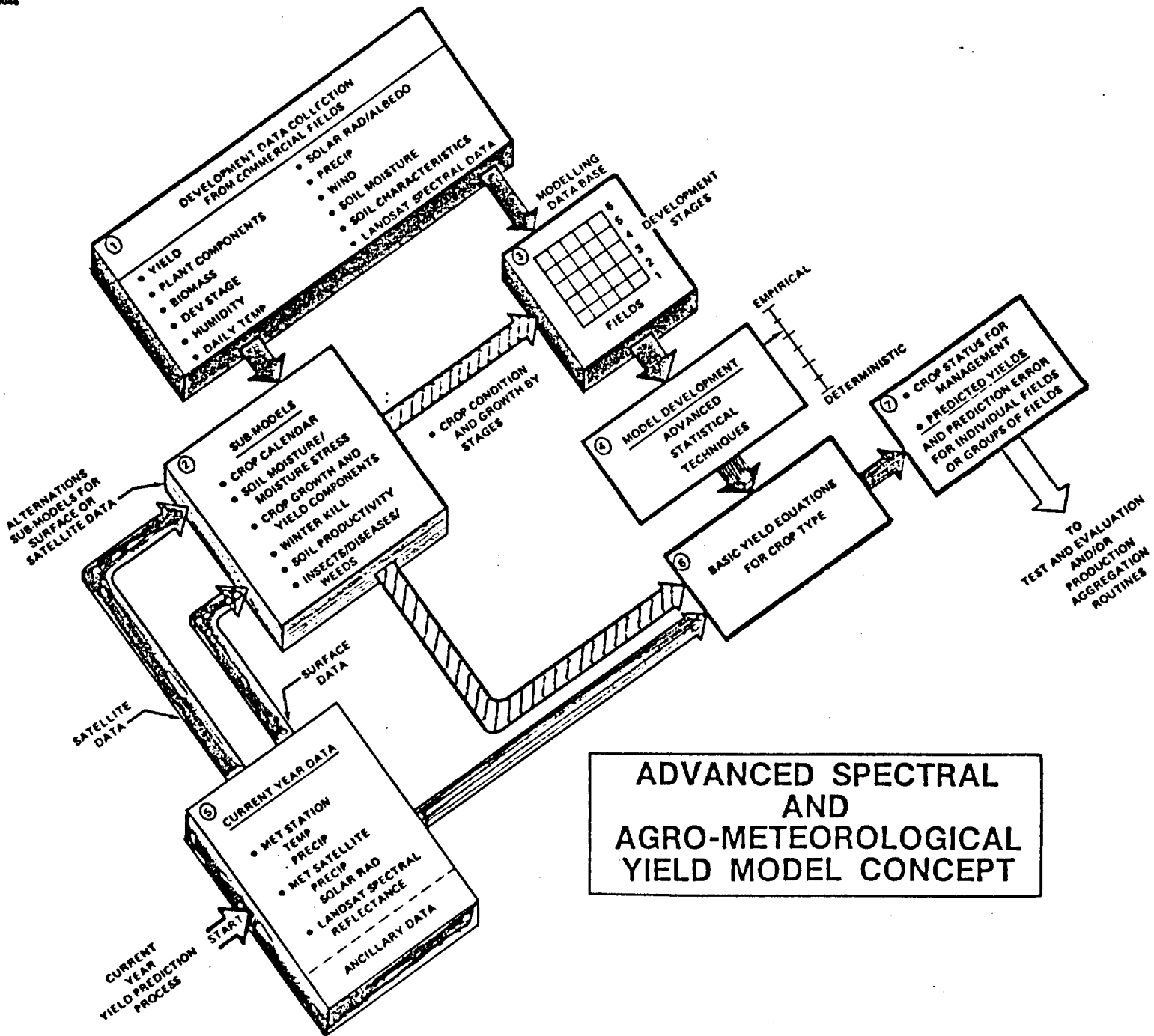
2-15



KANEMASU (KSU)  
YIELD MODEL CONCEPT



2-16



**ADVANCED SPECTRAL AND AGRO-METEOROLOGICAL YIELD MODEL CONCEPT**

## RATIONALE FOR METEOROLOGICAL-SPECTRAL HYBRID MODELS

- FOR METEOROLOGICAL PARTS
  - ENVIRONMENTAL CONDITIONS AT CRITICAL TIMES IN CROP'S LIFE CYCLE CAN AFFECT YIELD WITHOUT CHANGING ITS APPEARANCE
  - IN MOST GRAIN CROPS THE YIELD COMPONENT IS HIDDEN FROM VIEW AND VARIES IN PROPORTION TO THE VISIBLE VEGETATIVE COMPONENTS
  - CAN UTILIZE AVAILABLE DATA SOURCES WHICH ARE INDEPENDENT OF CLOUD COVER
  - INCORPORATE EXTENSIVE MODELING EXPERIENCE
  
- FOR SPECTRAL PARTS
  - STANDING CROPS INTEGRATE MOST ENVIRONMENTAL AND CULTURAL EFFECTS UP TO ANY POINT IN TIME, THUS HAVE POTENTIAL FOR DIRECT ASSESSMENT OF NET STRESS OR DAMAGE...YIELD
  - CORRELATION OF SPECTRAL DIFFERENCES WITH FIELD-TO-FIELD YIELD DIFFERENCES DEMONSTRATED
  - DATA IS NOT SUBJECT TO ACCURACY DIFFERENCES BETWEEN REGIONS

## TECHNICAL ISSUES

- DEFINITION OF OPTIMUM AGROPHYSICAL STRATA FOR YIELD AND AREA ESTIMATION
- QUALITY CONTROL AND STANDARDIZATION OF MODEL BUILDING, TESTING, AND OPERATIONAL DATA
- SAMPLING ENVIRONMENTAL FACTORS FOR FULL STRATA PREDICTION VS. PREDICTING YIELD FOR A SAMPLE OF A STRATUM
- OPTIMUM COORDINATES AND FREQUENCY FOR INTERPRETATION OF METEOROLOGICAL INPUTS FOR ANY PARTICULAR MODEL
- DEFINITION OF CROP FEATURES VIEWED BY REMOTE SENSORS AT VARIOUS TIMES OF SEASON
- ACCOUNTING FOR WITHIN AND BETWEEN STRATA VARIABILITY OF CROP CALENDARS, SOIL CHARACTERISTICS AND MANAGEMENT PRACTICES
  - ADEQUATE AGROMET AND SPECTRAL METHODS TO PREDICT PLANTING AND CROP DEVELOPMENT STAGES
  - ADEQUATE MODELS TO TRACK SOIL MOISTURE AVAILABILITY TO CROPS
- DEVELOPMENT OF INTERCHANGEABLE SPECTRAL OR METEOROLOGICAL INPUTS FOR A COMMON YIELD MODEL
- ESTIMATION OF FACTORS WHICH CAUSE TRENDS IN YIELD
- DEFINING EFFECTS OF EPISODAL EVENTS WHICH ARE NOT TAKEN INTO COMPLETE ACCOUNT BY A MODEL
- USE OF LANDSAT-C THERMAL BAND DATA IN PREDICTING YIELD
- UTILIZATION OF SERIAL CORRELATIONS (TIME, SPACE, AND CROP TYPES) INTO YIELD PREDICTIONS
- APPROPRIATE TEST AND EVALUATION

## SECTION 3

### ON WINTER WHEAT YIELD FROM LANDSAT AND LANDSAT FOLLOW-ON SATELLITES

J. C. Harlan, Jr.  
Remote Sensing Center  
Texas A&M University  
College Station, Texas

The feasibility for determining winter wheat yield from earth observation satellite data has been examined. The desirability of utilizing crop observations for yield estimation is due in part to the limitations of meteorological yield models. Models based on meteorological data are adversely affected by the sparseness of weather stations. In addition, yield reducing factors which are not weather-related -- such as insects, diseases and soil fertility -- are difficult to quantify for inclusion in the models.

The hypothesis that wheat yield can be determined from multitemporal Landsat data is based on work relating grain yield to the size and duration of the crop photosynthetic system and on studies relating Landsat data to green biomass. Cereal crop grain yield can largely be attributed to the photosynthesis during the growth and maturation of the grain [1]. The amount of photosynthesis depends on two factors: the size and duration of the photosynthetic system; and the efficiency of that system.

The correlation between green biomass and the Transformed Vegetation Index has been established [2, 3, 4]. The size of the photosynthetic system of wheat is reflected in the Landsat measurement of green biomass. Likewise, the duration of the system is determinable from repetitive Landsat coverage. The system efficiency is variety dependent, not measurable from Landsat, and, therefore, a noise factor.

In this study data has been analyzed for selected locations in the southern Great Plains region of the United States, from four crop years. High resolution spectral data acquired of commercial wheat fields were used to simulate data from Landsat and projected Landsat Follow-On sensors. Actual Landsat data were used as well. Field-by-field yield data were acquired from farmers in terms of actual harvested grain weight or from the U.S. Department of Agriculture (USDA) in terms of yield/area extrapolated from field samples.

All Landsat data utilized in this study were treated under a standard procedure. The data preprocessing consists of 1) application of a cosine correction for sun angle so that the sun appears to have been at zenith; 2) grouping pixels by individual land units (in this case, farmers' fields); and 3) calculation of the Landsat band mean vector and correlation matrix for each of the fields. The Transformed Vegetation Index (TVI) is calculated from the following equation:

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Work supported by the U.S. National Aeronautics and Space Administration through contract NAS9-14470.

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$$TVI = \sqrt{\frac{MSS7 - MSS5}{MSS7 + MSS5}} + 0.5$$

Where the MSS values are the mean radiances (sun angle corrected) for the given field.

S-191H spectral reflectance data (field spectra referenced to a barium sulfate coated panel) were processed to the bandpasses of the Landsat MSS plus two other near infrared bands, one of which is equivalent to the 1.55-1.75  $\mu\text{m}$  band proposed for the Thematic Mapper for Landsat D. The bands are given below. Vegetation parameters (VP) of the same form as the TVI were utilized with the S-191H reflectance data. These parameters each use two of the bandpasses at one time as follows:

$$VP2i = \sqrt{\frac{\text{Band } i - \text{Band } 2}{\text{Band } i + \text{Band } 2}} + 0.5$$

Where  $i = 3, 4, 5$  and  $6$ ; the Band values are the mean reflectance values for the given field and the band limits are:

1	0.50-0.60 $\mu\text{m}$	4	0.80-1.10 $\mu\text{m}$
2	0.60-0.70 $\mu\text{m}$	5	1.15-1.30 $\mu\text{m}$
3	0.70-0.80 $\mu\text{m}$	6	1.45-1.75 $\mu\text{m}$

Preliminary to determining the relationship of yield to spectral data the correlation between Landsat TVI, calculated from sun angle corrected radiance values, and the S-191H vegetation parameters, calculated from reflectance was determined. Landsat-1 and the S-191H acquired data on the same date twice during the spring of 1974 (3/16 and 5/27) and once within a day of each other under the same atmospheric conditions (4/3 and 4/4). To compare the data sets from the two sensors, the TVI and VP2i values were calculated for all wheat fields observed by both. Regression analysis of the TVI versus each of the S-191H vegetation parameters produced the results expressed in Table 1. Correlation coefficients for TVI versus VP2i are given for each date. For each date VP23, VP24 and VP25 are seen to be very highly correlated to the Landsat TVI. VP26, where band 6 is the 1.55-1.75  $\mu\text{m}$  Thematic Mapper band, is radically different, however, particularly during ripening (5/27). VP26 does not measure the same thing, then, and the 1.55-1.75  $\mu\text{m}$  band pass must contain unique information.

The first efforts in the investigation were applied to data collected at one site during the 1973-1974 crop year. Seven Landsat acquisitions of a 4.8 by 4.8 km (3 by 3 mile) commercial farming area were examined which covered all growth stages from fall establishment to ripe. TVI values were determined for each Landsat pass for 23 wheat fields for which yield data were available. The yield values ranged from 0.86 to 4.035 metric tons/hectare (12.8 to 60.0 bushels/acre). Linear regressions were applied with yield as the dependent variable and TVI or  $(TVI)^2$  for each date as the independent variables. The best combinations of variables from three or less Landsat acquisitions are given in Table 2. More variables did not significantly improve the relationship. Results for four or

TABLE 1 Correlation Coefficient  
Between S-191H Vegetation Parameters and LANDSAT TVI

Date	VP23	VP24	VP25	VP26
3/16/74 Jointing	0.944816	0.946827	0.944610	0.562205
4/4/74 Jointing	0.903736	0.923658	0.910313	0.656690
5/27/74 Ripening	0.899234	0.882267	0.854460	-0.027195

less passes are the most useful since it is unlikely that more biophases than that could be consistently acquired of a given site by Landsat due to cloud cover or snow on the ground.

TABLE 2 Bushland 1973/1974 Yield Estimation  
Regression Models from Landsat TVI Values

R <sup>2</sup>	Number of Variables	Number/Names of Biophases	Order of Equation
0.874	3	2/Fall establishment (11/28/73) Heading (5/8/74)	2
0.861	3	2/Tillering (12/16/73) Heading (5/8/74)	2
0.888	5	3/Fall establishment (11/28/73) Tillering (12/16/73) Heading (5/8/74)	2

The results from the Bushland analysis were very encouraging. The work since that time has been dedicated to testing the Bushland technique. The first data set used in the testing is that from S-191H observations over western Kansas farms during 1974/1975. From the correlation between TVI and VP24 the ability to simulate TVI data from S-191H values was established. For each of the seven dates, representing five biophases the simulated TVI values were calculated and linear regressions again run, this time with TVI-cubed and TVI raised to the fourth power as additional variables. The actual biophases and variables chosen were somewhat different from the Bushland set. The R<sup>2</sup> values were also 10%-20% lower for western Kansas. Even so, the results indicate that the Landsat-derived parameters by themselves could explain most of the variation in the observed yield data.

The other S-191H vegetation parameters were also calculated for each wheat field. Regression analyses were run for each vegetation parameter using the VP value and its square as variables to determine the capability for explaining yield variation through other vegetation parameters besides TVI (VP24) and, specifically, to examine the use of the Thematic Mapper band, 1.55-1.75  $\mu\text{m}$  (S-191H band 6).

Table 3 summarizes the results of the regression analyses utilizing the S-191H vegetation parameters. Using no more than four passes it is apparent that each vegetation parameter is capable of explain-

ing most of the yield variation. As noted above the VP26 contains different information than VP24 and VP25. This comes through again in that different biophases were chosen when using VP26, while the resulting R<sup>2</sup> values were comparable to those obtained using the other two parameters. It can be concluded that although no apparent increase in yield estimation accuracy occurred by using the 1.55-1.75  $\mu$ m information in this vegetation parameter the flexibility of using the satellite-borne Thematic Mapper in yield estimation will be greater since more combinations of three or four cloud free passes could be used with the same accuracy. For example, if tillering and ripening were the only cloud free passes, then TVI could be used; while if jointing and heading were good, but tillering not, then "TVI26" could be used where the 2 and 6 were, respectively, the MSS 5 equivalent and the 1.55-1.75  $\mu$ m band.

TABLE 3 Regression Model Results From Landsat Band and Proposed Sensor Band Parameters

Parameter	R <sup>2</sup>	Number of Variables	Number/Names of Biophases	Order of Equation
VP24	0.756	4	3/Tillering (3/20/75) Ripening (6/2/75) Ripening (6/9/75)	2
VP25	0.743	4	4/Tillering (3/20/75) Ripening (6/2/75) Ripening (6/9/75) Ripening (6/17/75)	2
VP26	0.654	4	3/Jointing (4/8/75) Green Headed (5/21/75) Ripening (6/17/75)	2
	0.738	5	4/Jointing Green Headed Ripening (6/9) Ripening (6/17)	2

Results of work relating temporal series of vegetation parameter values to wheat yield pointed out that some important yield influencing factors were not accounted for in the data set. This conclusion was evident because algorithms developed for one location or one year were not accurate when applied to another location or even a second year at the same location. Consequently two approaches for further work were taken.

One to be done in-house at NASA/Johnson Space Center involved examination of the TVI yield estimation technique in a year-to-year mode. That is, determining if estimates of year-to-year variation of yields corresponded to variation of TVI at certain growth stages. The approach involved combining the temporal series of TVI values per year per field or CRD (crop reporting district) unit into terms 'TVI(75-76)' and 'TVI(76-77)'. These would be combined with the known yield for crop year '75-'76, 'Y(75-76)', to determine an estimate of the '76-'77 yield, 'Y(76-77)':

$$\hat{Y}(76-77) = Y(75-76) * \frac{TVI(76-77)}{TVI(75-76)}$$

The accuracy of these yield estimates would be determined by comparing against ASCS- and SRS-reported yields for '76-'77.

The second approach, implemented at Texas A&M University, involves examining the response of multispectral scanners to occurrences of yield detractant phenomena such as drought and disease. The emphasis is being placed on quantifying the relationship between crop condition and scanner parameters. The ultimate goal is to increase the universality of Landsat-based yield estimation techniques.

Johnson Space Center Agricultural Field Measurements Program data are used exclusively since there are no other sources of such information. NASA helicopter-borne spectrometer (S-191H) and truck-mounted spectrometer data have been used to simulate Landsat MSS and Thematic Mapper band values. These are used in conjunction with agronomic ground data acquired by the USDA/ASCS and NASA/JSC in support of the Field Measurements Program flights and Landsat passes. Data have been used from the 1974-1975 and 1975-1976 crop years at both the Williams County, North Dakota, Intensive Test Site and Agricultural Experiment Station and from the Finney County, Kansas, Intensive Test Site and Agricultural Experiment Station.

At the writing of this document analysis of the responses of individual scanner bands to yield/growth detractant occurrences is nearing completion. Analysis of the visible and reflective infrared band values substantiates the unique character of the proposed 1.55-1.75  $\mu\text{m}$  Thematic Mapper band 5 mentioned above. When fields were grouped by ASCS-reported detractant (no detractant, drought, uneven stand, or weeds) for a given growth stage the reflectance within the Thematic Mapper band 5 was generally different for "detractant" groups than for "no-detractant" groups (control fields). This was also true, but to a lesser extent, with a band between 2.10 and 2.35  $\mu\text{m}$ . It was not the case with either the present Landsat MSS bands of the Thematic Mapper bands 1 through 4. The Thematic Mapper, therefore, appears to afford future analysts the opportunity to classify wheat into condition classes or groups, related to probable yield, on each satellite pass.

A separate analysis scenario of the simulated Landsat C and Thematic Mapper thermal infrared band data for the Kansas Intensive Test Site has been applied. After eliminating advection from upwind fields as



a source of radiative temperature difference, within-field causes for differences were hunted. Spots within several fields were noted as relatively warmer or cooler than the mean field value on not one, but two separate dates three weeks apart (April 18 and May 6, 1976). A comparison of soil maps and relative canopy density (from aerial photos) has shown that, in general, the warm spots occur on patches of silt loam soils supporting less dense vegetation than the majority of the field area. These patches are more droughty than the most prevalent soil in the site. On the other hand the cooler spots are found in patches of clay which tend to retain moisture. The primary response of the thermal infrared band appears to be from the combination of moisture and canopy cover. Analysis is proceeding in this area in an attempt to quantify the thermal band sensitivity to these scene factors. The thermal band of Landsat C, to be available in 1978, should be valuable in interpreting crop condition from scanner data.

1. P. J. Welbank et al., *Annals of Botany*, N.S. 30 (118) 291 (1966).
2. J. W. Rouse, Jr. et al., in: Third ERTS-1 Symposium, NASA-Goddard Space Flight Center, 1973, p. 309.
3. R. H. Haas et al., in: Earth Resources Survey Symposium, NASA-Johnson Space Center, 1975, p. 43.
4. D. W. Deering et al., in: Tenth International Symposium on Remote Sensing of Environment, University of Michigan, 1975, p. 1169.

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

SITE DESIGNATOR: GP50\*1T                      CELLS 2309 TO 2428  
 IMAGE IDENTIFIER: 1619-16530                LINES 200 TO 280  
 DATE ACQUIRED: 03APR74                      TOTAL POINTS 40

\*\*\*CORRECTED FOR SUN ELEVATION 49 DEGREES\*\*\*

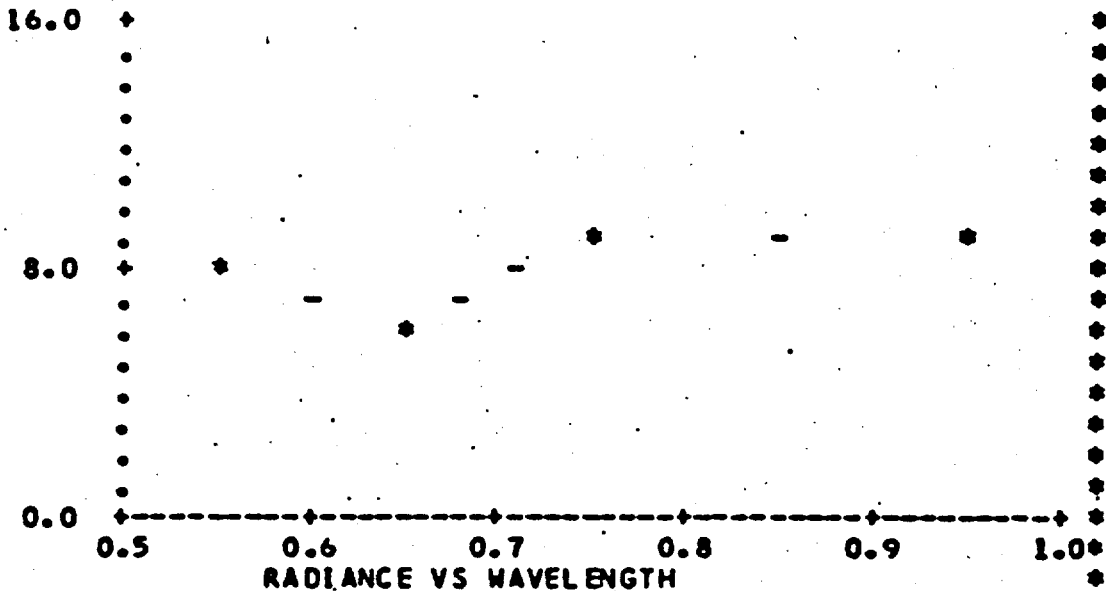
RADIANCE (MWATTS/SQCM-STR-MICROMETER)

	MEAN	STANDARD DEVIATION	WAVELENGTH (MICROMETERS)
BAND 4	7.58	0.54	.5 - .6
BAND 5	5.70	0.80	.6 - .7
BAND 6	9.10	0.98	.7 - .8
BAND 7	9.36	1.41	.8 - 1.1

NORMALIZED COVARIANCES

	BAND 4	BAND 5	BAND 6	BAND 7
BAND 4	1.000	0.808	-0.094	-0.163
BAND 5	0.808	1.000	-0.395	-0.484
BAND 6	-0.094	-0.395	1.000	0.937
BAND 7	-0.163	-0.484	0.937	1.000

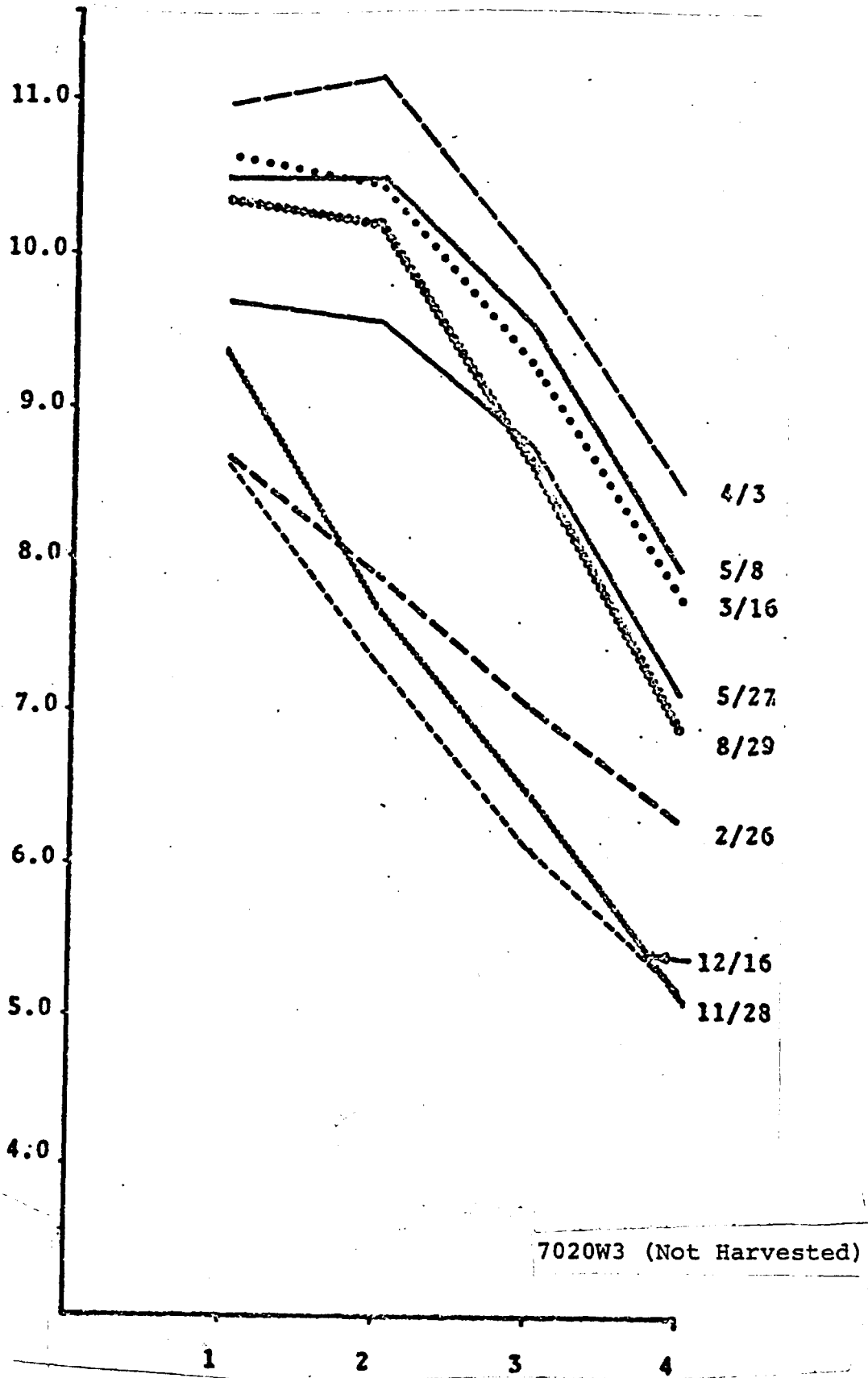
BAND RATIO PARAMETER 0.243 (Part of TVI)  
 TRANSFORMED PARAMETER 0.862 (TVI)



PREPARED BY: TEXAS A&M UNIVERSITY, REMOTE SENSING CENTER  
 DATA ANALYSIS LABORATORY 22JAN75

Figure 2-1. A Typical LANDSAT MSS Data Site Processing Report.

RADIANCE



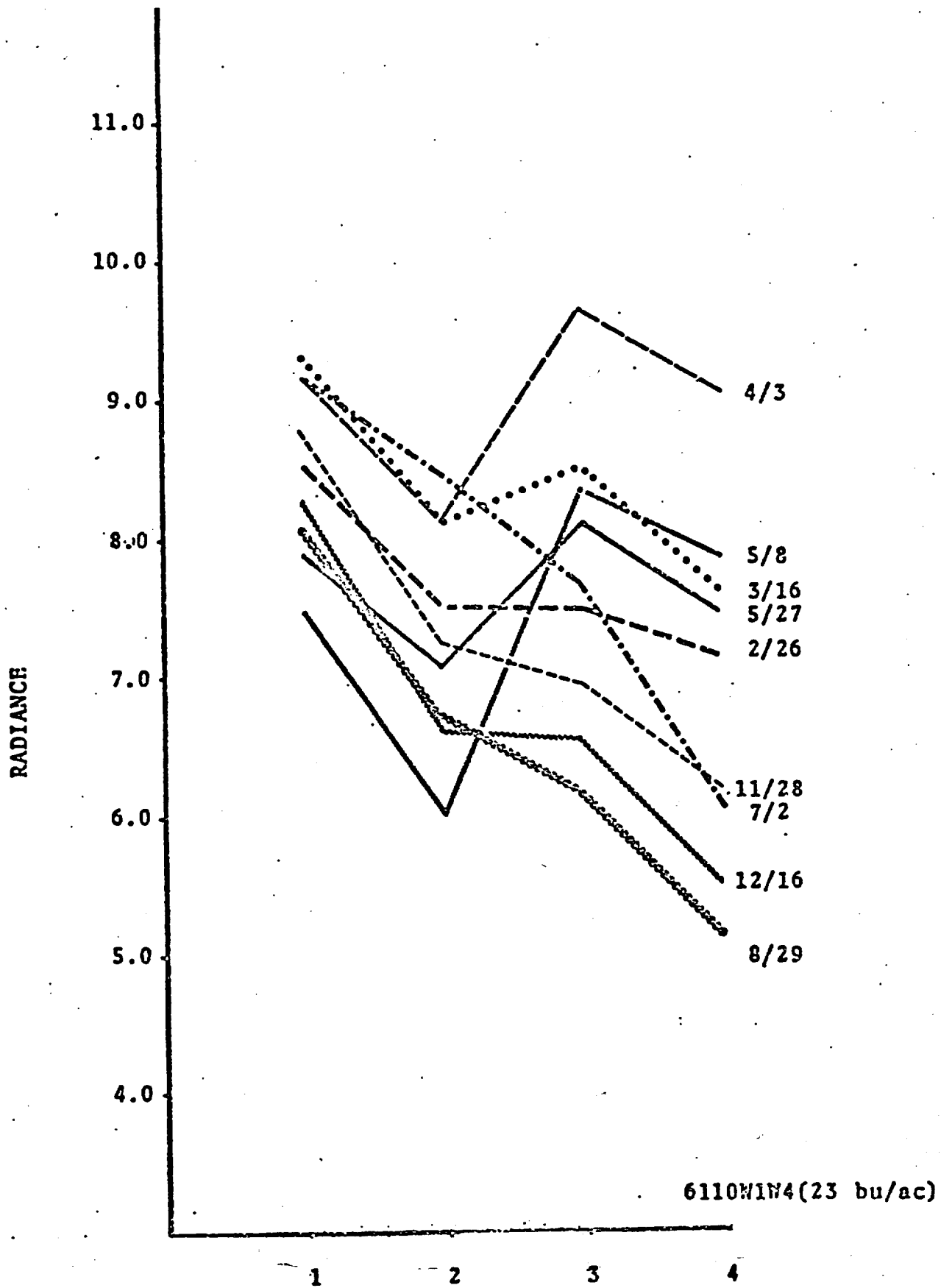
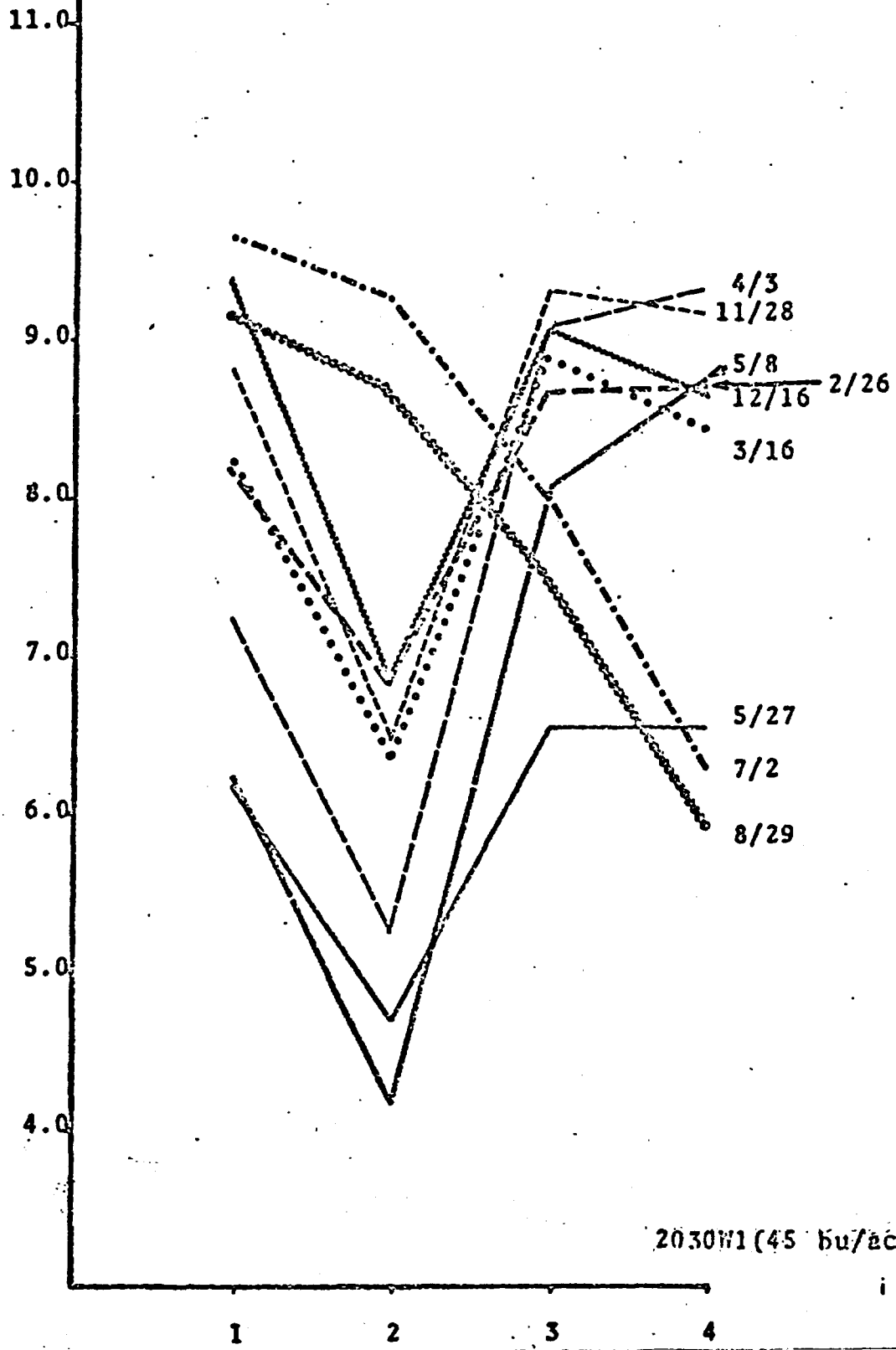
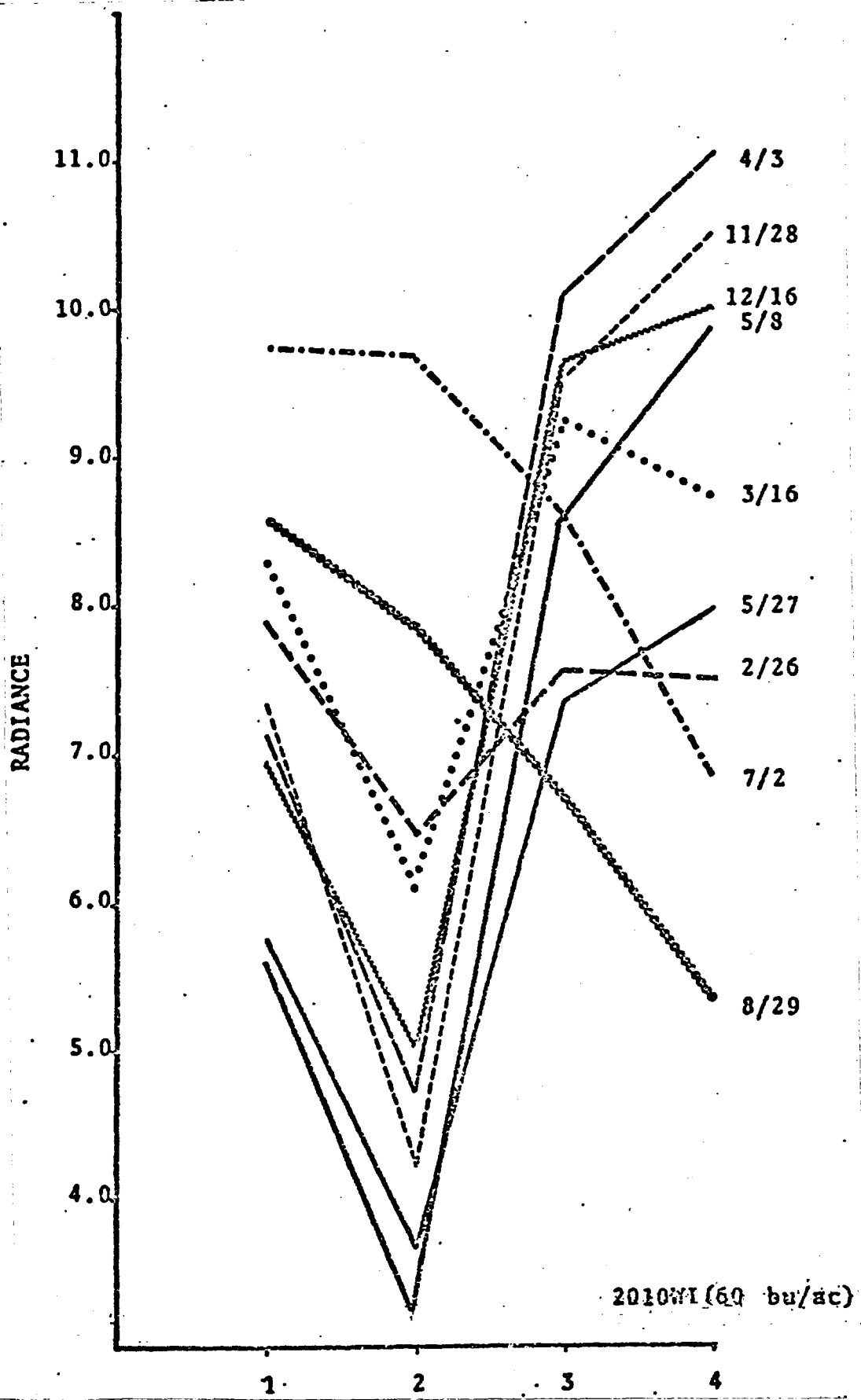


Figure 3-3. Radiance Values for a Low Yielding Irrigated Wheat Field.

RADIANCE





LANDSAT AND OTHER PROPOSED SENSOR BANDS

LANDSAT PLUS 2 OTHERS

1 0.50-0.60  
2 0.60-0.70  
3 0.70-0.80  
4 0.80-1.10  
5 1.15-1.30  
6 1.45-1.75

THEMATIC MAPPER

0.48-0.53  
0.53-0.60  
0.62-0.68  
0.74-0.91  
1.55-1.75  
THERMAL IR

CONCLUSIONS FROM PREVIOUS CONTRACT WORK:

- 1) HIGH CORRELATIONS WERE ACHIEVED BETWEEN WHEAT YIELD AND MULTITEMPORAL VALUES OF LANDSAT MSS AND THEMATIC MAPPER VEGETATION INDICES FOR EACH INDIVIDUAL LOCATION AND/OR YEAR.
- 2) REGRESSION MODELS DIFFERED, HOWEVER, FOR DIFFERENT LOCATIONS AND/OR YEARS. FACTORS NOT ACCOUNTED FOR BY THE VEGETATION PARAMETERS NEED TO BE EXAMINED.
- 3) CONCLUSION 2) LED TO THE PRESENT CONTRACT WORK AS WELL AS A JSC IN-HOUSE PROJECT TO ESTIMATE YEAR-TO-YEAR VARIATION IN YIELD FROM CORRESPONDING VARIATION OF THE VEGETATION PARAMETER TVI AT SELECTED GROWTH STAGES.
- 4) A NON-DESTRUCTIVE LAI (LEAF AREA INDEX) MEASUREMENT TECHNIQUE WAS DEVELOPED FROM PHOTOGRAPHY AND LAI MEASUREMENTS TAKEN FOR THE AGRICULTURAL FIELD MEASUREMENTS PROJECT AT THE FINNEY COUNTY SUPERSITE.



ISSUE: IMPROVED YIELD MODELS

PRESENT TASK: STRESS, STAND QUALITY AND CROP CONDITION FROM  
SCANNER DATA

OBJECTIVES RELATED TO ISSUE:

- 1) DETERMINE THE RESPONSE OF MULTISPECTRAL SCANNERS (LANDSAT 1 AND 2 MSS, LANDSAT C MSS AND THEMATIC MAPPER) TO OCCURRENCES OF YIELD DETRACTANTS SUCH AS DROUGHT AND DISEASE.
- 2) DEVELOP ALGORITHMS RELATING SPECTRAL RESPONSE TO YIELD.

APPROACH:

- 1) USE FSS AND TRUCK SPECTROMETER DATA FROM FINNEY COUNTY AND WILLIAMS COUNTY SUPERSITES FOR 1974/1975 AND 1975/1976 TO DETERMINE LANDSAT MSS AND THEMATIC MAPPER REFLECTANCE VALUES.
- 2) CALCULATE VEGETATION PARAMETERS FROM THE REFLECTANCE VALUES AND CORRELATE THEM WITH CROP CONDITION TO DETERMINE STRESS EFFECTS.
- 3) SUMMARIZE RESULTS AND ANALYZE AND INTERPRET THEM IN TERMS OF IDENTIFICATION AND QUANTIFICATION OF STRESSES AND THEIR EFFECTS.

1975 & 1976 KANSAS WINTER WHEAT:  
DEPENDENCIES OF SPECTRAL DATA ON GROUND DATA

SCANNER BAND	WITHOUT DETRACTANTS	WITH DETRACTANTS	
MSS 6	STAND QUALITY	DETRACTANTS	} WEEDS, UNEVEN STANDS
MSS 7	STAND QUALITY	DETRACTANTS	
THERMAL (8.0 - 13.5 $\mu$ m)	CANOPY HEIGHT	CANOPY HEIGHT	
TM 3	----	DETRACTANTS	} WEEDS, UNEVEN STANDS
TM 4	STAND QUALITY, CANOPY HEIGHT	DETRACTANTS	
TM 5	CANOPY HEIGHT	DETRACTANTS, CANOPY HEIGHT	} DROUGHT BOTH YEARS
2.10 - 2.35 $\mu$ m	STAND QUALITY	DETRACTANTS	
TVI7	CANOPY HEIGHT	DETRACTANTS, CANOPY HEIGHT	

\*GROWTH STAGE AND PERCENT GROUND COVER WERE BOTH CORRELATED WITH EACH BAND.

STAND QUALITY - 1 TO 6

GROWTH/YIELD DETRACTANTS - CODED

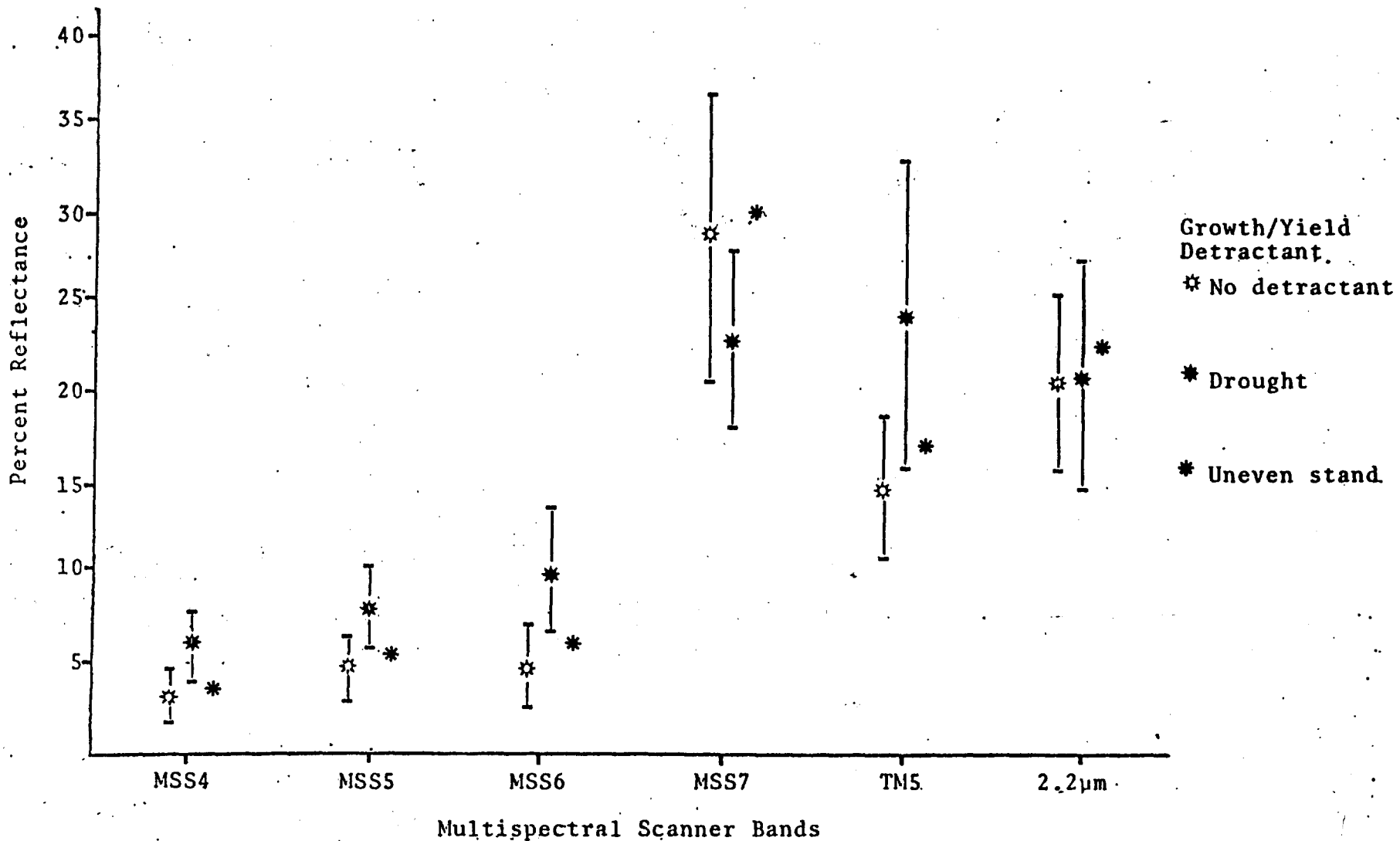
GROWTH STAGES - 1 TO 10

GROUND COVER - 1 TO 5 IN 20% INCREMENTS

CANOPY HEIGHT - IN INCHES

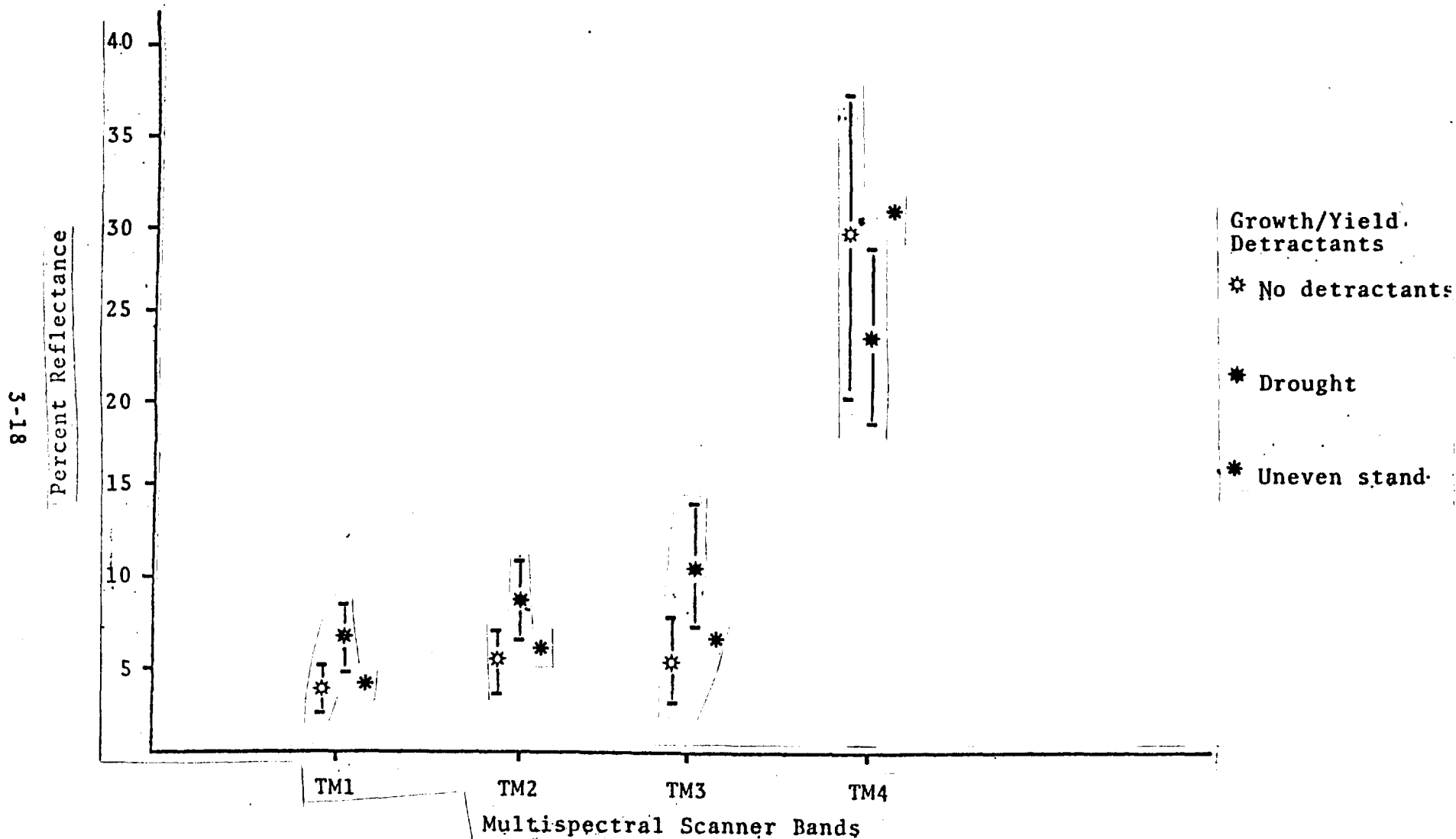
Winter Wheat, Kansas 1975. Growth Stage: Beginning to head

3-17



YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS

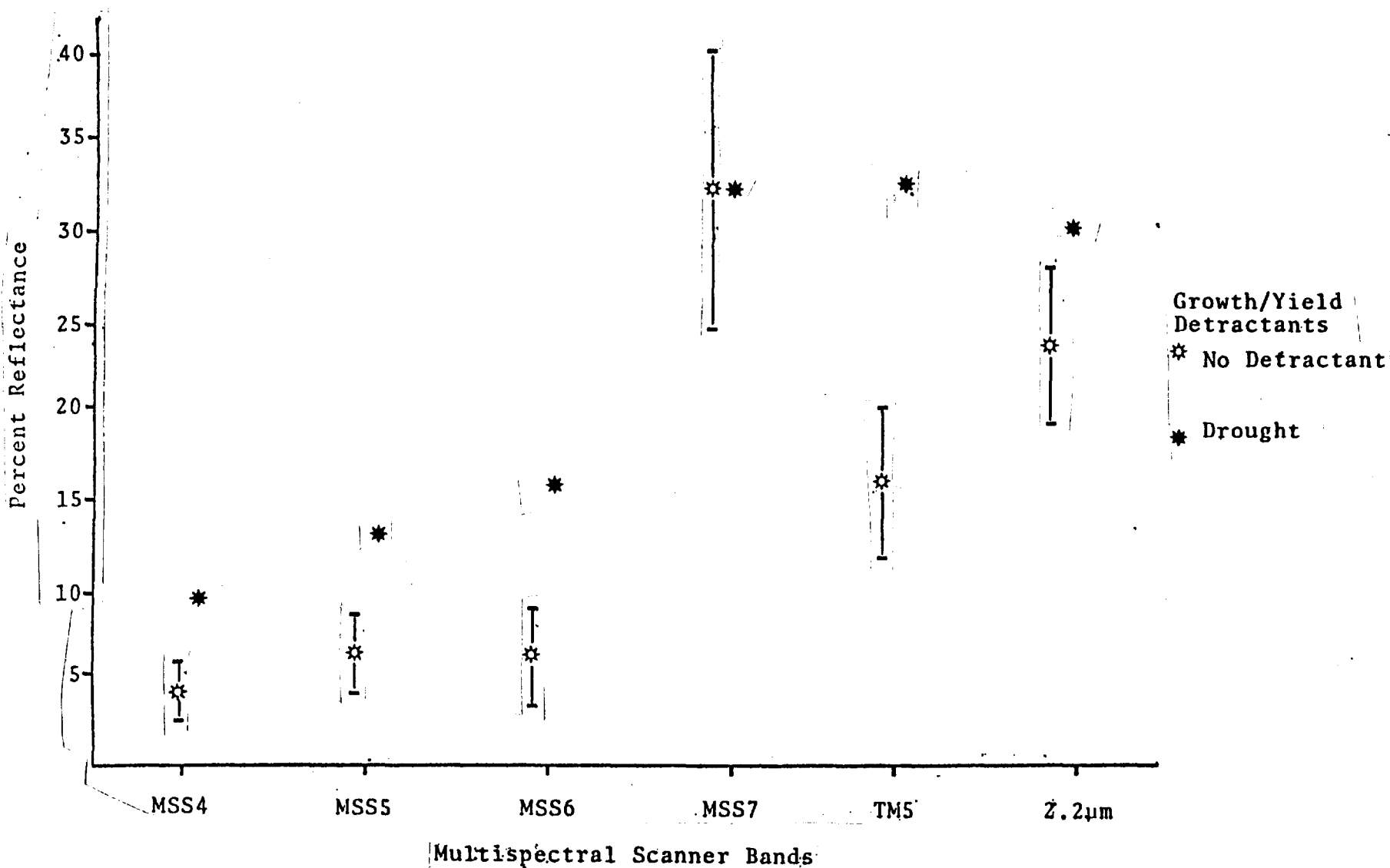
Winter Wheat, Kansas 1975. Growth Stage: Beginning to head



YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS

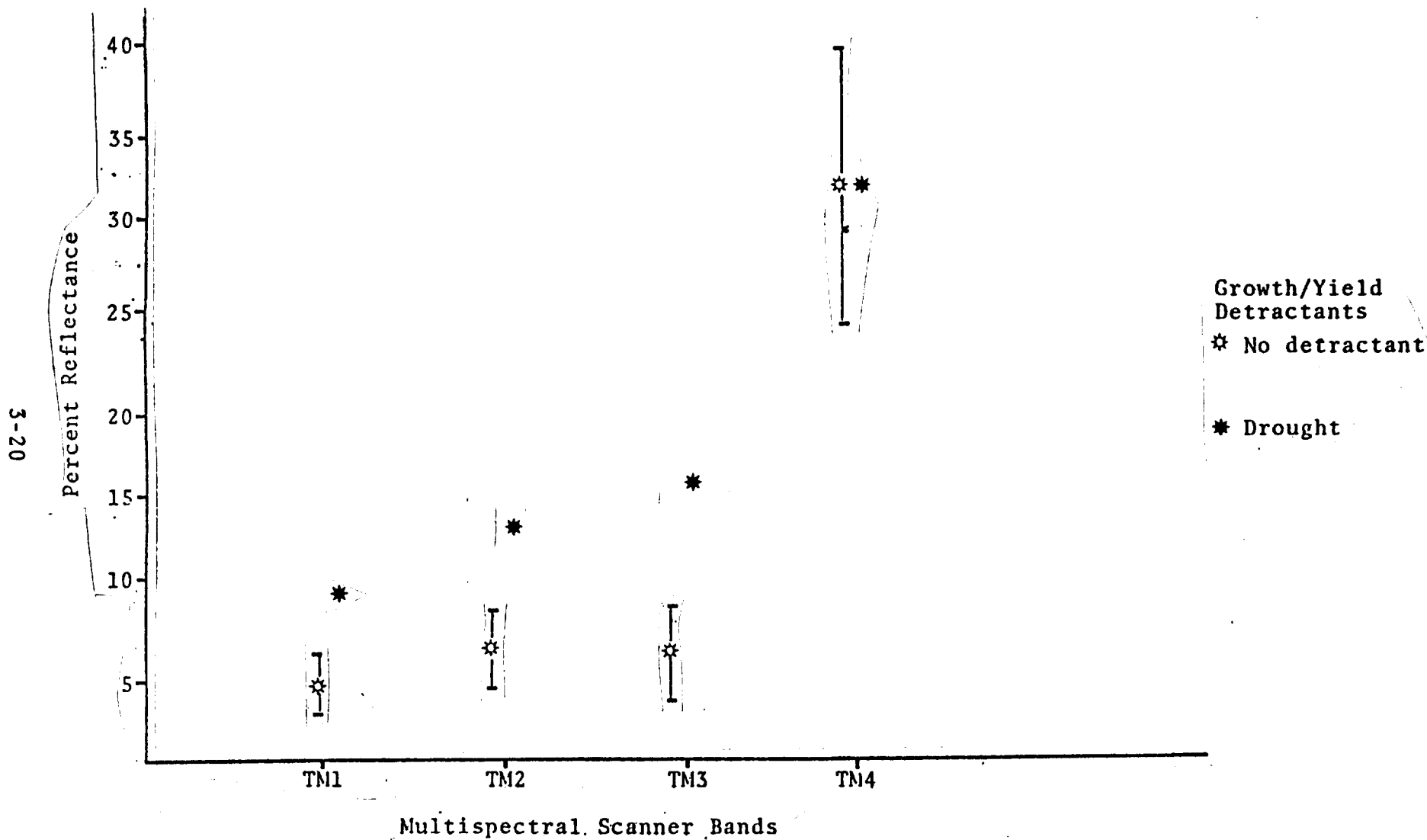
Winter Wheat, Kansas 1975. Growth Stage: Fully headed

61-5



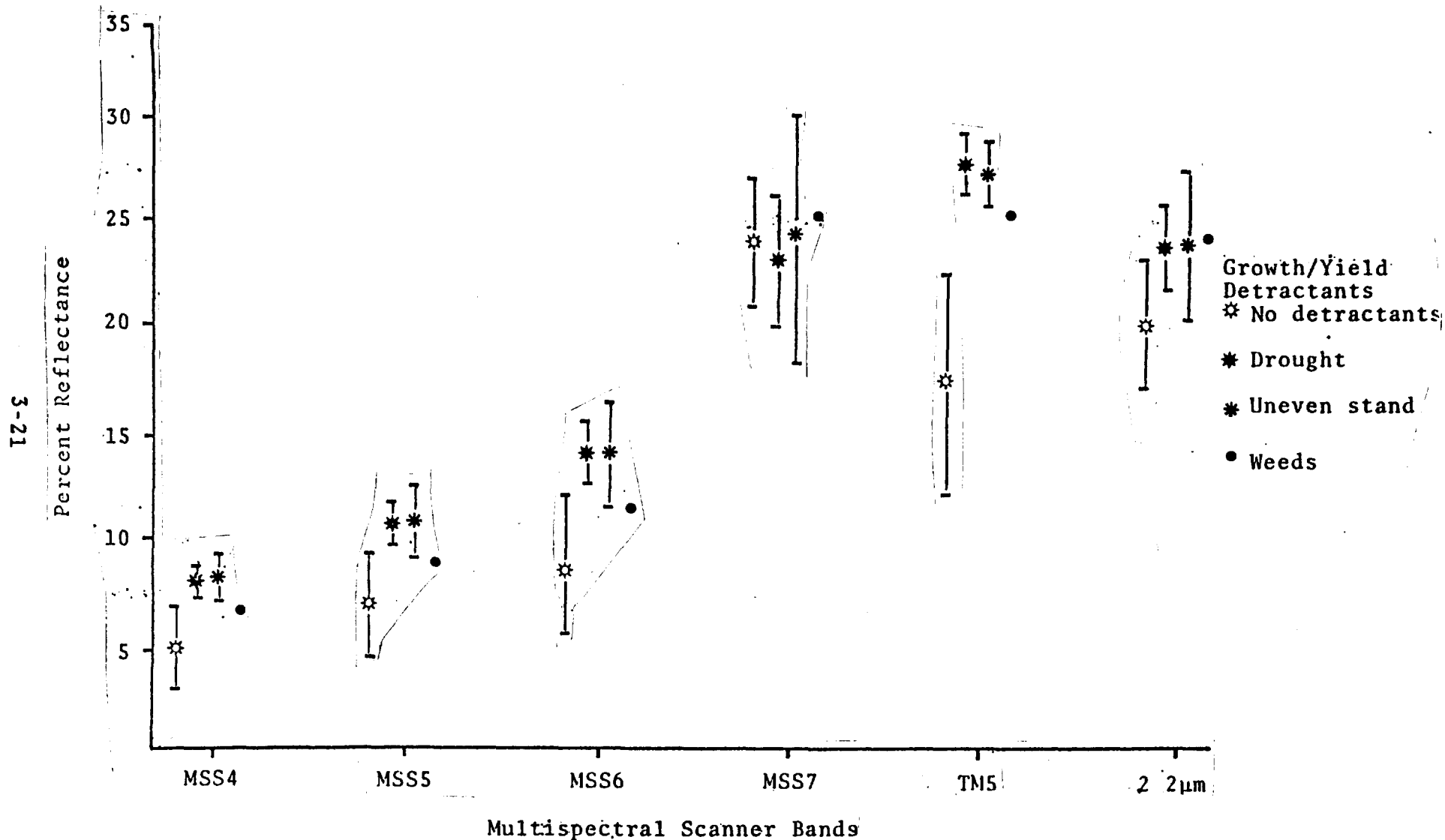
YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS

Winter Wheat, Kansas 1975. Growth Stage: Fully headed



YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNTER BANDS

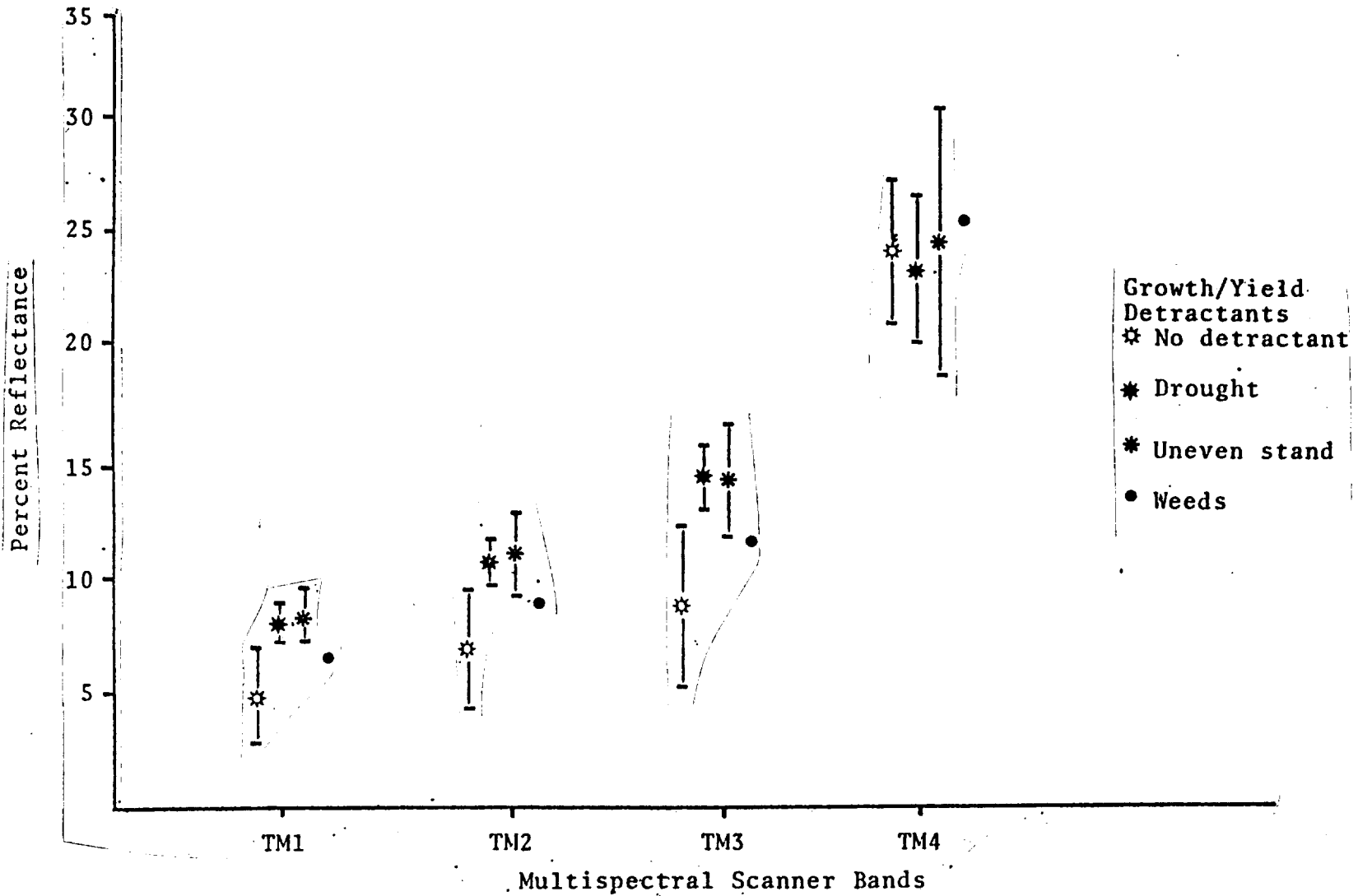
Winter Wheat, Kansas 1976. Growth Stage: Beginning to ripen



YIELD/GROWTH DETRACTANTS CLASS MEAN REFLECTANCE VALUES IN CERTAIN SCANNER BANDS

Winter Wheat, Kansas 1976. Growth Stage: Beginning to ripen

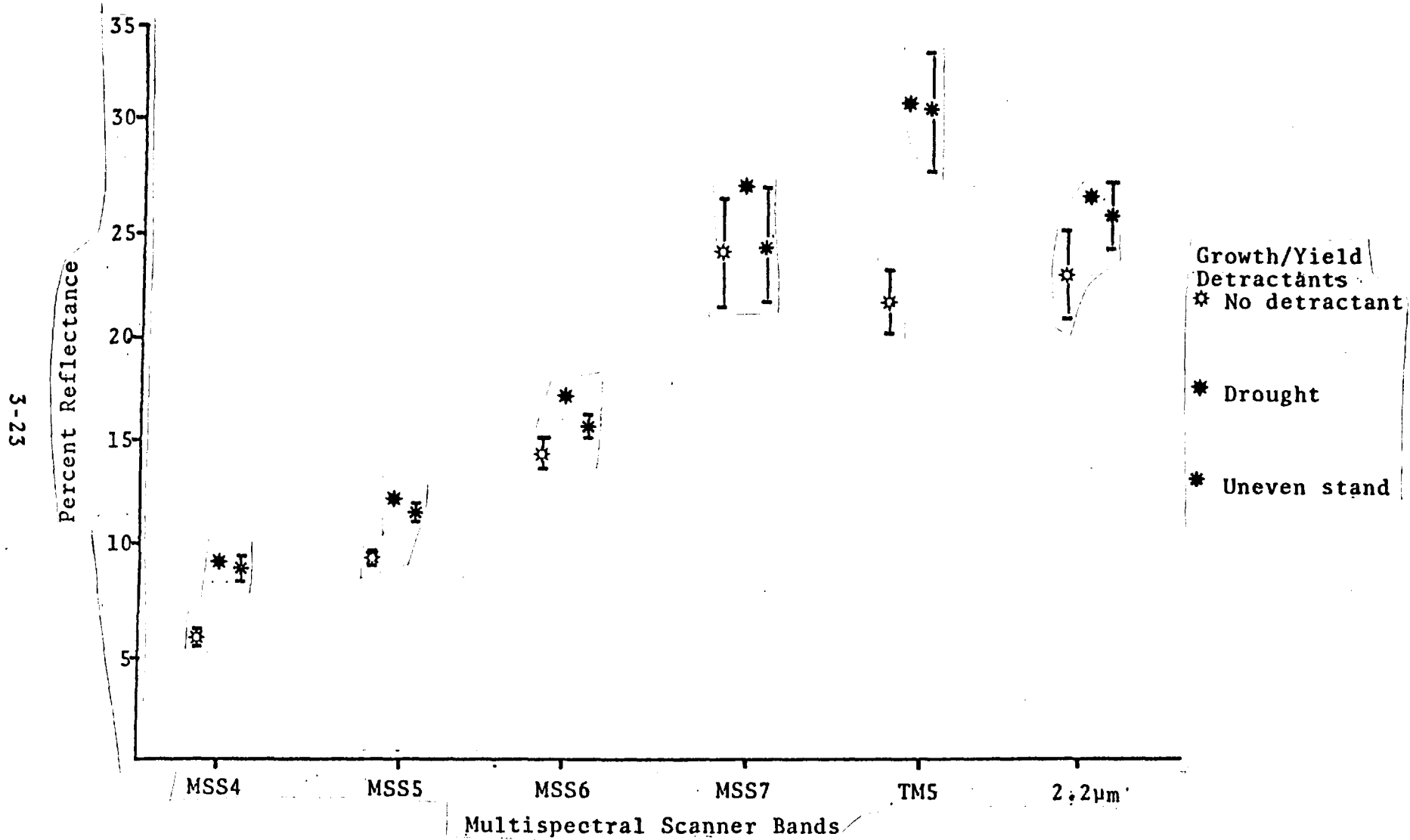
3-22



YIELD/GROWTH DETRACTANTS CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS/

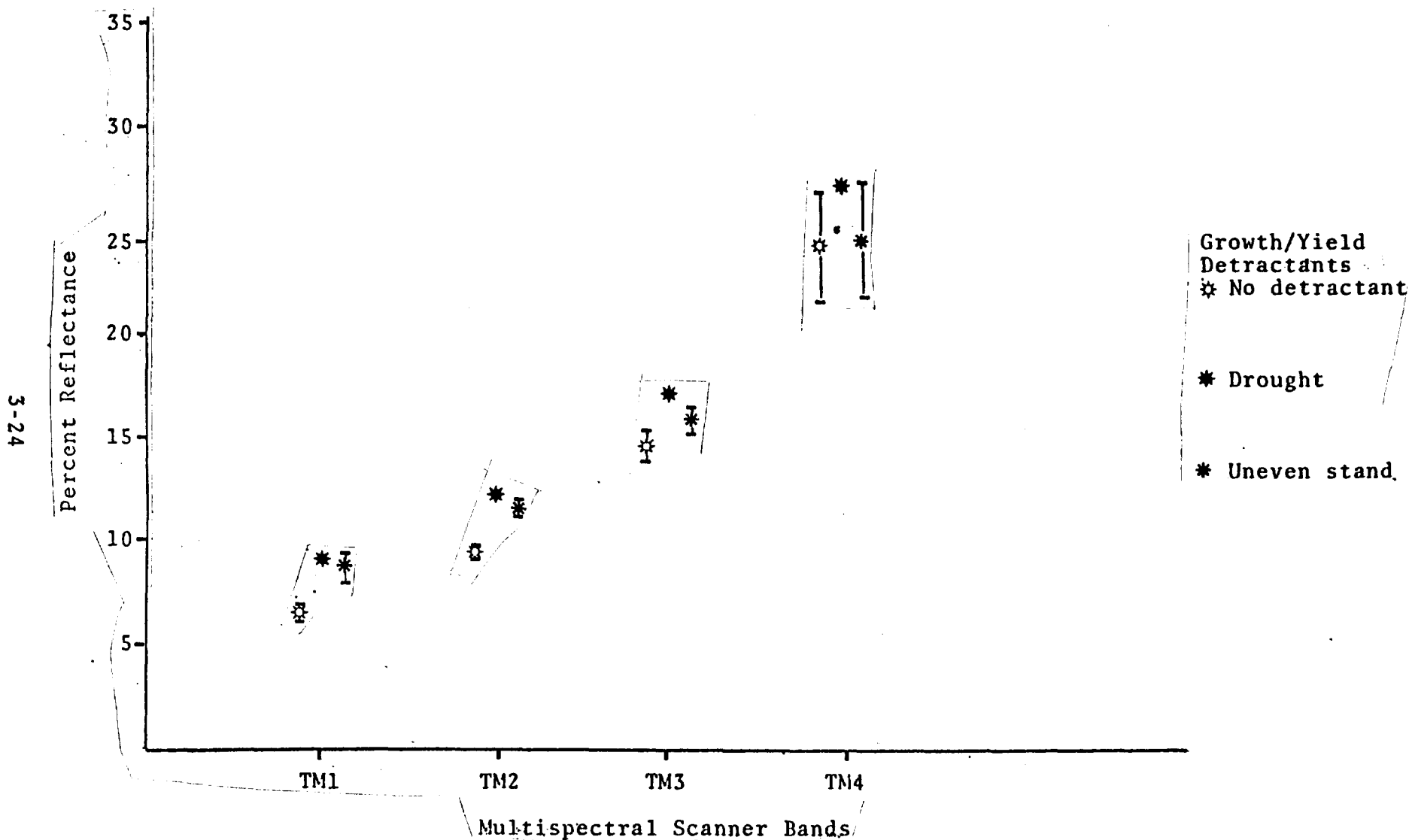


Winter Wheat, Kansas 1976. Growth Stage: Ripe, mature



YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN CERTAIN SCANNER BANDS

Winter Wheat, Kansas 1976. Growth Stage: Ripe, mature



YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS

ADVECTIVE INFLUENCES ON  
MEAN FIELD TEMPERATURE

APRIL 18, 1976

FLIGHT LINE NUMBER	DISSIMILAR FIELDS UPWIND	SIMILAR FIELDS UPWIND
10	82.98* 4	85.013 1
9	83.423 4	83.342 5
8	83.586 5	82.393 1
	$\bar{X} = 83.416$	$\bar{X} = 83.332$

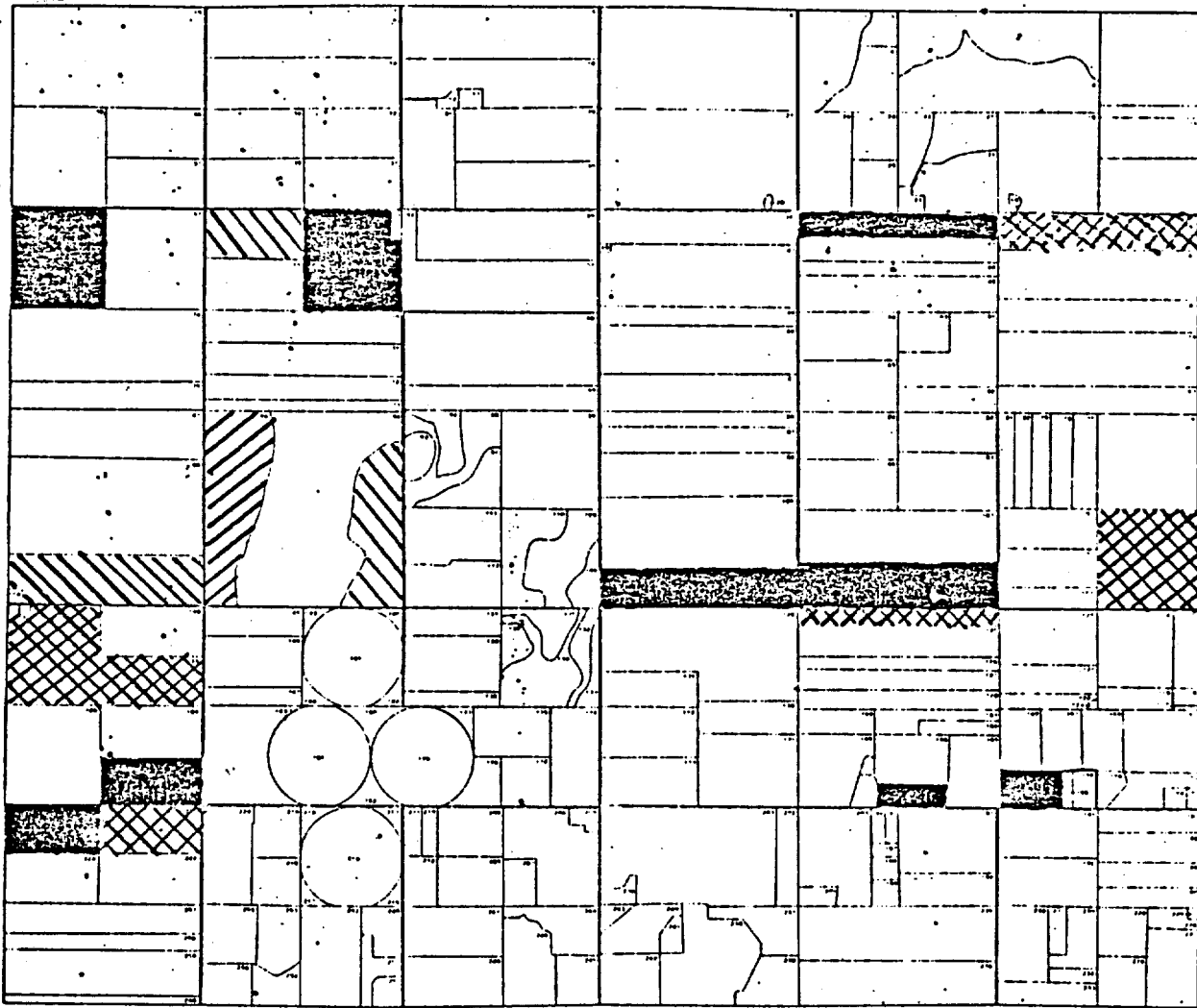
MAY 6, 1976

FLIGHT LINE NUMBER	DISSIMILAR FIELDS UPWIND	SIMILAR FIELDS UPWIND
10	73.312 3	75.427 1
9	74.298 4	73.425 5
8	73.913 5	73.480 1
	$\bar{X} = 73.891$	$\bar{X} = 73.755$

\* UNITS ARE  $\text{MW CM}^{-2} \text{SR}^{-1} \mu^{-1} \times 10^{-1}$ . SPECTRAL BANDWIDTH IS 8.0 - 13.5  $\mu\text{M}$ .

# FINNEY COUNTY, KANSAS (SUPER SITE)

## LACIE INTENSIVE STUDY SITE







Photography Acquired November 1973

Approximate Scale 1:24,000

LAND USE DATA COLLECTED BY THE ASCS JANUARY 1976  
 PHOTOGRAPHY ACQUIRED NOVEMBER 1973  
 PREPARED BY ISCO, CARTOGRAPHIC LABORATORY  
 EARTH OBSERVATIONS DIVISION  
 S & AD JSC/NASA  
 HOUSTON, TEXAS FEBRUARY 1976

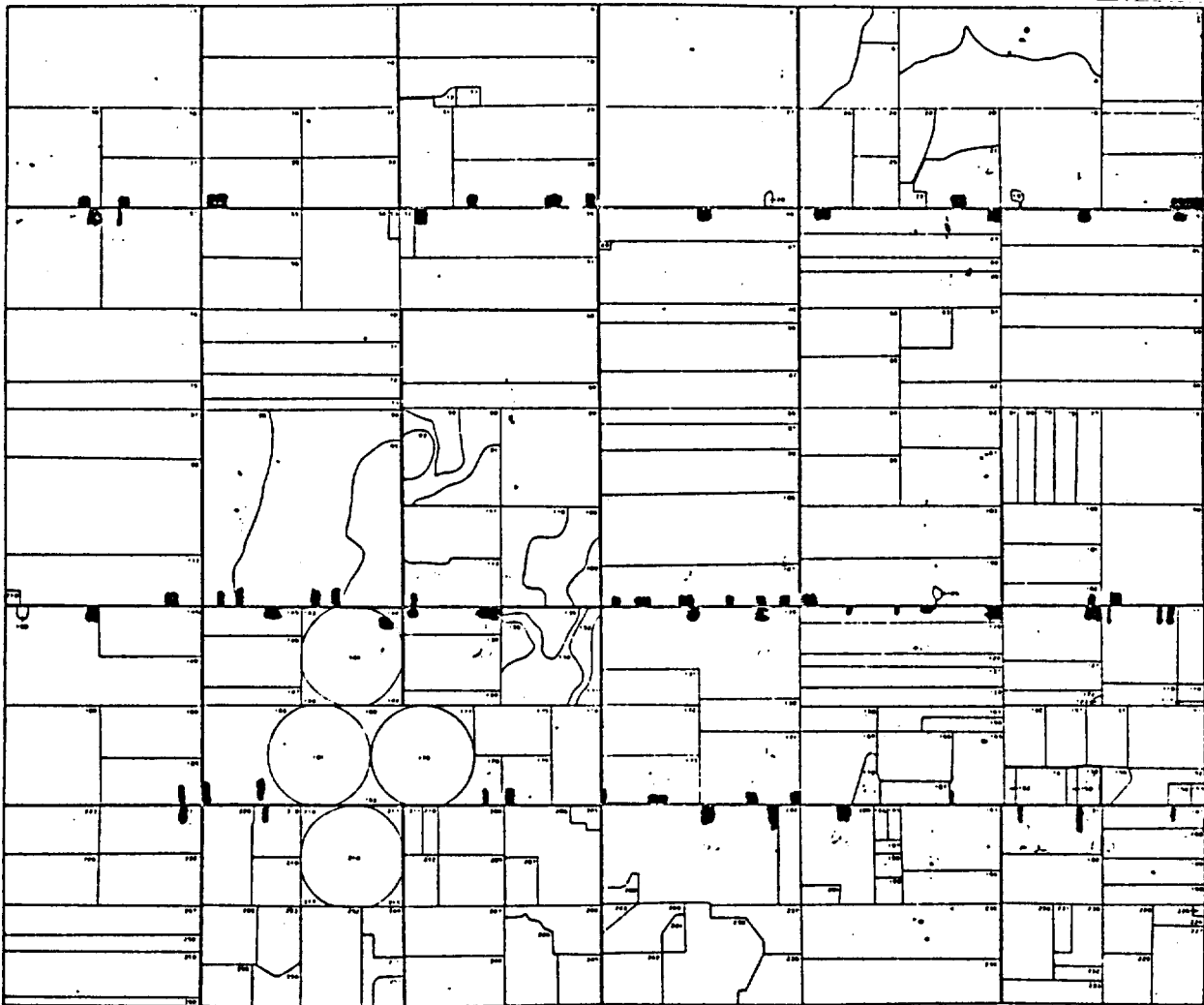
Land Use Data Collected  
by The ASCS January 1976

Prepared by:  
ISCO, Cartographic Laboratory  
Earth Observations Division  
S & AD JSC/NASA  
Houston, Texas February 1976

-  Wheat upwind both dates
-  Bare fields upwind both dates
-  4/18 - Wheat upwind
-  5/6 - Wheat upwind

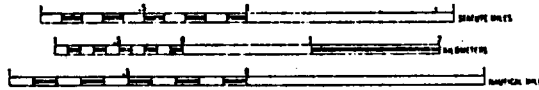
COMMON HOT/COLD AREAS  
ON 4/18 & 5/6

FINNEY COUNTY, KANSAS (SUPER SITE)  
LACIE INTENSIVE STUDY SITE



Photography Acquired November 1973

Approximate Scale 1:24,000



Land Use Data Collected  
by The ASCS January 1976

Prepared by:  
PSO, Cartographic Laboratory,  
Earth Observations Division,  
S & AD, JSC/NASA  
Houston, Texas, February 1976

PLANS FOR FURTHER ANALYSIS:

- COMPLETION OF PRESENT TASKS BY NOVEMBER 30, 1977  
(END OF CONTRACT).
- FOR "IMPROVED YIELD MODELS" - DEVELOP ALGORITHMS  
RELATING SPECTRAL RESPONSE TO YIELD.
- FOR "LANDSAT C USE" - COMPLETE EXAMINATION OF THERMAL  
BAND SENSITIVITY TO CHANGES IN SCENE FACTORS. DELINEATE  
THESE RELATIONSHIPS FOR USE AS INTERPRETATION TOOLS.
- FOR "R & D DATA SET AVAILABILITY" - COMPLETE DEVELOPMENT  
AND TEST THE NON-DESTRUCTIVE LAI TECHNIQUE.

## SECTION 4



FORMERLY WILLOW RUN LABORATORIES, THE UNIVERSITY OF MICHIGAN

### WORLDWIDE WHEAT PRODUCTION FORECASTS USING LANDSAT DATA\*

Richard F. Nalepka\*\*

#### ABSTRACT

Discussion is presented of the philosophy, background, and activities carried out at ERIM to utilize Landsat data to help forecast the yield and production of wheat. Results are presented which demonstrate the empirical relationships between wheat yield and percent green wheat cover, percent green wheat cover and a Landsat green measure, and wheat yield and the Landsat green measure. Correlations of early season Landsat estimates of yield with farmers harvested yield are shown to be as good or better than more conventional estimates made later in the growing season. The variance in yield accounted for by Landsat variables is also shown to parallel that accounted for by several important cultural variables (detailed information on these variables would normally not be available in an operational system). Results of yield prediction extension are also presented.

A discussion of a new direct production forecasting procedure using Landsat data is presented which potentially overcomes many of the serious problems (e.g., small fields and cloud cover over specific sites) being faced by other available approaches. Initial test results are presented which demonstrate quite accurate early season forecasts of production over regions as small as LACIE sites and as large as a crop reporting district.

Further activities are recommended to investigate the use of Landsat data for identifying crop condition and estimating yield and to investigate the joint use of Landsat data, Metsat data, and agromet models. A strong recommendation is made that direct wheat production forecasting procedures should be further developed and evaluated.

---

\* Presented at the Landsat Crop Condition and Yield Briefing held at NASA Headquarters on September 27, 1977.

\*\* Mr. Nalepka is the Head of the Multispectral Analysis Section of the Environmental Research Institute of Michigan's (ERIM) Infrared and Optics Division.

WORLDWIDE WHEAT PRODUCTION FORECASTS USING LANDSAT DATA

PRINCIPAL INVESTIGATOR

RICHARD F. NALEPKA

CO-INVESTIGATOR

JOHN E. COLWELL

PRESENTED AT THE LANDSAT CROP CONDITION AND YIELD BRIEFING

NASA HEADQUARTERS

SEPTEMBER 27, 1977



## OUTLINE

- BASIC PHILOSOPHY
- BACKGROUND
- DESCRIPTION OF SITES EXAMINED
- TYPES OF ACTIVITIES
- ISSUES ADDRESSED
- DISCUSSION OF RESULTS
- CONCLUSIONS
- RECOMMENDATIONS

## BASIC PHILOSOPHY

AT ANY POINT IN TIME THE CROP ITSELF BEST REPRESENTS AND INTEGRATES THE EFFECTS OF VARIABLES SUCH AS:

- PLANTING DATE
- AVAILABLE SUNLIGHT
- AVAILABLE AND USEFUL MOISTURE
- HAIL OR WIND DAMAGE
- WINTERKILL
- FERTILIZATION
- INSECT AND DISEASE DAMAGE
- FARMING PRACTICES

## BACKGROUND

- THEORETICAL STUDY FOR NASA/JSC IN EARLY 70'S USING ERIM GROWTH AND CANOPY REFLECTANCE MODELS TO INVESTIGATE THE POSSIBILITY OF SUCCESSFULLY USING SATELLITE MSS DATA TO AID IN FORECASTING WHEAT YIELD
  
- EMPIRICAL INVESTIGATION FOR NASA/GSFC TO ESTABLISH HOW WELL:
  - WHEAT YIELD IS RELATED TO FIELD VEGETATIVE CONDITION
  - LANDSAT DATA CAN BE USED TO ESTIMATE FIELD VEGETATIVE CONDITION
  - LANDSAT DATA CAN BE USED TO HELP FORECAST WHEAT YIELD (PRODUCTION)

## SITES EXAMINED

### KANSAS (74-75 & 75-76)

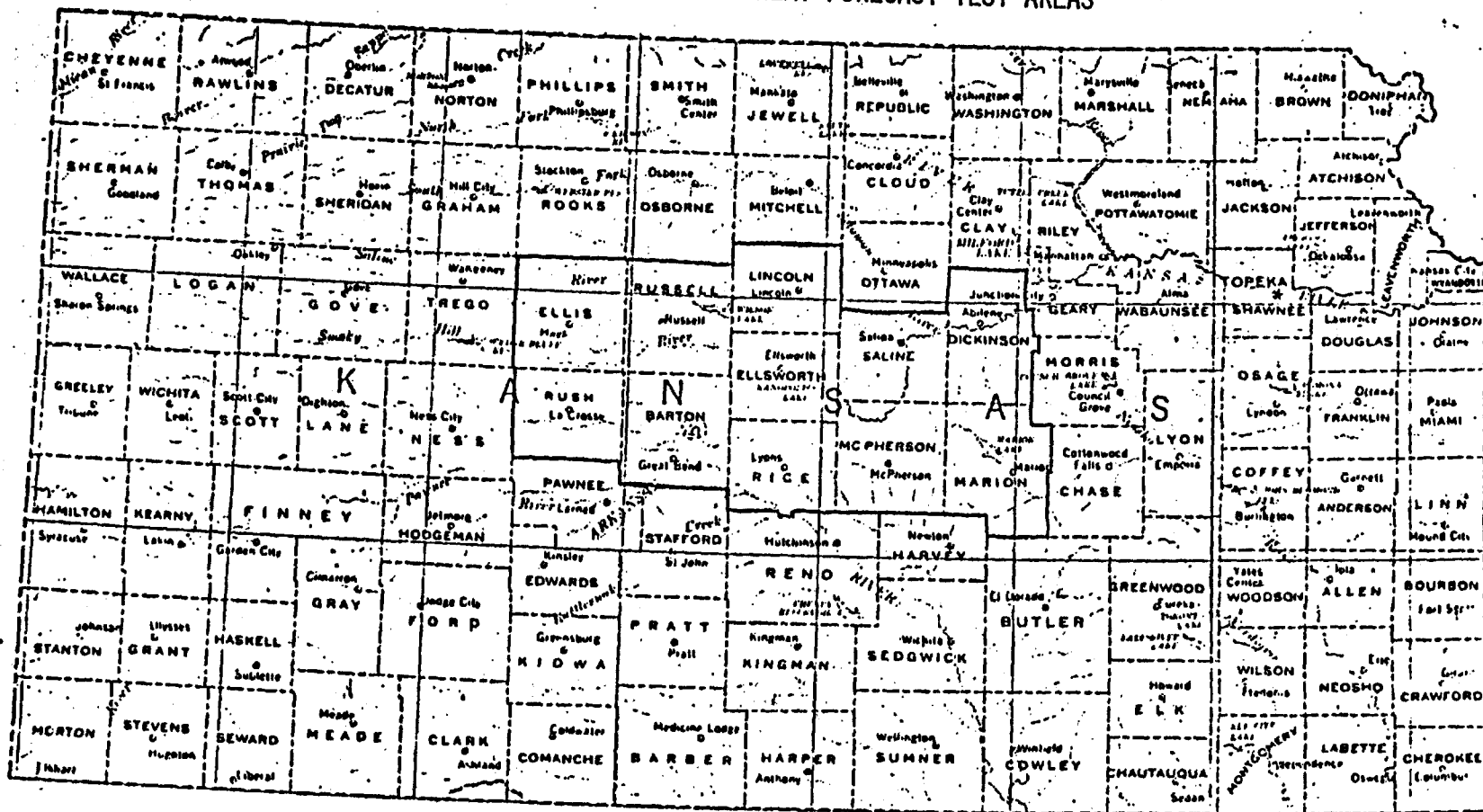
- LACIE INTENSIVE TEST SITES

- FINNEY (OLD AND NEW)
- ELLIS
- RICE
- SALINE

- LACIE BLIND SITES IN CENTRAL CROP REPORTING DISTRICT

- CENTRAL CROP REPORTING DISTRICT

# LOCATION OF WHEAT FORECAST TEST AREAS



4-7

## ACTIVITIES

- FIELD MEASUREMENTS AND SAMPLE COLLECTION
- LABORATORY MEASUREMENTS
- DATA REDUCTION AND ANALYSIS
- MODEL CALCULATIONS AND ANALYSIS
- LANDSAT DATA PROCESSING AND ANALYSIS

## ISSUES ADDRESSED IN SATISFYING INVESTIGATION OBJECTIVES

- OPTIMUM SINGLE TIME (NEAR HEADING)
- LANDSAT GREEN INDICATORS
- COMPARISON WITH ALTERNATE APPROACHES
- IMPORTANCE OF VARIOUS CULTURAL FACTORS
- MODEL EXTENSION (GEOGRAPHICALLY AND TEMPORALLY)
- DATA SCREENING
- DIRECT PRODUCTION FORECASTS

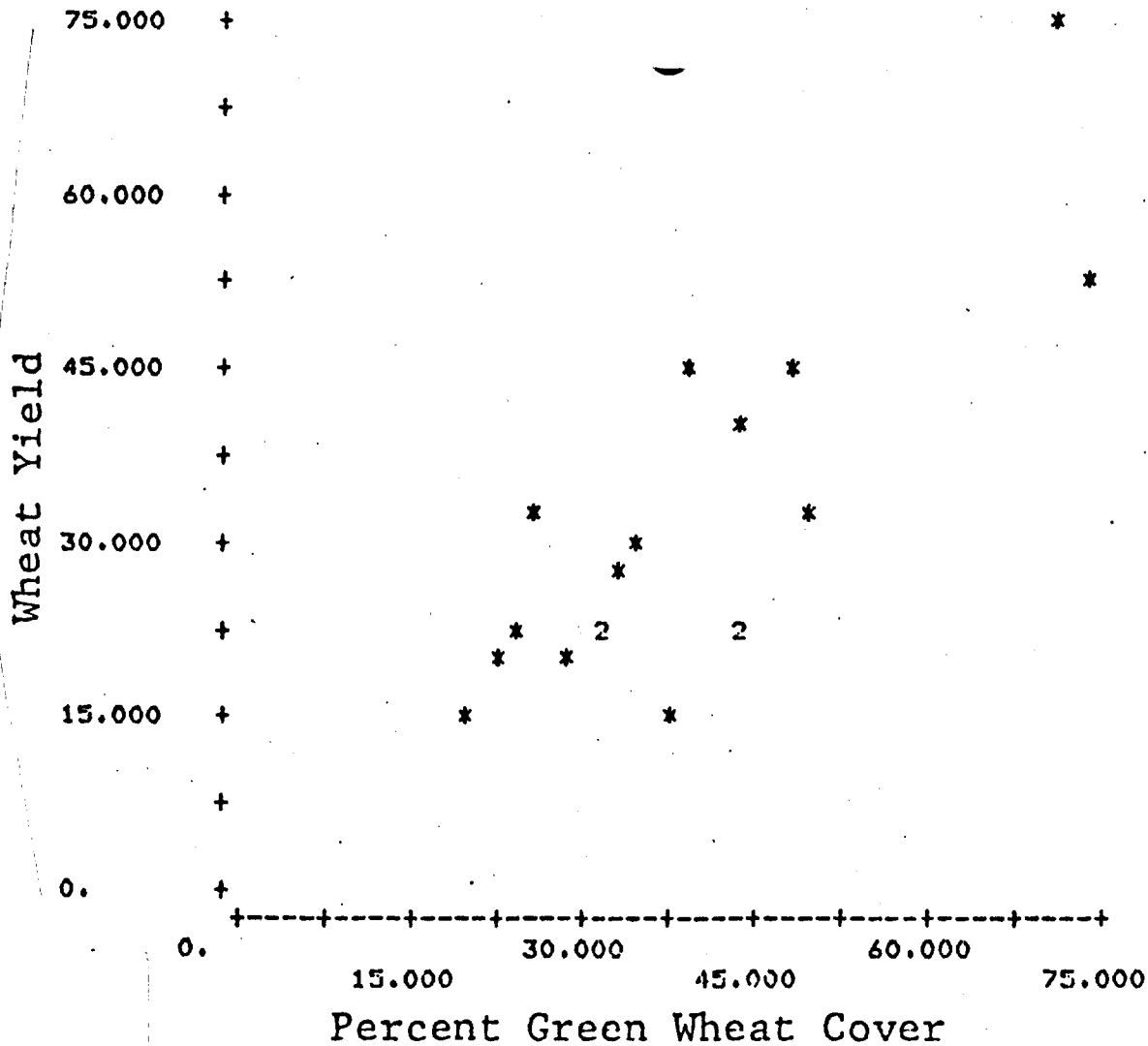
The logo for SERIM, featuring a stylized Greek letter sigma (Σ) followed by the letters ERIM.

## LANDSAT GREEN INDICATORS EXAMINED

- TASSELED CAP GREEN CHANNEL
- $MSS7/MSS5 = R75$
- $\sqrt{MSS7/MSS5} = SQ75$
- $\sqrt{(MSS7 - MSS5)/(MSS7 + MSS5) + 0.5} = TVI$
- $MSS4 - MSS7 + 96 = G$



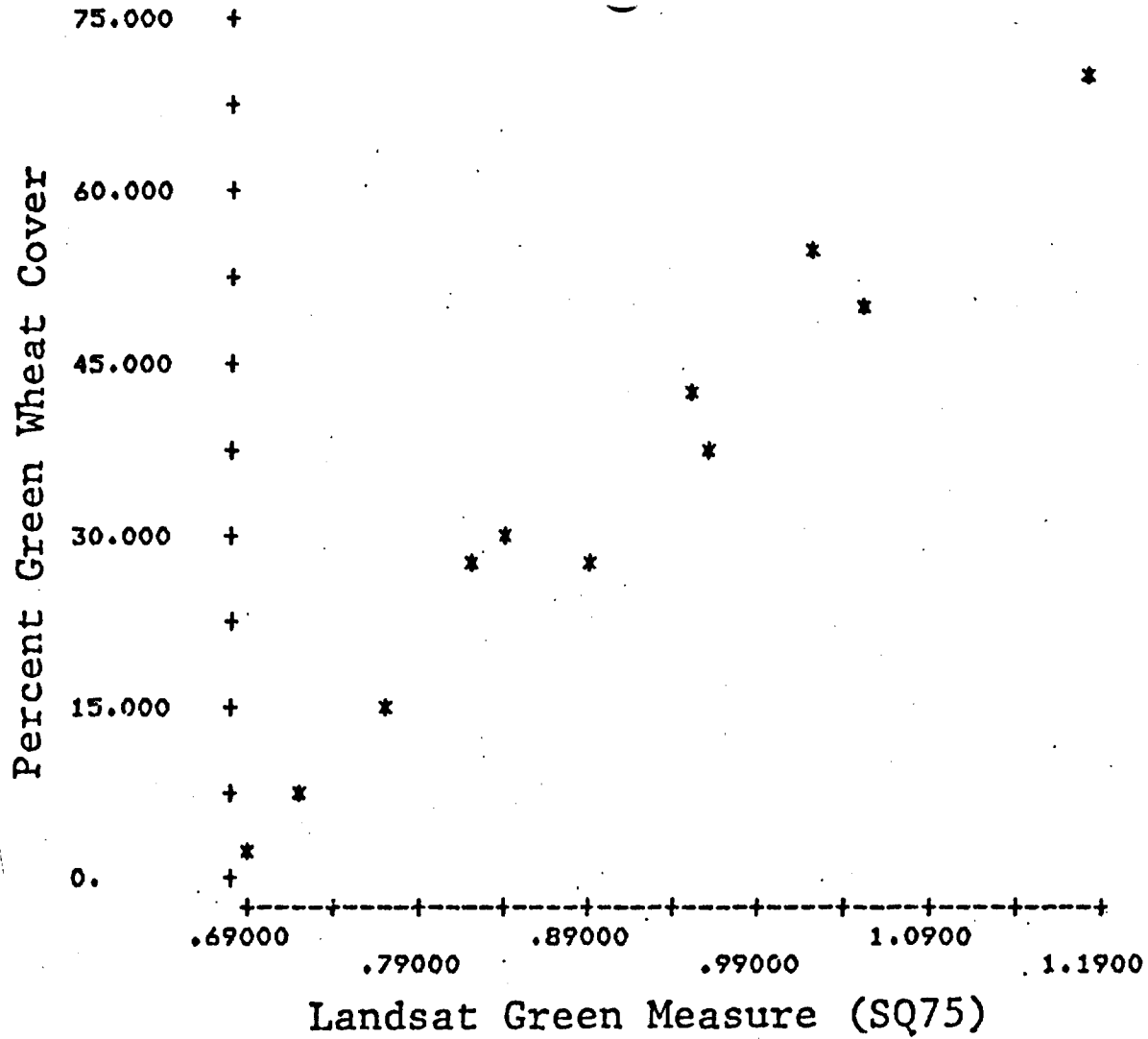
4-11



ERIM MEASUREMENTS OF PERCENT COVER VS WHEAT YIELD  
(Combined 1976 and 1975 Data)

FINNEY ITS  
2 YRS. 9 FIELDS EACH  
MID-MAY

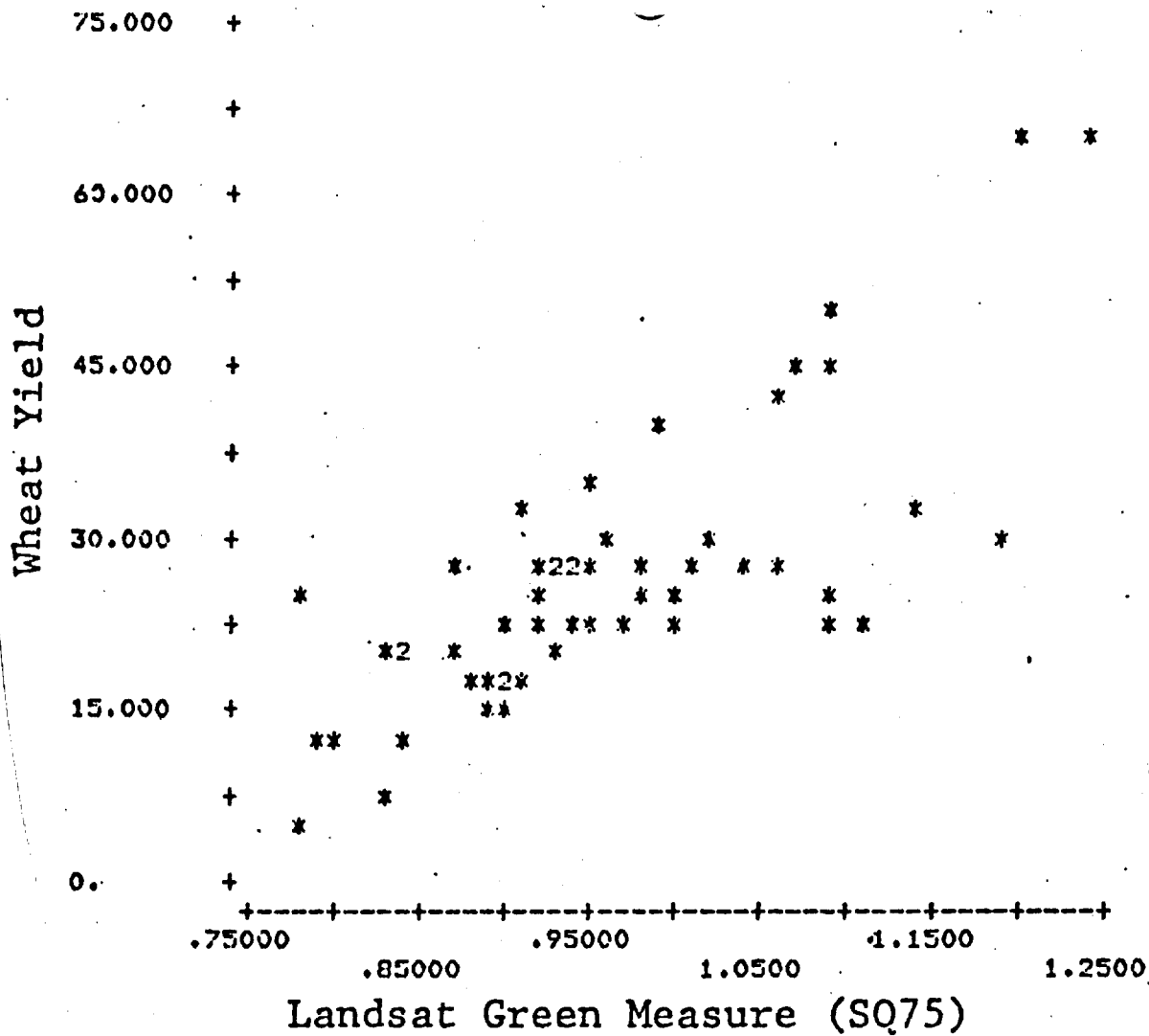
ERIM



LANDSAT GREEN MEASURE VS ERIM MEASUREMENTS  
OF PERCENT GREEN WHEAT COVER

CORRELATION = .98





LANDSAT GREEN MEASURE VS WHEAT YIELD

CORRELATION = .8

1 SITE/DATE

1 PT/FIELD

LATE APRIL-EARLY MAY



CORRELATIONS OF FARMERS YIELD WITH FIELD ESTIMATES  
AND LANDSAT ESTIMATES OF YIELD

<u>YIELD ESTIMATOR</u>	<u>SITE A</u>	<u>SITE B</u>	<u>SITE C</u>	<u>AVERAGE</u>
FCIC*	0.95 <sup>1</sup>	0.26 <sup>1</sup>	0.74 <sup>1</sup>	0.65
STAND QUALITY**	0.47 <sup>1</sup>	0.78 <sup>1</sup>	0.89 <sup>1</sup>	0.71
LANDSAT (4 BANDS)	0.94 <sup>2</sup>	0.80 <sup>4</sup>	0.79 <sup>3</sup>	0.84
LANDSAT (TVI)	0.93 <sup>2</sup>	0.79 <sup>4</sup>	0.64 <sup>3</sup>	0.79

DATES WHEN ESTIMATORS WERE AVAILABLE:

<sup>1</sup>PRE-HARVEST (MID-LATE JUNE); <sup>2</sup>15 APRIL; <sup>3</sup>21 MAY; <sup>4</sup>6 MAY

\* FEDERAL CROP INSURANCE CORPORATION OBJECTIVE ESTIMATES.

\*\* AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE SUBJECTIVE ESTIMATES.

 ERIM

PERCENT OF VARIANCE IN YIELD ACCOUNTED FOR  
SEPARATELY BY SEVERAL CULTURAL FACTORS

<u>CULTURAL FACTORS</u>	<u>PERCENT OF VARIANCE</u>
PLANTING DATE	0.1
WHEAT VARIETY	10.6
FALLOW PREVIOUS YEAR (YES/NO)	35.8
IRRIGATION (YES/NO)	56.3
FERTILIZATION (YES/NO)	55.0
AMOUNT FERTILIZATION (LB/ACRE)	57.4

PERCENT OF VARIANCE IN YIELD ACCOUNTED FOR BY SEVERAL  
COMBINATIONS OF CULTURAL AND LANDSAT VARIABLES

<u>VARIABLES</u>	<u>PERCENT VARIANCE</u>	<u>STANDARD ERROR</u>
1-6 (ALL CULTURAL VARS)	74.9	6.89
7-10 (ALL LANDSAT VARS)	87.3	4.78
4,5,7,10 (OPTIMUM FOUR VARS)	90.7	4.10
1-10 (ALL VARS)	93.6	3.65

VARIABLE KEY:

1 = VARIETY	6 = AMOUNT FERTILIZER
2 = IRRIGATION	7 = SQ75 (MAY 6)
3 = FERTILIZATION	8 = SQ75 (JUNE 2)
4 = PLANTING DATE	9 = SQ75 (JUNE 12)
5 = CROPPING	10 = SQ75 (APRIL 18)

## TWO TESTS OF EXTENSIONS OF LANDSAT WHEAT YIELD PREDICTION

<u>FROM</u>	<u>TO</u>	<u>LANDSAT PREDICTOR</u>	<u>RMS ERROR<sup>1</sup></u>		<u>BIAS<sup>2</sup></u>
			<u>LOCAL</u>	<u>NON-LOCAL</u>	
21 MAY	20 MAY	4 BANDS	4.40	6.70	-5.00
SITE A	SITE A	SQ75 <sup>3</sup>	5.24	5.08	0.00
		TVI <sup>4</sup>	5.03	4.88	0.02
18 APRIL	18 APRIL	4 BANDS	7.41	9.10	-0.23
SITE A	SITE B	SQ75 <sup>3</sup>	8.12	10.18	2.15
		TVI <sup>4</sup>	7.98	9.29	1.17

<sup>1</sup>ON FIELD BY FIELD BASIS,  
IN BUSHELS.

<sup>2</sup>AVERAGE DIFFERENCE BETWEEN ACTUAL  
AND PREDICTED YIELD, IN BUSHELS.

<sup>3</sup> $\sqrt{MSS7/MSS5}$

<sup>4</sup> $\sqrt{(MSS7-MSS5)/(MSS7+MSS5)+0.5}$

## MAJOR PREMISES OF ERIM DIRECT PRODUCTION FORECASTING

- AT A SPECIFIC TIME OR TIMES IN THE GROWTH OF WINTER WHEAT ONE CAN ESTABLISH A STABLE RELATIONSHIP BETWEEN A LANDSAT GREEN MEASURE AND THE PRODUCTION OF WHEAT
- AS A RESULT OF SPECTRAL DIFFERENCES OR SPECTRAL/TEMPORAL DIFFERENCES BETWEEN WHEAT AND NON-WHEAT, NON-WHEAT PIXELS WILL CONTRIBUTE MINIMALLY TO THE FORECASTS OF WHEAT PRODUCTION
- LANDSAT PIXELS CONTAINING BOTH WHEAT AND NON-WHEAT (E.G., BOUNDARY PIXELS) WILL PROVIDE AN INTERMEDIATE GREEN MEASURE THEREBY LEADING TO FORECASTS OF PRODUCTION FOR SUCH PIXELS WHICH ARE INTERMEDIATE AND CORRECT.



## ERIM DIRECT PRODUCTION FORECAST PROCEDURE

- DEFINE PRODUCTION-PREDICTIVE RELATIONSHIP (BASED ON PREVIOUS YEARS' DATA)
- STRATIFY REGION TO BE PROCESSED ACCORDING TO CROP CALENDAR
- SELECT PREVIOUSLY ESTABLISHED PRODUCTION-PREDICTIVE RELATIONSHIP APPROPRIATE TO STRATUM
- AUTOMATICALLY SCREEN LANDSAT DATA TO DEFINE BAD DATA, CLOUDS, CLOUD SHADOWS, DENSE HAZE, AND NON-WHEAT CATEGORIES SUCH AS WATER, TREES, AND URBAN AREAS
- FOR EACH STRATUM AND EACH PIXEL TO BE PROCESSED (PERHAPS A SAMPLE OR PERHAPS ALL NON-SCREENED PIXELS) DETERMINE LANDSAT GREEN MEASURE AND ESTIMATE PRODUCTION
- DETERMINE FINAL STRATUM PRODUCTION FIGURE BY ADJUSTING ACCUMULATED STRATUM PRODUCTION TO ACCOUNT FOR SCREENED PIXELS

## POTENTIAL ADVANTAGES OF ERIM DIRECT PRODUCTION FORECAST PROCEDURE

- PROVIDES AN EARLY SEASON ESTIMATE
- ELIMINATES NEED TO LOCATE AND IDENTIFY FIELDS
- PROVIDES AN APPROACH TO OPERATING IN REGIONS OF SMALL OR IRREGULARLY SHAPED FIELDS
- ACCOUNTS FOR NON-UNIFORMITIES IN FIELDS
- ADDRESSES REDUCED TOTAL PRODUCTION DUE TO DISEASE, DROUGHT, ETC.
- MAY ELIMINATE NEED FOR YEARLY TRAINING
- ELIMINATES NEED FOR IDENTIFYING SPECIFIC SITES IN ADVANCE
- POTENTIALLY REDUCES EFFECT OF CLOUD COVER AND SAMPLING ERROR

INITIAL RESULT FROM ERIM DIRECT WHEAT PRODUCTION FORECAST PROCEDURE  
 (Two LACIE INTENSIVE TEST SITES)

<u>SITE</u>	<u>LANDSAT OVERPASS</u>	<u>TRUE PRODUCTION</u>	<u>ERIM PRODUCTION FORECAST</u>	<u>ERROR (%)</u>
A	6 MAY 76	40,600 BU	42,700 BU	5.2
A	18 APR 76	40,600 BU	42,800 BU	5.4
B	6 MAY 76	27,900 BU	24,700 BU	-11.5
A+B	6 MAY 76	68,500 BU	67,400 BU	1.6

4-21



FURTHER RESULTS FROM ERIM DIRECT WHEAT PRODUCTION FORECAST PROCEDURE  
(TEN COUNTIES OF KANSAS CENTRAL CRD)

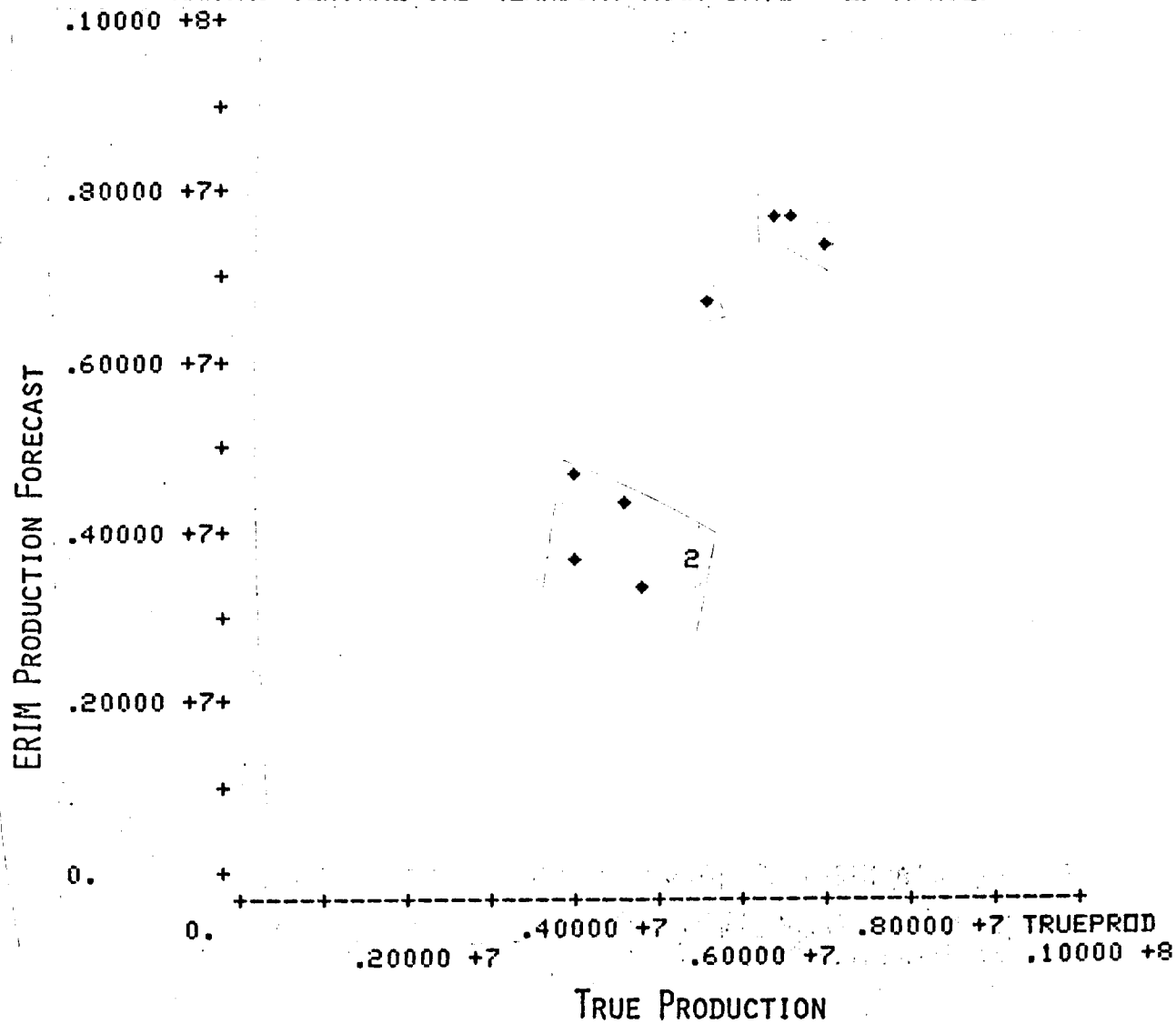
2 ITS + 3 BLIND SITES

<u>LANDSAT OVERPASS</u>	<u>TRUE PRODUCTION</u>	<u>ERIM PRODUCTION FORECAST</u>	<u>ERROR (PERCENT)</u>
17 APR 76	5.38 x 10 <sup>6</sup> BUSHELS	5.24 x 10 <sup>6</sup> BUSHELS	2.6

4-22

 ERIM

PLOT OF ERIM PRODUCTION FORECAST VS TRUE PRODUCTION FOR TEN COUNTIES OF THE KANSAS CENTRAL CRD (LANDSAT Acq. DATE - 17 APRIL)



4-23



## CONCLUSIONS

- LANDSAT DATA CAN BE EFFECTIVELY USED TO ESTIMATE CERTAIN VARIABLES WHICH ARE REQUIRED IN EXISTING YIELD MODELS (SUCH AS LAI OR PERCENT COVER)
- LANDSAT INDICATORS OF YIELD ARE AS HIGHLY CORRELATED WITH INDIVIDUAL FIELD YIELD AS ARE ESTIMATES USING TRADITIONAL FIELD SAMPLING METHODS, EVEN WHEN USING LANDSAT DATA COLLECTED SEVERAL WEEKS BEFORE THE FIELD SAMPLES ARE MADE
- A CONSIDERABLE AMOUNT OF THE VARIANCE IN INDIVIDUAL FIELD YIELD WHICH IS NOT EXPLAINABLE BY METEOROLOGICAL DATA CAN BE ACCOUNTED FOR BY LANDSAT DATA
- IN ORDER FOR LANDSAT DATA TO BE OF MAXIMAL USE IN AN OPERATIONAL SYSTEM, IMPROVEMENTS IN THE ABILITY TO REMOVE THE EXTERNAL EFFECTS (PARTICULARLY ATMOSPHERIC EFFECTS) ARE REQUIRED
- THE POSSIBILITY OF MAKING DIRECT WHEAT PRODUCTION FORECASTS USING EARLY-SEASON LANDSAT DATA LOOKS VERY PROMISING

## RECOMMENDATIONS

- INVESTIGATIONS OF THE USE OF LANDSAT DATA TO IDENTIFY CROP CONDITION AND ESTIMATE YIELD SHOULD CONTINUE
- JOINT USE OF LANDSAT DATA, METSAT DATA, AND AGROMET MODELS SHOULD BE EXAMINED
- DIRECT WHEAT PRODUCTION FORECASTING PROCEDURES SHOULD BE FURTHER DEVELOPED AND EVALUATED

## SECTION 5

### MONITORING DROUGHT AND YIELD COMPONENTS BY LANDSAT

D. R. THOMPSON

#### Abstract

In the Large Area Crop Inventory Experiment, Landsat images and digital data were used to detect and monitor the drought that occurred in the U.S. Great Plains during the 1976 wheat growing season. Landsat color infrared images (100 by 100 nautical miles) were used to determine and monitor the areal extent. The drought area was rated subjectively as to the acreage affected by comparing the 1976 and 1975 Landsat imagery. A technique was devised using a vector transformation of Landsat digital data to indicate when vegetation is undergoing moisture stress. A relation was established between the remote-sensing-based criterion (the Green Index Number) and a ground-based criterion (Crop Moisture Index).

Landsat was shown to be correlated to plant properties that influence yield. Direct correlation of Landsat to yield appears to be feasible only at specific growth stages. The use of Landsat for yield estimation is difficult because the biological system is dynamic and because of atmospheric effects on Landsat. Some problems exist in the different methods of acquiring ground truth (yield estimations) and the variations that exist among and within fields. However, assessing yield from Landsat appears to be feasible.



## Introduction

A Large Area Crop Inventory Experiment (LACIE) has been undertaken jointly by the U.S. Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, and the National Aeronautics and Space Administration (NASA) to prove an economical application of remote sensing from space (3). The experiment is being conducted over three consecutive crop seasons in a 3-1/2-year timespan and is divided into three corresponding phases (3). Each phase is designed to build on the experience of the previous phase or phases. Phase I was conducted during the 1975 crop year and concentrated on a system test to identify and estimate the wheat acreage within selected major U.S. wheat growing regions and to evaluate wheat recognition analyses in other selected regions throughout the world. Phases II and III concentrated on bringing all elements of a system together in a quasi-operational environment to test the technological capability of developing area, yield, and production estimates for U.S. test regions and other major wheat producing regions of the world. During Phase II (crop year 1976), the drought that occurred in the U.S. Great Plains wheat growing area was detected and monitored using Landsat data (4,5,6). The approach and results of this study are presented in this paper.

## Methods

Two approaches were devised for monitoring drought using remote-sensing-based criteria. One approach utilizes color

infrared transparencies of Landsat scenes (100 by 100 nautical miles) to determine and monitor the areal extent of drought (4,5). The other approach utilizes LACIE sample segments (5 by 6 nautical miles) and Landsat digital data to indicate automatically when an area is undergoing moisture stress (6). These two methods will be referred to, respectively, as Landsat imagery approach and Landsat digital approach throughout the paper.

#### Landsat Imagery Approach

The Landsat imagery approach utilized meteorological data to initially locate the area where potential drought might occur. Once an area was flagged and delineated from meteorological data, Landsat color composite transparencies, prepared from band 4 (0.5 to 0.6 micron), band 5 (0.6 to 0.7 micron), and band 7 (0.8 to 1.1 microns), were used to refine the delineation of the 100-by 100-nautical-mile area. These color transparencies were evaluated by comparison to Landsat imagery of essentially the same date in previous years and also to previous 9-day acquisitions of the current year. Normal green vegetation on the ground is recorded on the Landsat color composites as a bright red color. As moisture stress browns the vegetation on the ground, Landsat-recorded signatures correspondently decrease in redness. Thus, by relating the lack of redness in the signatures where red signatures should be present, the areal extent of the drought was monitored and delineated by compiling a mosaic of Landsat images over the potential drought area. Within the drought area,

the effect of the drought upon the wheat crop was evaluated subjectively by comparison with the previous year's Landsat data. The area was monitored at 9-day intervals until harvest of the wheat crop.

### Results of Landsat Imagery Approach

#### U.S. Southern Great Plains

The drought that occurred in the 1975-76 winter wheat crop area originated in the summer of 1975 when the soil moisture supply was not recharged after the 1974-75 harvest. This acute moisture shortage covered a period of over 30 days, between planting and emergence of the wheat. During the 1975 Thanksgiving week, a major storm system moved through the Great Plains, bringing blizzard conditions to most of the U.S. Great Plains. The combination of these conditions caused the winter wheat to go into dormancy with very little root system or top growth. These areas were monitored from planting using Landsat imagery. At the start of spring greenup, it became apparent that portions of the U.S. Great Plains winter crop were affected by the extreme dry conditions. LACIE monitored the area every 9 days until harvest. The drought-affected area in the U.S. southern Great Plains was determined from Landsat to be located in the southwestern corner of Kansas, in southeast Colorado, and in the Oklahoma and Texas Panhandles. The areal extent of the affected area as of April 1, 1976, is shown in figure 1. The drought severity within the area was rated subjectively by comparing the 1976 and 1975 Landsat imagery. These ratings corresponded to the acreage

losses developed from ground-based observations. The Crop Moisture Index (CMI) for April 3, 1976, shows that this general area was undergoing moisture stress (figure 2).

#### U.S. Northern Great Plains

The droughts in the U.S. northern Great Plains also originated in the summer of 1975 when subsoil moisture was not fully recharged. Precipitation was adequate for winter wheat from emergence to spring greenup. Spring wheat had adequate moisture for planting, emergence, and early growth; however, lack of subsoil moisture and spring rains caused moisture stress by mid-May.

LACIE, using techniques developed from the U.S. southern Great Plains drought study, indicated a potential for drought damage in the U.S. northern Great Plains by early May. The areal extent of the drought was determined from Landsat full-frame color infrared transparencies by monitoring the full-frame Landsat images from April 18, 1976, until harvest.

The initial drought-affected area, as determined from full-frame images, was located within South Dakota. From April 18 to June 12, 1976, the area appeared to be deteriorating, but the full-frame imagery did not indicate severe effects. The June 11 to 13 overpass did show the effects of the drought. The area delineated at this time continued to expand until the July 8 to 11 overpass when the drought area stabilized (figure 3). From this overpass, the drought area was rated subjectively as having been severely or moderately affected. The July 10, 1976, CMI shows that this area was under severe moisture stress (figure 4).

### Landsat Digital Approach

The Landsat imagery approach involves the subjective judgment of the analyst-interpreter in deciding that a region is or is not drought affected.

A procedure was devised in an attempt to quantify the subjective judgment of the analyst-interpreter. The data used were Landsat multispectral scanner (MSS) values for LACIE sample segments throughout South Dakota, which were acquired during the 1975 and 1976 crop years (figure 5). This procedure, which uses the remote-sensing-based criterion to detect and monitor crop moisture deficiencies without analyzing a long record of climatological data, was evaluated against the CMI, which is developed from ground-based meteorological data.

This procedure, the Green Index Number (GIN), was developed using ideas presented by Kauth and Thomas (1). The four Landsat channels are rotated into the Kauth and Thomas greenness and brightness vectors. Each vector is inspected automatically, and any vector having values unreasonable for agricultural data is discarded. From these data, a green number is computed. The green number indicates the density and vigor of vegetation. Once the green numbers are computed for each picture element (pixel) within the 5- by 6-nautical-mile sample segment, the GIN is computed. The GIN then is an estimate of the percentage of pixels in a Landsat scene having green numbers high enough ( $\geq 15$ ) to indicate full cover of green vegetation. It is computed using only Landsat data.

The plot of GIN versus time for a normal, predominantly wheat sample segment should follow a curve such as  $\alpha$  in figure 6. If an observed point for a segment fell into the shaded region, the segment was classified as drought affected. The bounds for the shaded region were defined empirically as shown in figure 6, with  $t$  defined as the approximate spring emergence date in days. For different areas or years, the shaded area can be moved from side to side to match the greenup curve. The initial point in South Dakota was usually near day 110 ( $t = 110$ ). This classification was compared to a classification based on the CMI for a Crop Reporting District (CRD), wherein a CRD was classified as drought affected if the CMI fell below  $-0.5$  for 2 consecutive weeks. Both classifications were restricted to similar time frames. Classification was performed only for data between April 1 and July 10.

#### Results of Landsat Digital Approach

The data used in the digital approach study consisted of all LACIE sample segments in South Dakota which had at least 5 percent wheat as measured by the LACIE Classification and Mensuration Subsystem [CAMS (2)] in the 1976 growing season. This definition yields 17 segments (figure 5) with 34 possible classifications. Of the 34, 4 had either insufficient data during the growing season or data were inaccessible for other reasons. The final data set contained 22 segment years for 13 LACIE segments (table 1). (NOTE: A segment year is defined as an observation of 1 segment for 1 year.) The contingency table (table 2),

TABLE 1. RESULTS OF GIN AND CMI CLASSIFICATIONS

[From reference 6]

D = Drought conditions  
 W = Normal conditions  
 - = No data

Segment	1975		1976	
	GIN	CMI	GIN	CMI
A	W	W	-	D
B	-	W	W	D
C	W	W	D	D
D	W	W	D	D
E	W	W	D	D
F	W	W	W	D
G	W	W	W	D
H	W	W	D	W
I	W	W	-	W
J	W	W	D	D
K	W	W	D	D
L	D	D	D	D
M	-	D	W	D

TABLE 2. CONTINGENCY TABLE OF GIN AND CMI CLASSIFICATION METHODS

[From reference 6]

		CMI		
		Normal	Dry	
GIN	Normal	10	4	14
	Dry	1	7	8
		11	11	22

$\chi^2 = 7.07$  with 1 degree of freedom.

$\hat{P} = 0.0082$  = level of significance.

which applies the two classification methods to the 22 good segment years, shows that the classifications based on the CMI and GIN are related. It was concluded that the GIN is detecting moisture through crop condition.

One example of the segment classification procedure is shown in figure 7. The GIN indicates that 1975 was normal for the entire crop season for segment J. In 1976, the GIN indicates that by May 24 there was moisture stress in segment J, which indicates that the GIN detected vegetation moisture stress at the same time as the CMI.

#### Conclusions

Landsat full-frame color transparencies provide a means of locating, delineating, and monitoring areal extent of moisture stress over large areas. A technique was developed using Landsat digital data for 5- by 6-nautical-mile sample segments, which indicates when agricultural vegetation is undergoing moisture stress. A relationship between this technique, which utilizes remote sensing, and a ground-based criterion (the CMI) has been shown. Indications are that Landsat is capable of detecting crop moisture deficiencies in areas of the world where ground information is not available or reliable.



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1. Kauth, R. J., and Thomas, G. S. July 1976. *The tasselled cap - a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat*. Proc. Symp. on Machine Processing of Remotely Sensed Data, Purdue Univ. (W. Lafayette, Ind.), IEEE cat. 76, CH1103-1 MPRSD.
2. *Large Area Crop Inventory Experiment (LACIE) Classification and Mensuration Subsystem requirements*. Jan. 1977. LACIE-C00200, vol. II (rev. C), JSC-11330, NASA/JSC (Houston, Tex.).
3. MacDonald, R. B. Oct. 1976. *The Large Area Crop Inventory Experiment*. 2nd Annual William T. Pecora Memorial Symp. (Sioux Falls, S. Dak.).
4. Thompson, D. R. Sept. 1976. *Results of LACIE drought analysis (South Dakota drought 1976)*. LACIE-00437, JSC-11666, NASA/JSC (Houston, Tex.).
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6. Thompson, D. R., and Wehmanen, O. A. Apr. 1977. *The use of Landsat digital data to detect and monitor vegetation water deficiencies*. Eleventh Int. Symp. on Remote Sensing of Environment (Ann Arbor, Mich.).
7. *Weekly Weather and Crop Bulletin*. Apr. 3, 1976. U.S. Dept. of Commerce, NOAA; USDA Statistical Reporting Service (USDA/SRS); vol. 63, no. 14 (Washington, D.C.), p. 15.

8. *Weekly Weather and Crop Bulletin*. July 13, 1976. U.S. Dept. of Commerce, NOAA; USDA/SRS; vol. 63, no. 28 (Washington, D.C.), p. 11.

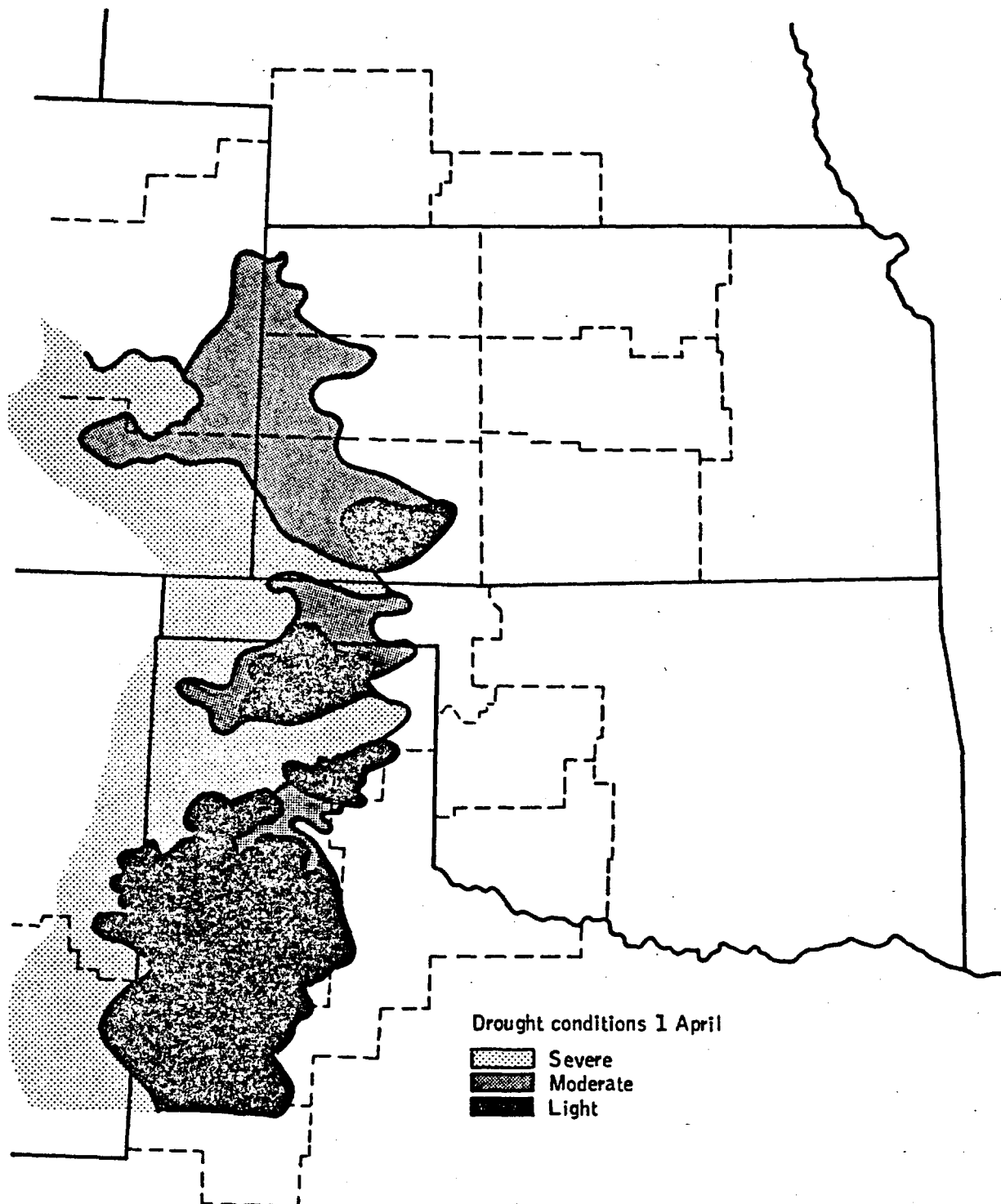


FIGURE 1. AREAL EXTENT AND EFFECT OF DROUGHT ON APRIL 1, 1976.  
 [From reference 5.]

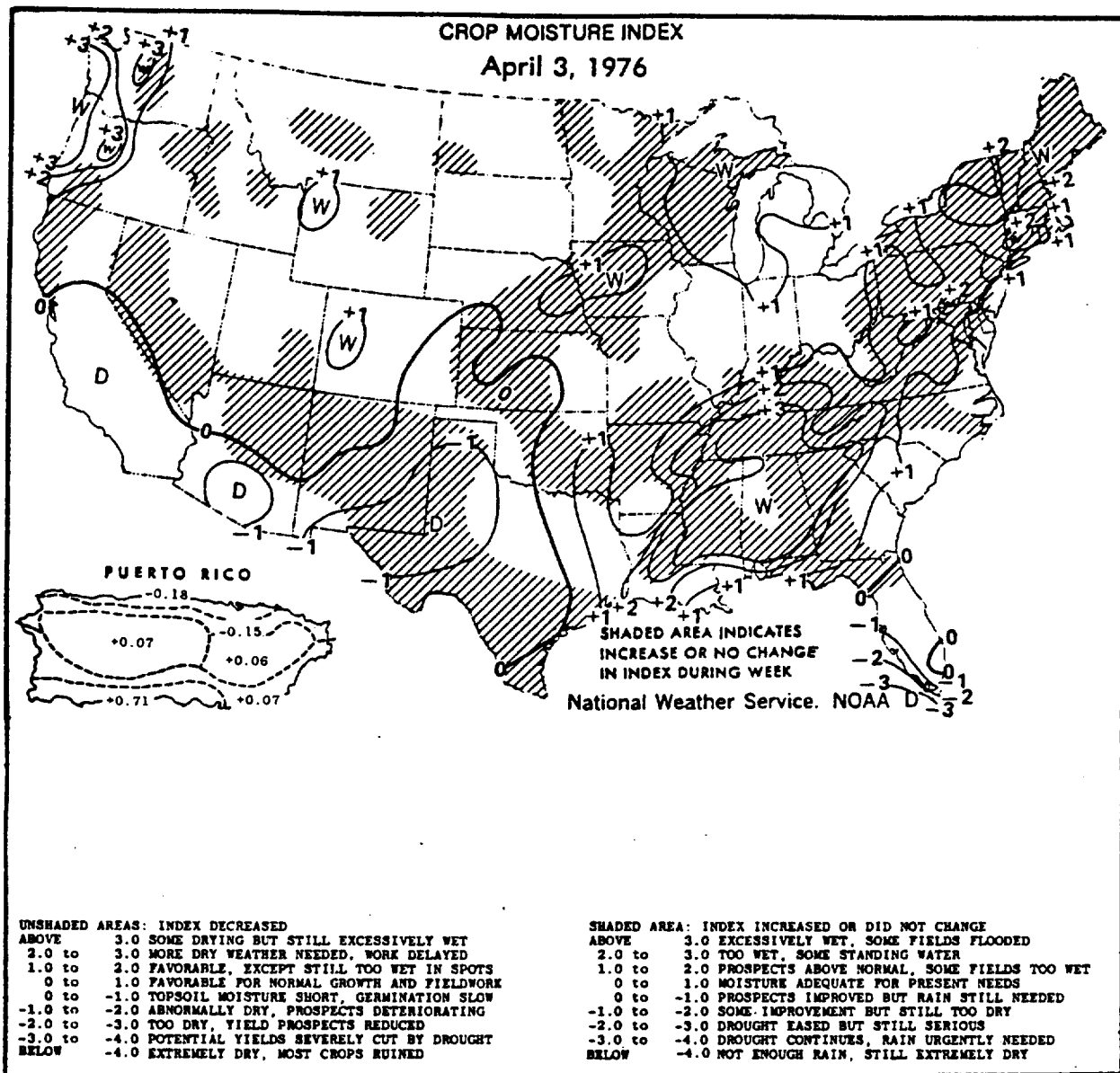


FIGURE 2. CROP MOISTURE INDEX FOR APRIL 3, 1976.  
[From reference 7.]

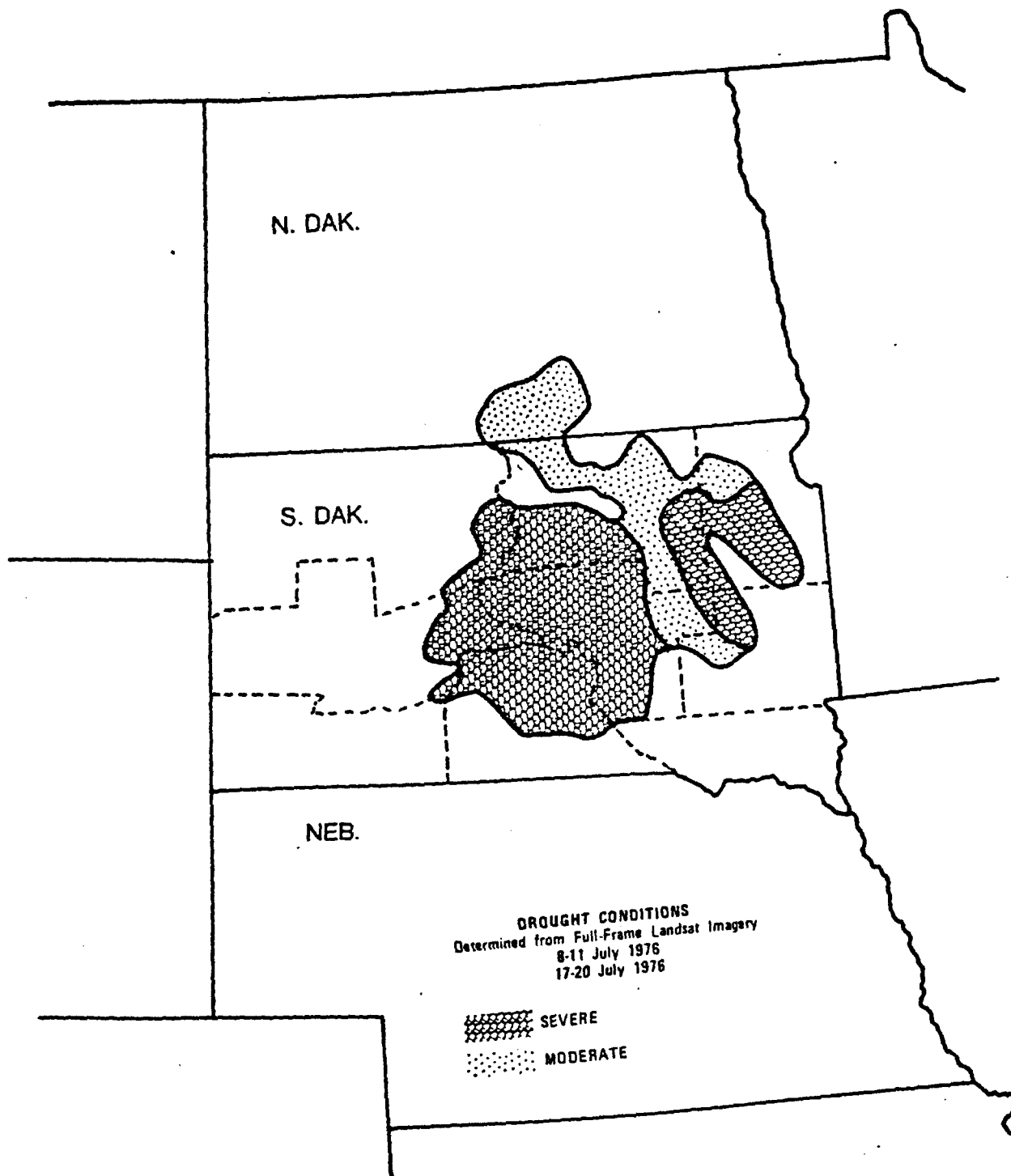


FIGURE 3. DROUGHT-AFFECTED AREA AS DETERMINED FROM LANDSAT FULL-FRAME IMAGERY FOR JULY 8 TO 11 AND JULY 11 TO 20, 1976. [From reference 4.]

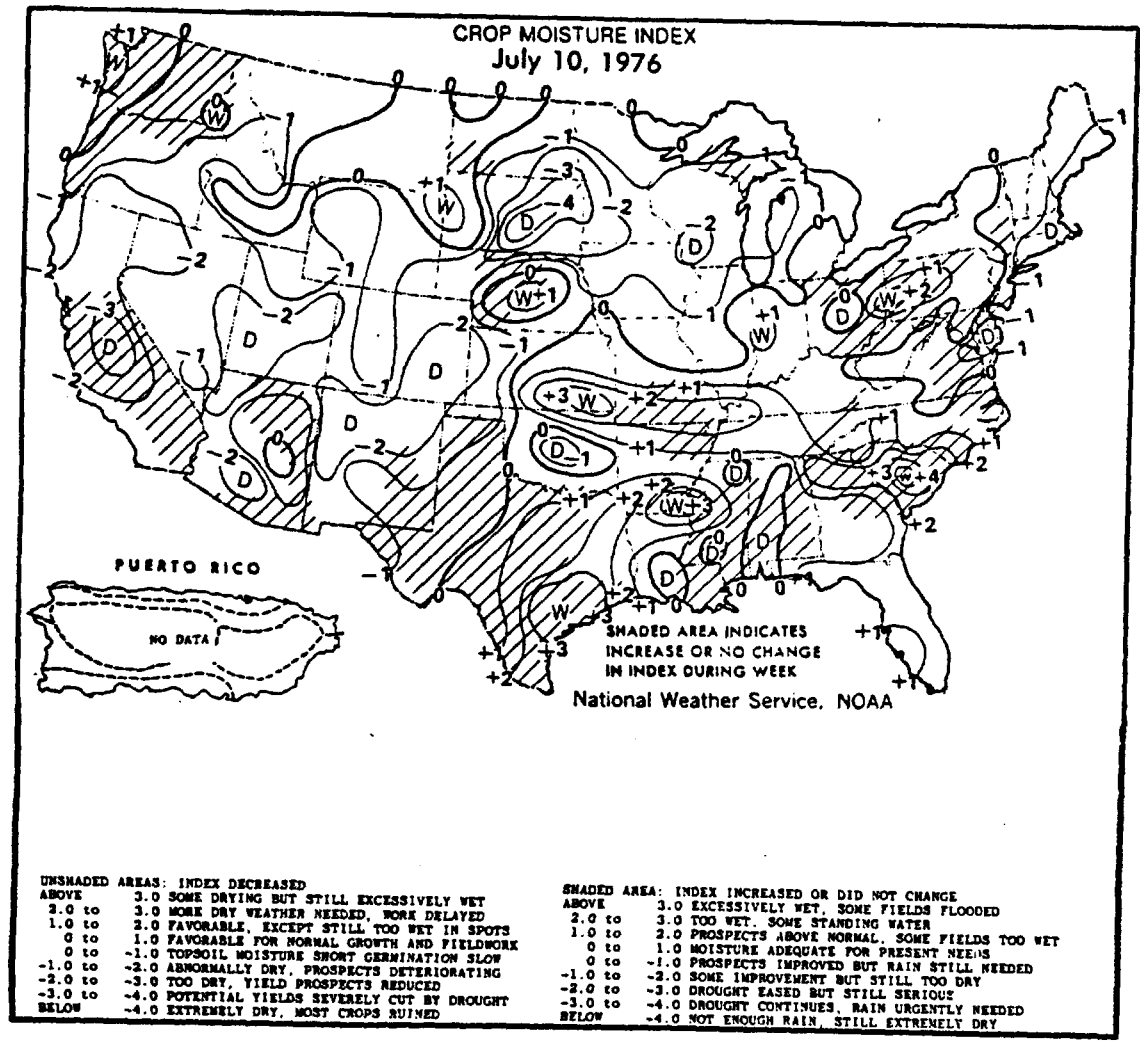


FIGURE 4. CROP MOISTURE INDEX FOR JULY 10, 1976.  
[From reference 8.]

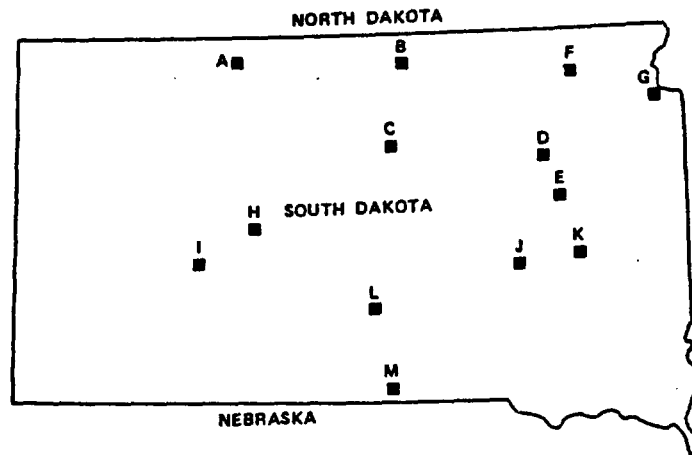


FIGURE 5. SEGMENT LOCATIONS. Map of South Dakota showing locations of LACIE 5- by 6-nautical-mile sample segments. [From reference 6.]

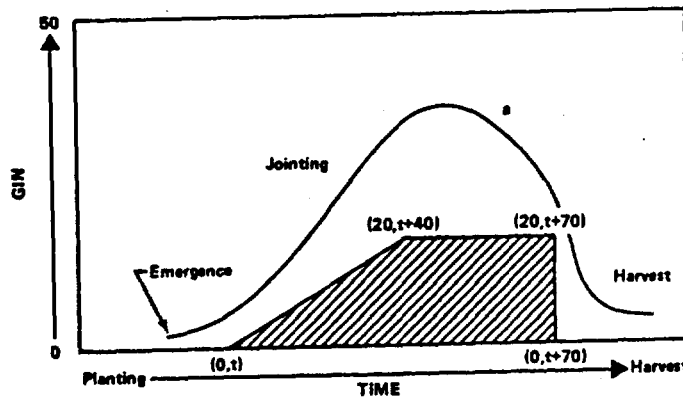


FIGURE 6. PLOT. GIN versus time for a normal, predominantly wheat segment. [From reference 6.]

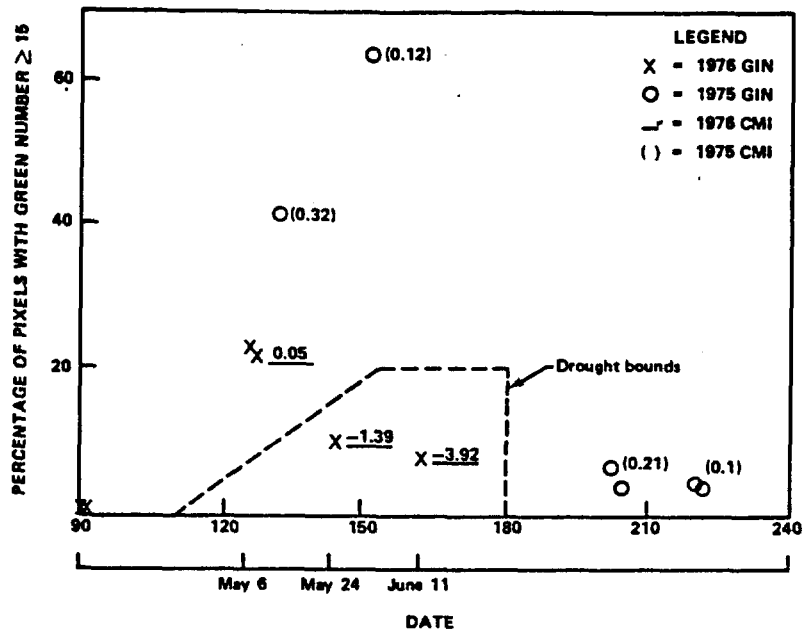


FIGURE 7. GRAPHIC PLOT. GIN versus time with CMI values for segment J. [From reference 6.]



- THE GREEN INDEX NUMBER (GIN) PROGRAM PROVIDES AN AUTOMATIC PROCEDURE FOR DETECTING AND MONITORING CROP STRESS OVER LARGE AREAS.
  - AN EXAMPLE OF HOW THIS PROGRAM IS USED IN LACIE IS SHOWN IN FIGURES 8-10
  - FIGURE 8 SHOWS THE RESULTS OF THE GIN PROGRAM FOR ONE LANDSAT PASS OVER THE USSR SPRING WHEAT REGION. MUCH OF THE AREA WAS UNDERGOING MOISTURE STRESS
  - FIGURE 9 SHOWS THE NEXT LANDSAT PASS OVER THE AREA AND INDICATES STRESS IS STILL OCCURRING OVER THE REGION
  - FIGURE 10 IS A COMPOSITE OF THE TWO LANDSAT PASSES AND SHOWS WHERE MOISTURE STRESS OCCURRED DURING JULY 1977.

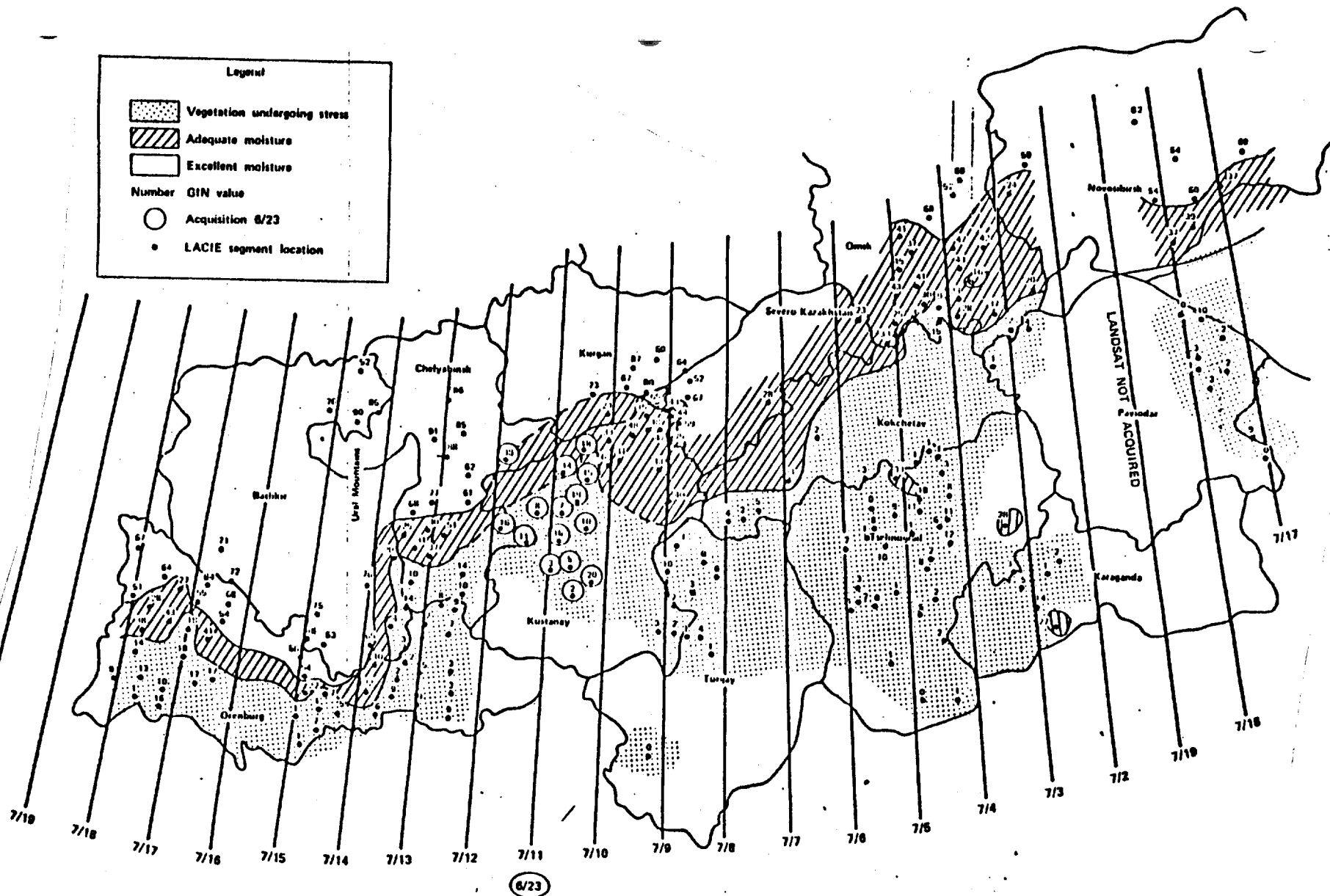


Figure 8.— Moisture conditions over U.S.S.R. spring wheat from the LACIE Green Index Number (GIN) monitoring program (Landsat data acquired June 23, 1977, and July 2 through July 19, 1977).

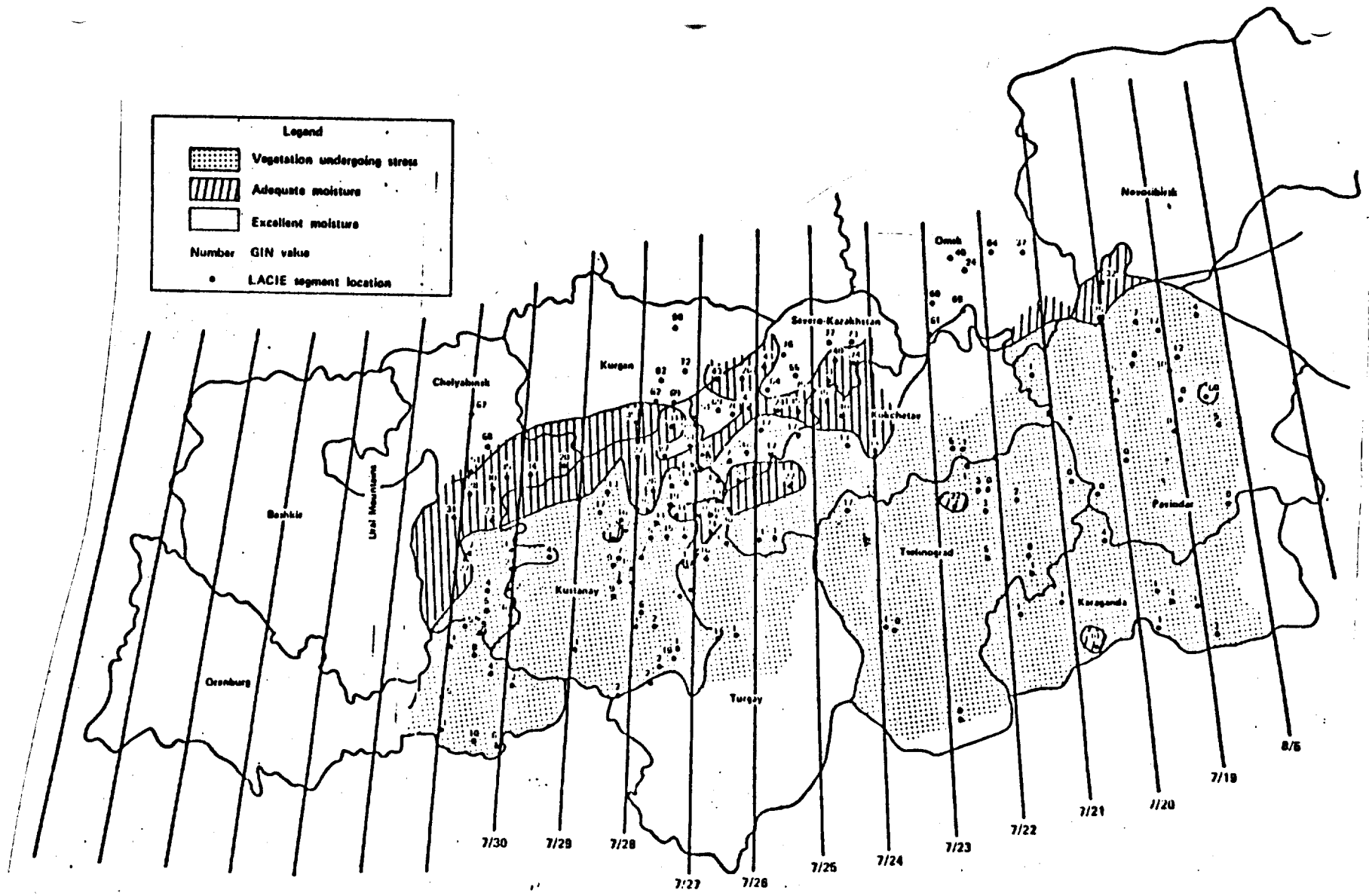


Figure 9.— Moisture conditions over U.S.S.R. spring wheat from the LACIE GIN monitoring program (Landsat data acquired July 19 through August 4, 1977).

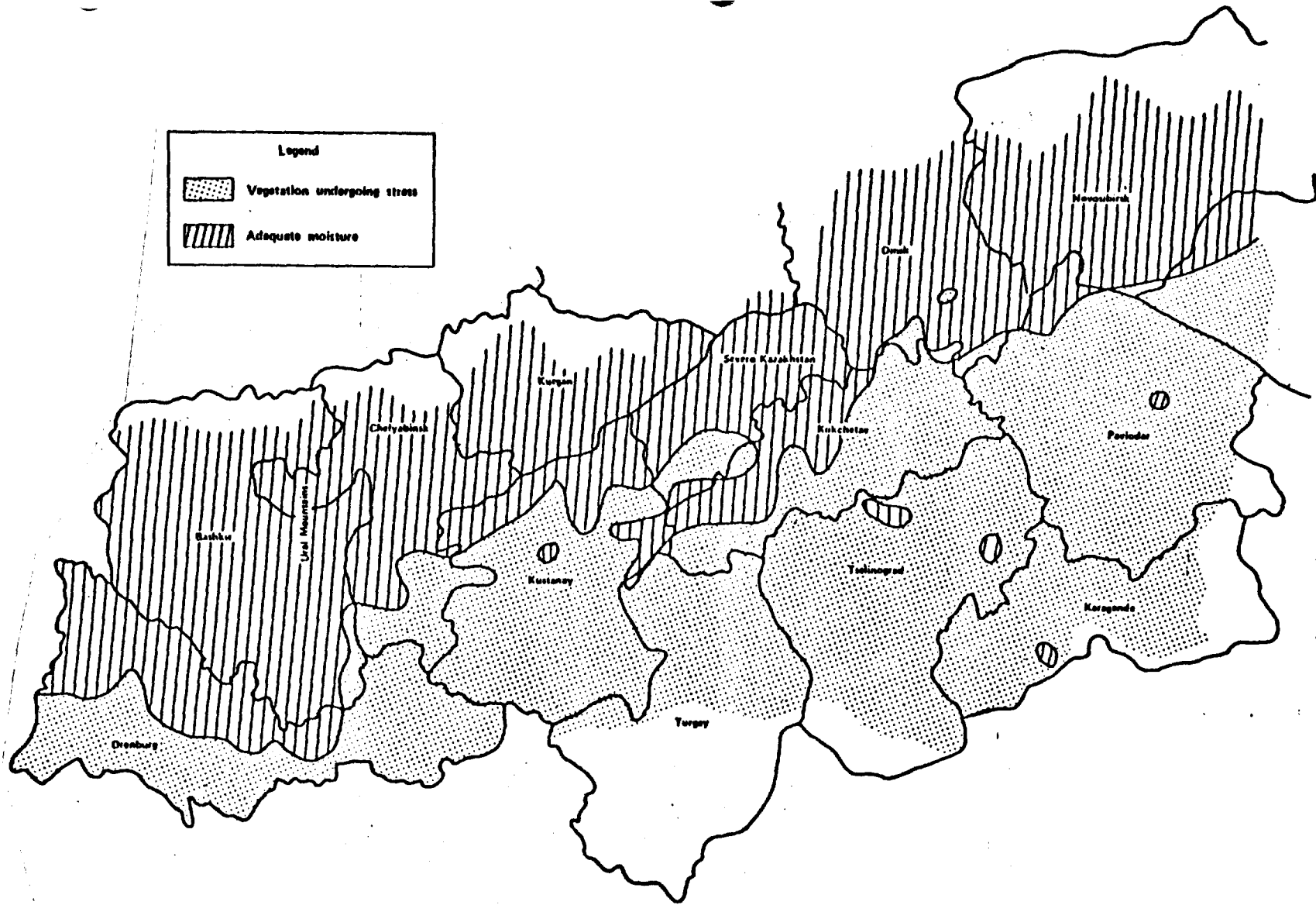


Figure 10.— Moisture conditions over U.S.S.R. spring wheat from the LACIE GIN monitoring program for July 1977.