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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

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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 1979

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 detractant 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 × 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

*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 interpretated overrides to crop diagnostic submodels (7-2), and monitoring the areal extend 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 develcpment 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 SUPPORTING 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 INPROVED 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

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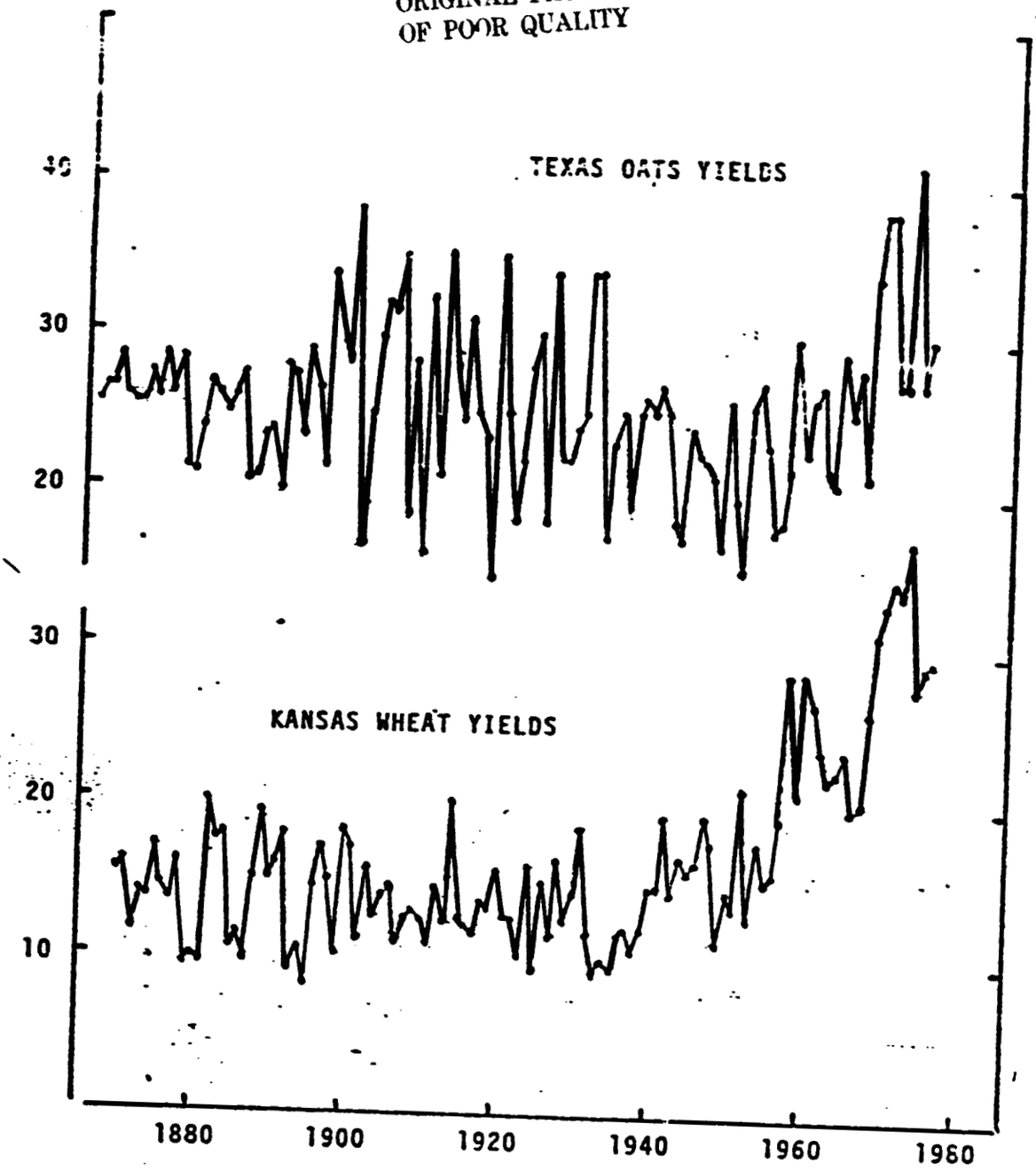

EXAMPLES OF YEAR-TO-YEAR VARIABILITY IN LARGE AREA CROP YIELDS

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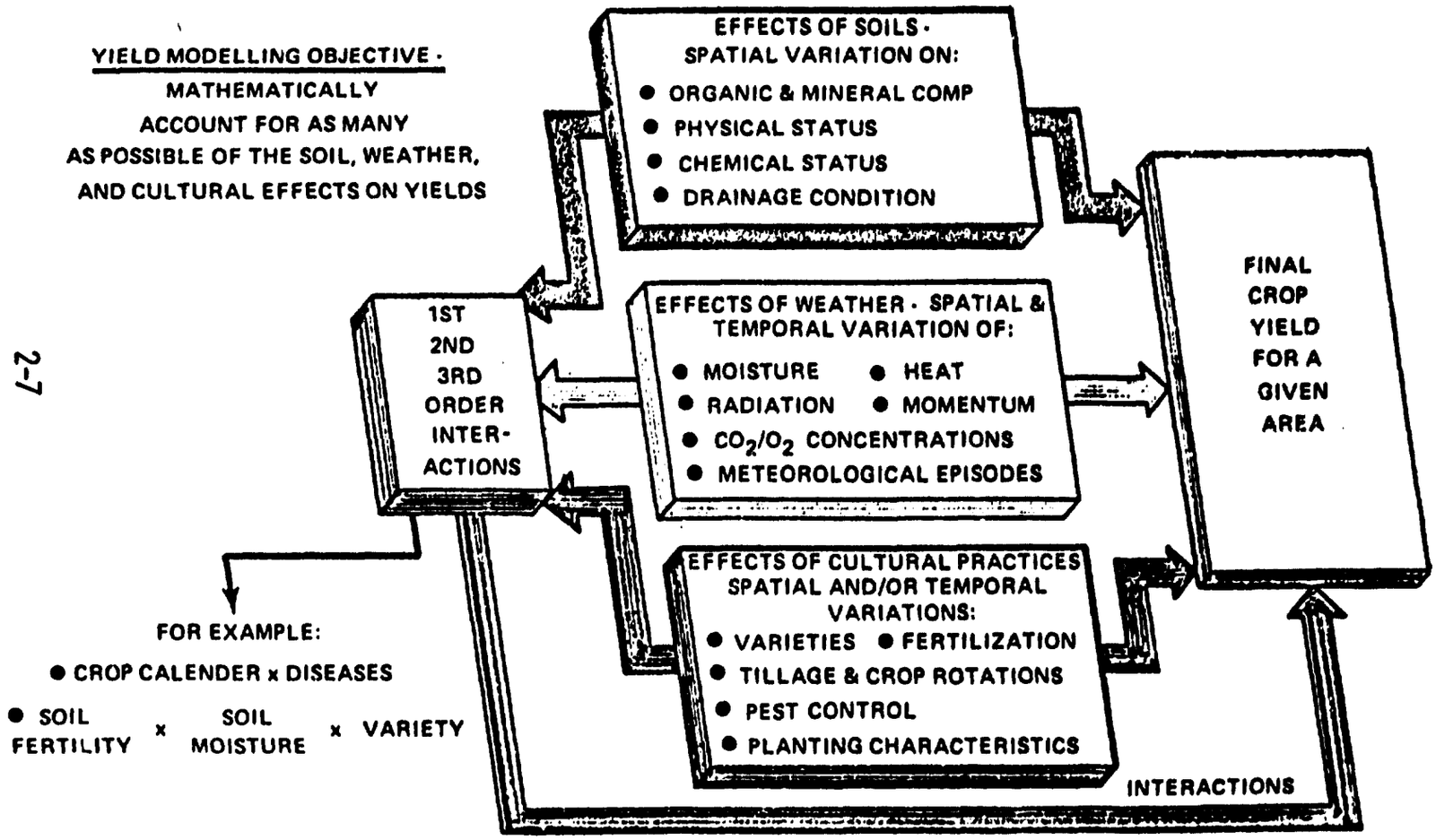
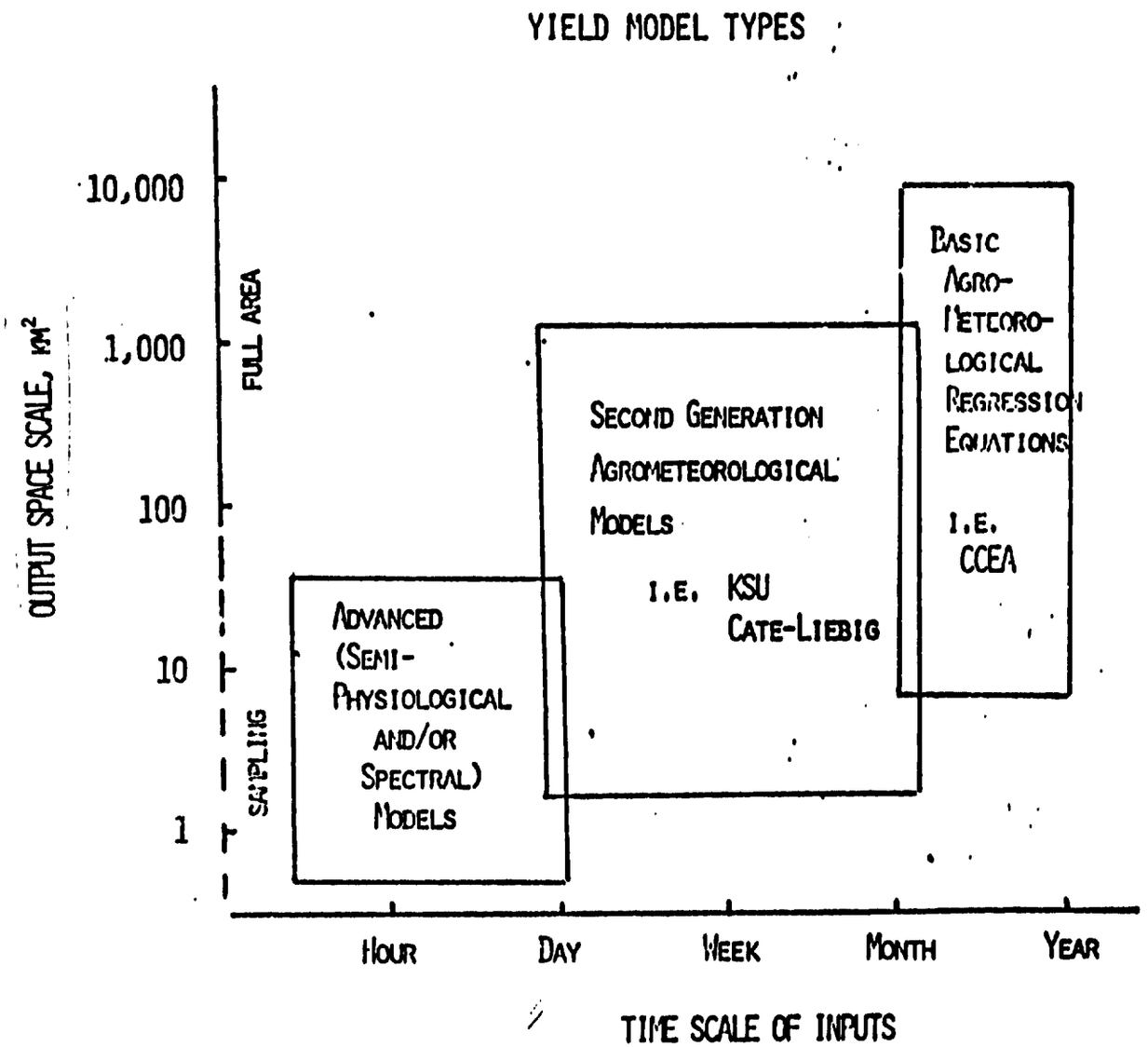
YIELDS ARE DETERMINED BY THE INTEGRATED EFFECTS OF BASIC SOILS, CLIMATE AND CULTURAL FACTORS BY CROPS




YIELD MODEL TYPES
OUTPUT SPACE SCALE, km²
10,000
1,000
100
10
1
FULL AREA
SAMPLING
ADVANCED (SEMI-PHYSIOLOGICAL AND/OR SPECTRAL) MODELS
SECOND GENERATION AGROMETEOROLOGICAL MODELS
I.E. KSU CATE-LIEBIG
BASIC AGRO-METEORO-LOGICAL REGRESSION EQUATIONS
I.E. CCEA
HOUR
DAY
WEEK
MONTH
YEAR
TIME SCALE OF INPUTS

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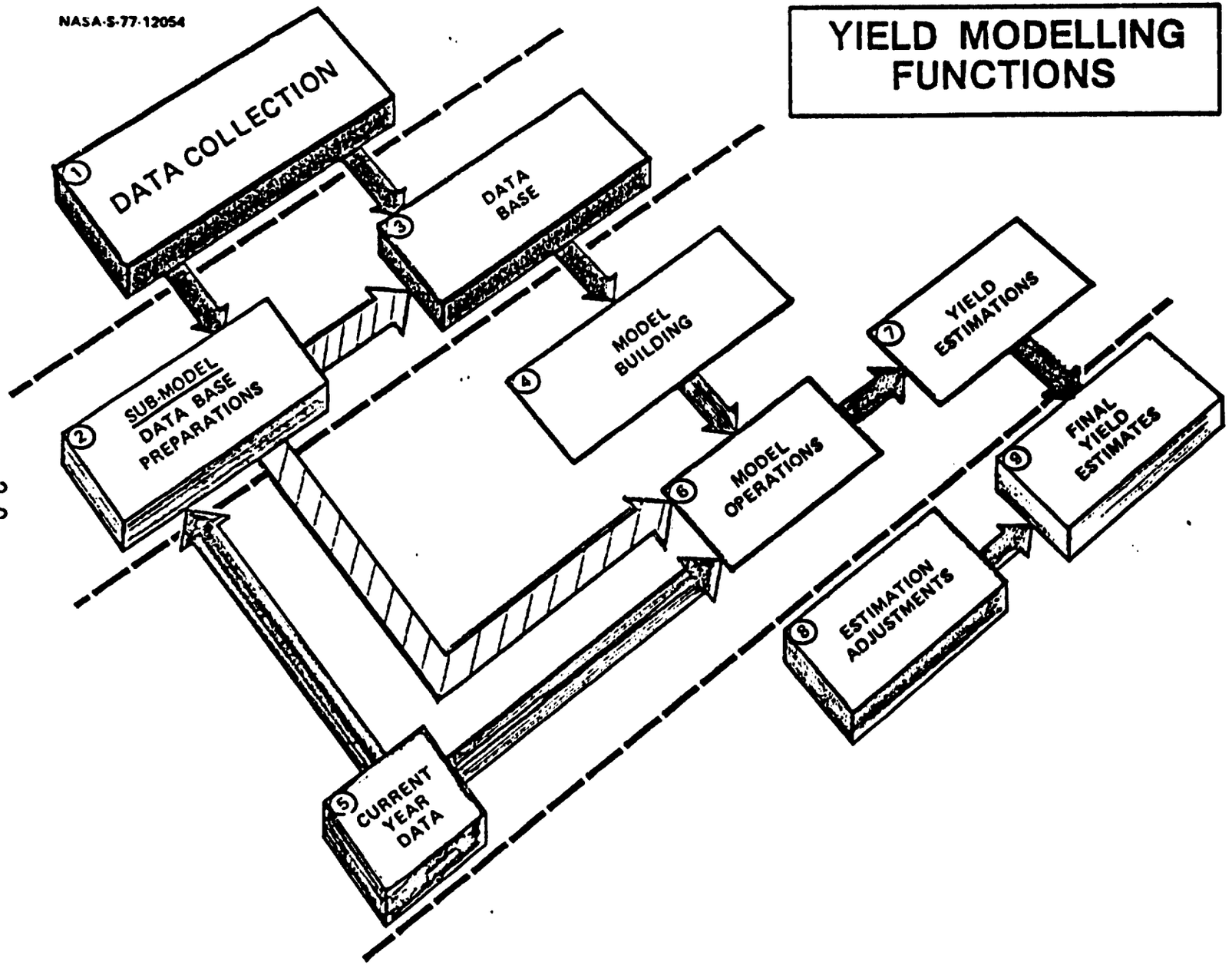
YIELD MODELLING FUNCTIONS



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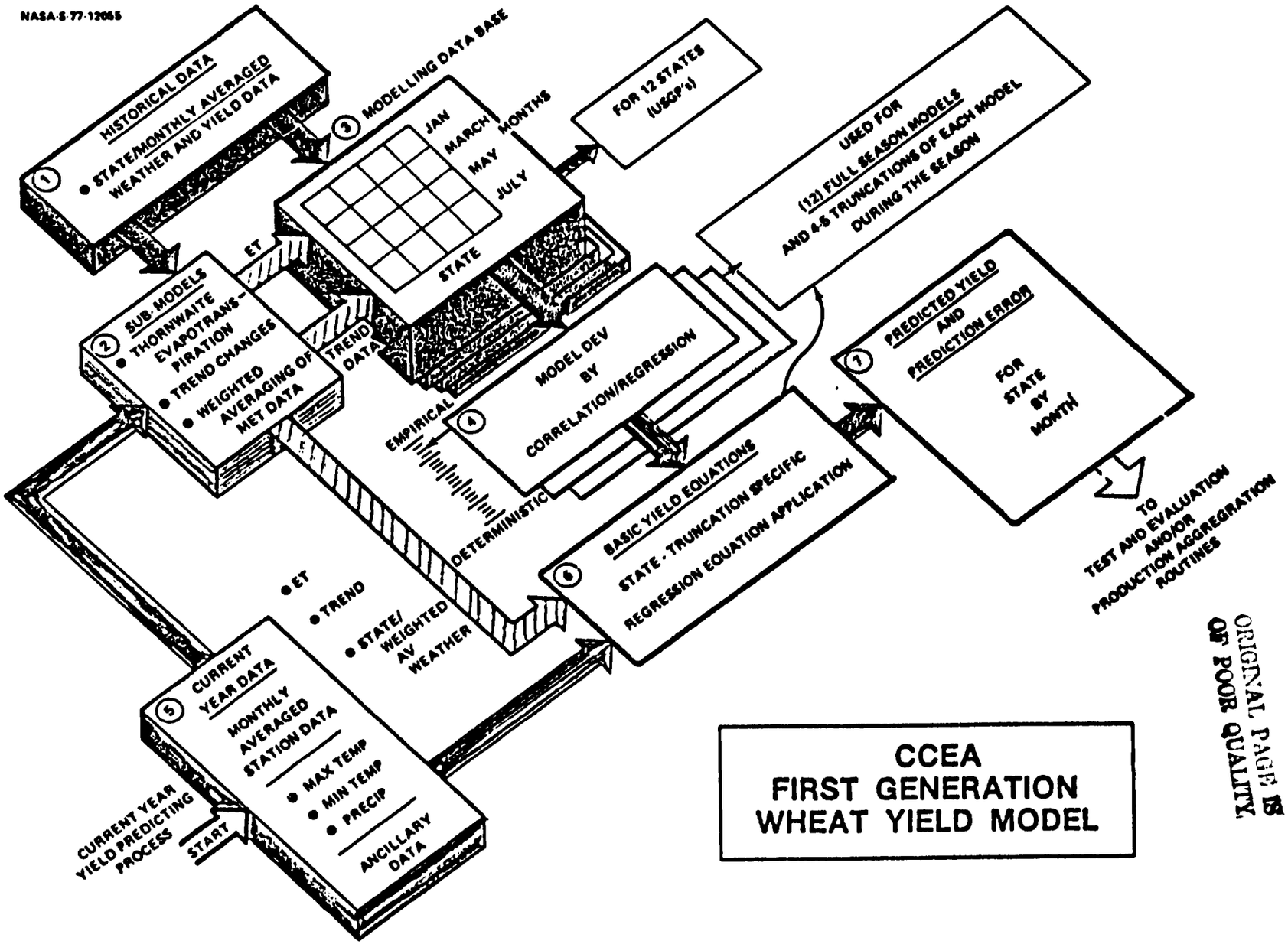

CCEA
FIRST GENERATION
WHEAT YIELD MODEL

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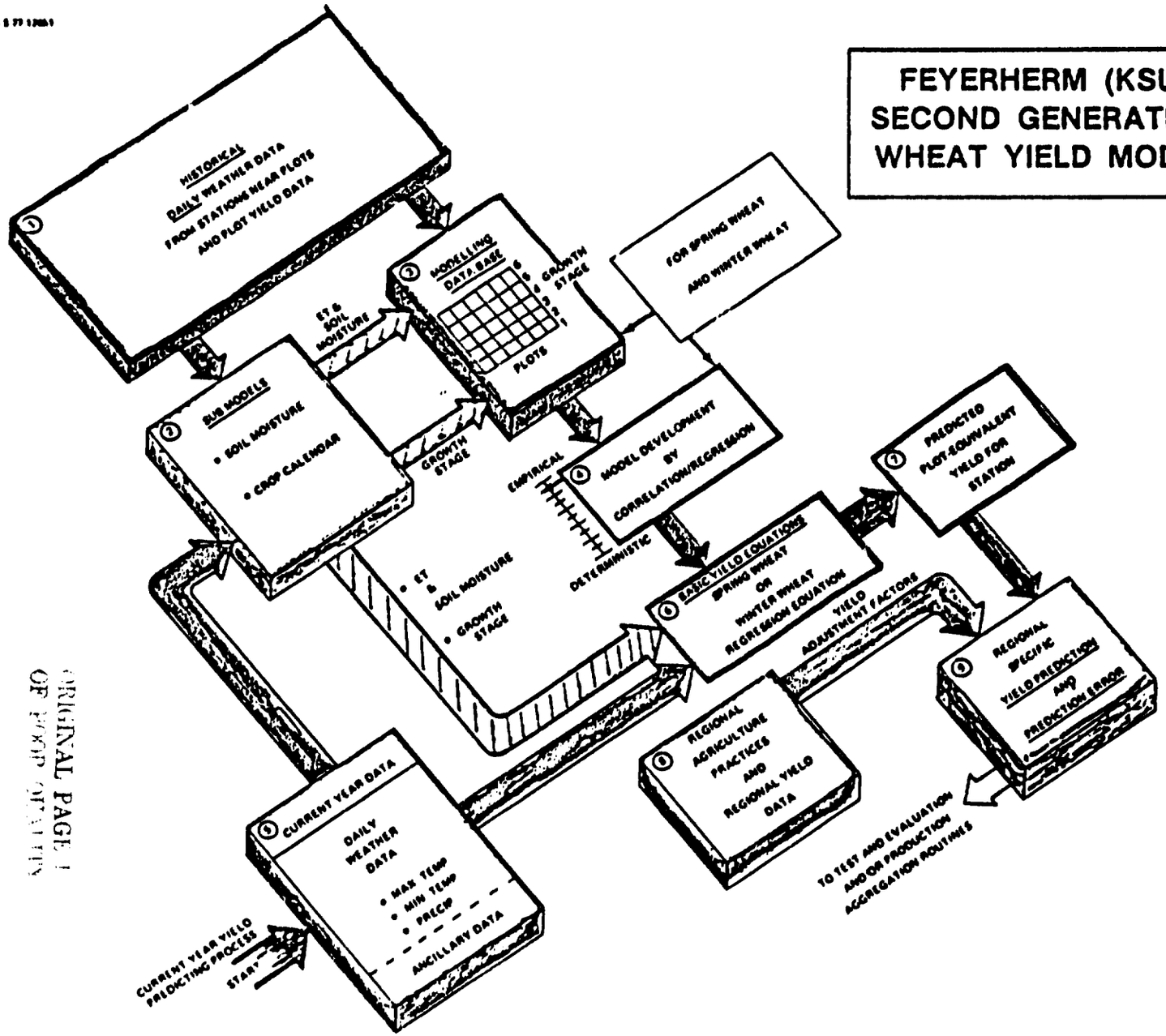
TEST AND EVALUATION RESULTS - SUMMARY TO DATE

- 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



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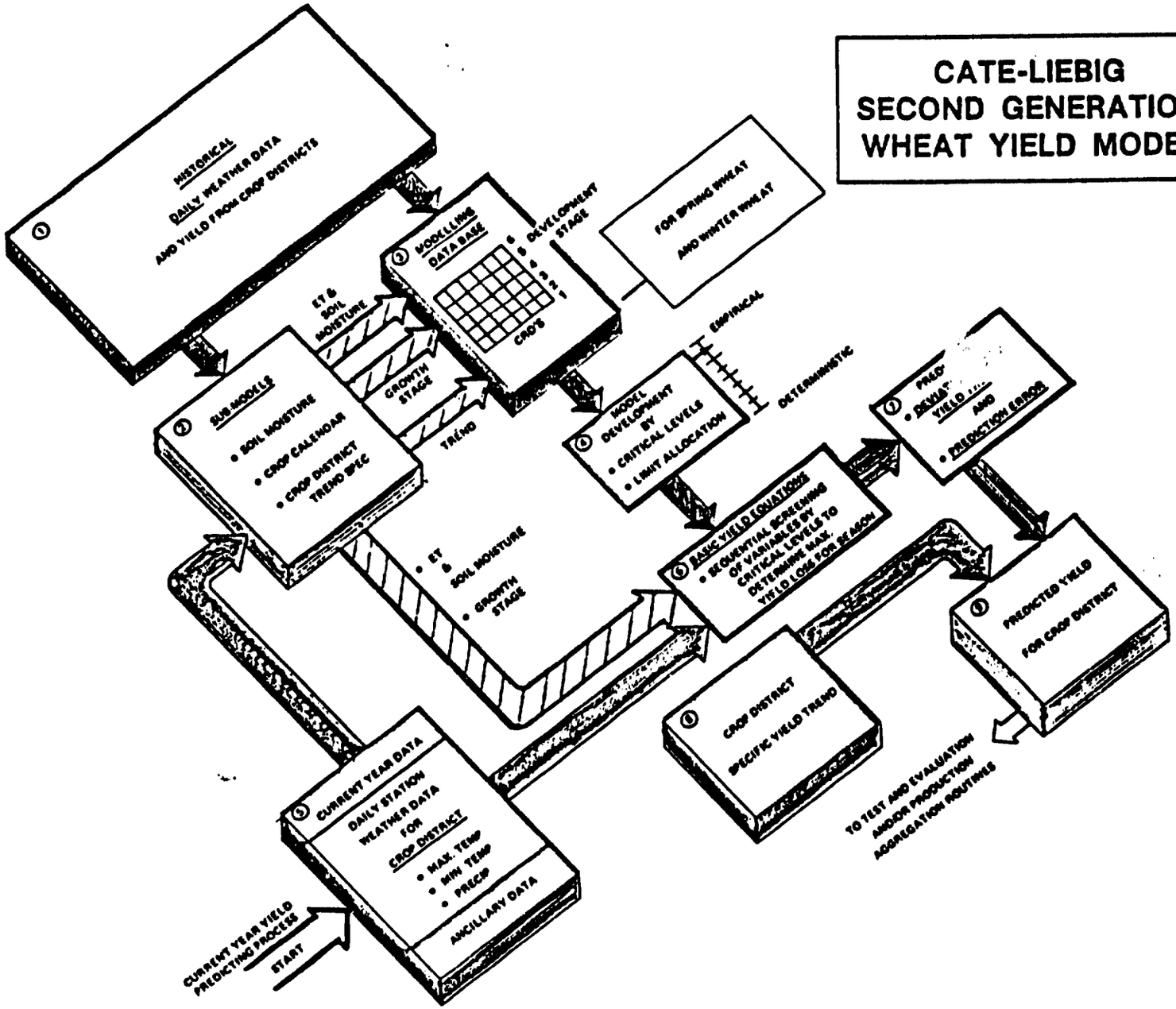
CATE-LIEBIG SECOND GENERATION WHEAT YIELD MODEL



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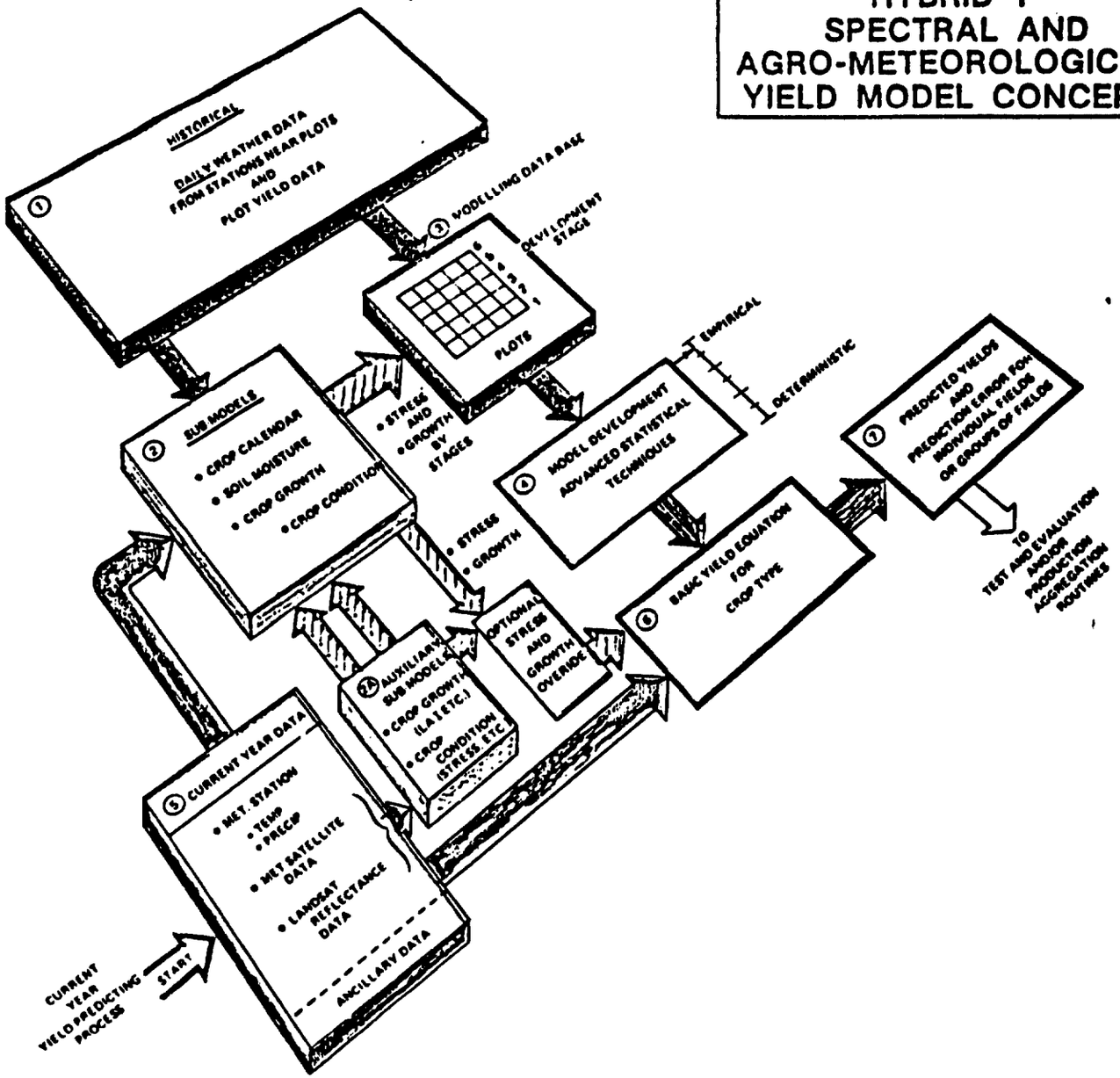
HYBRID 1 SPECTRAL AND AGRO-METEOROLOGICAL YIELD MODEL CONCEPT



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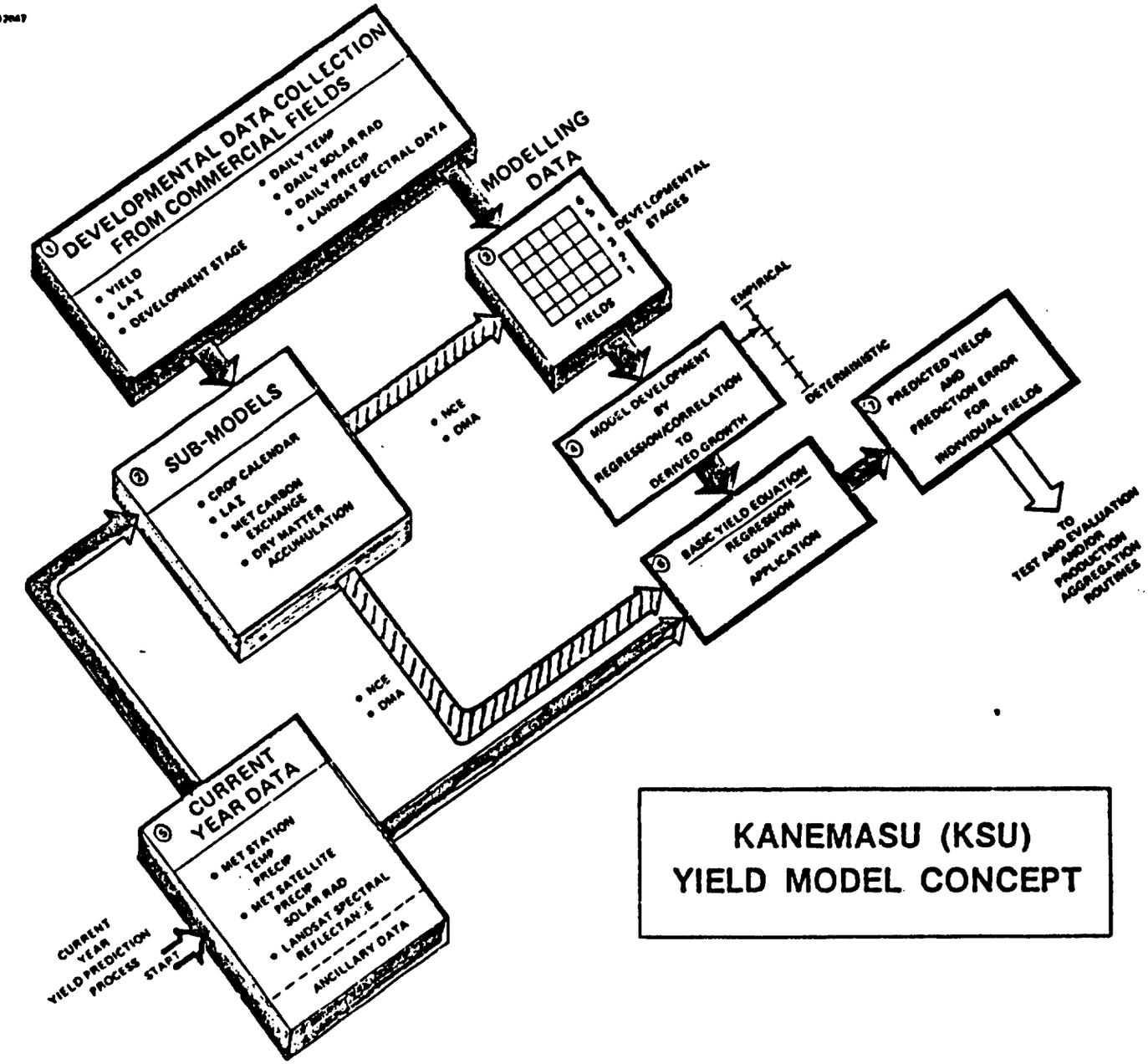
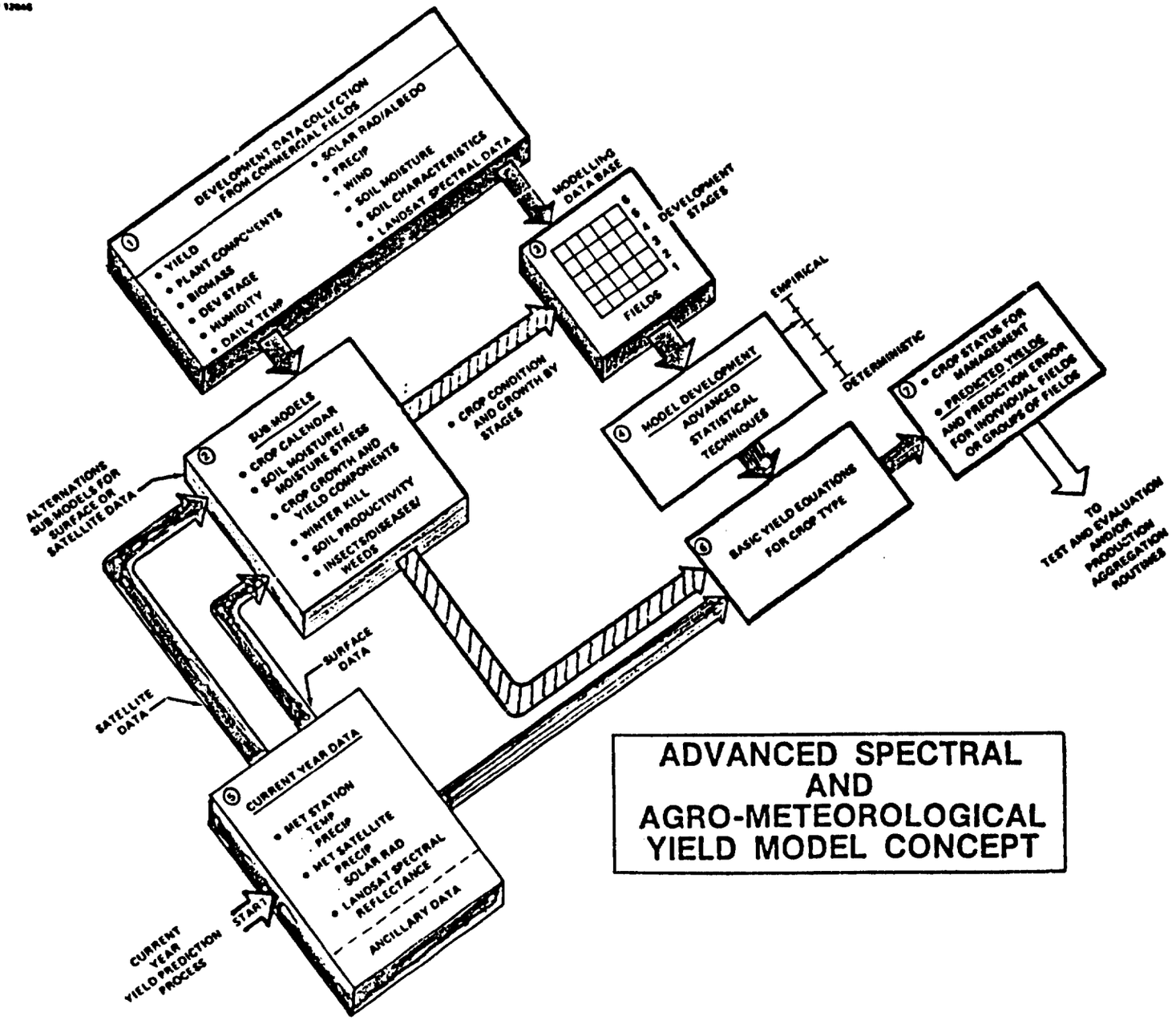


KANEMASU (KSU)
YIELD MODEL CONCEPT



ADVANCED SPECTRAL AND AGRO-METEOROLOGICAL YIELD MODEL CONCEPT

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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 NF 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

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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:

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

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

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 μm 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:

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

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

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 μm 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 μm 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^2	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^2 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 μm (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^2 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 μm 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 μm band.

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

Parameter	R^2	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, '$\hat{Y}$(76-77)':

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

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 μm 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 μm. 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).

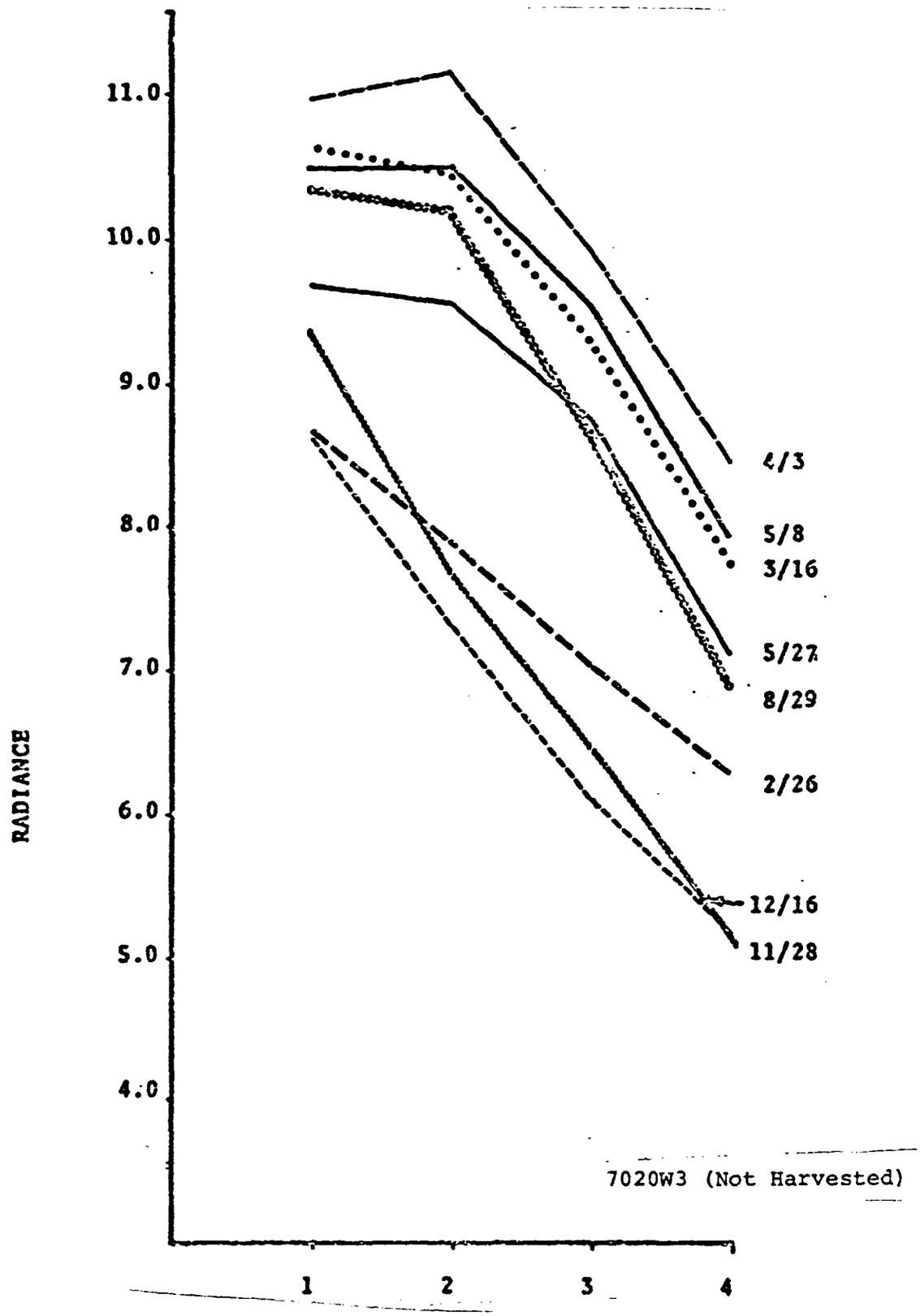
2. J. W. Rouse, Jr. et al., in: Third ERTS-1 Symposium, NASA-Goddard Space Flight Center, 1973, p. 309.

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   WAVELENGTH          *
*                             DEVIATION  (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)             *
*                                                            *
* 16.0  +                                                    *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*       .                                  *       -       *  *
*  8.0  +    *              -                                 *
*       .         -     -                                    *
*       .              *                                     *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*       .                                                    *
*  0.0  +---------+---------+---------+---------+---------+  *
*      0.5       0.6       0.7       0.8       0.9       1.0*
*              RADIANCE VS WAVELENGTH                        *
*                                                            *
*  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
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
1
2
3
4
4/3
5/8
3/16
5/27
8/29
2/26
12/16
11/28
7020W3 (Not Harvested)

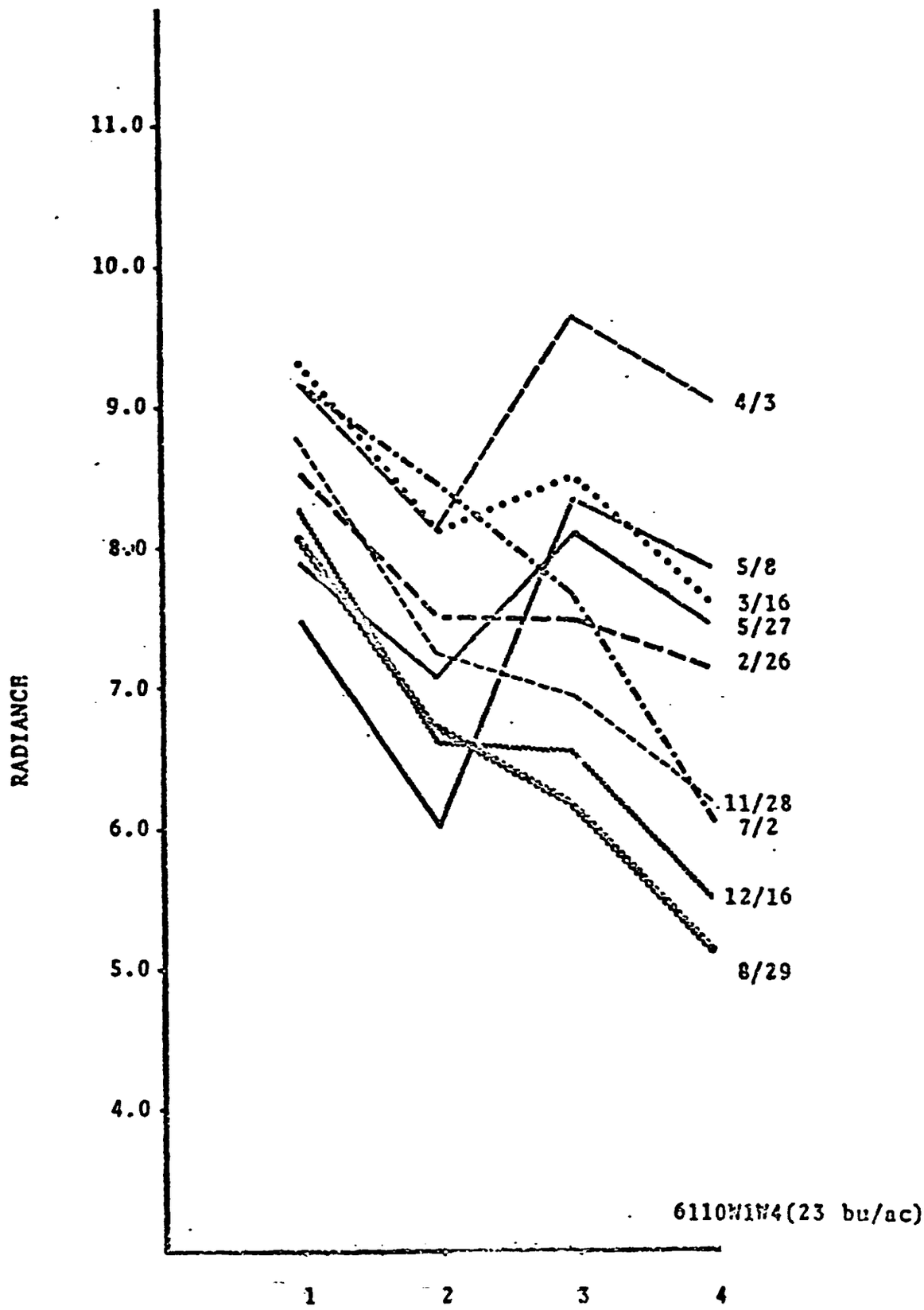
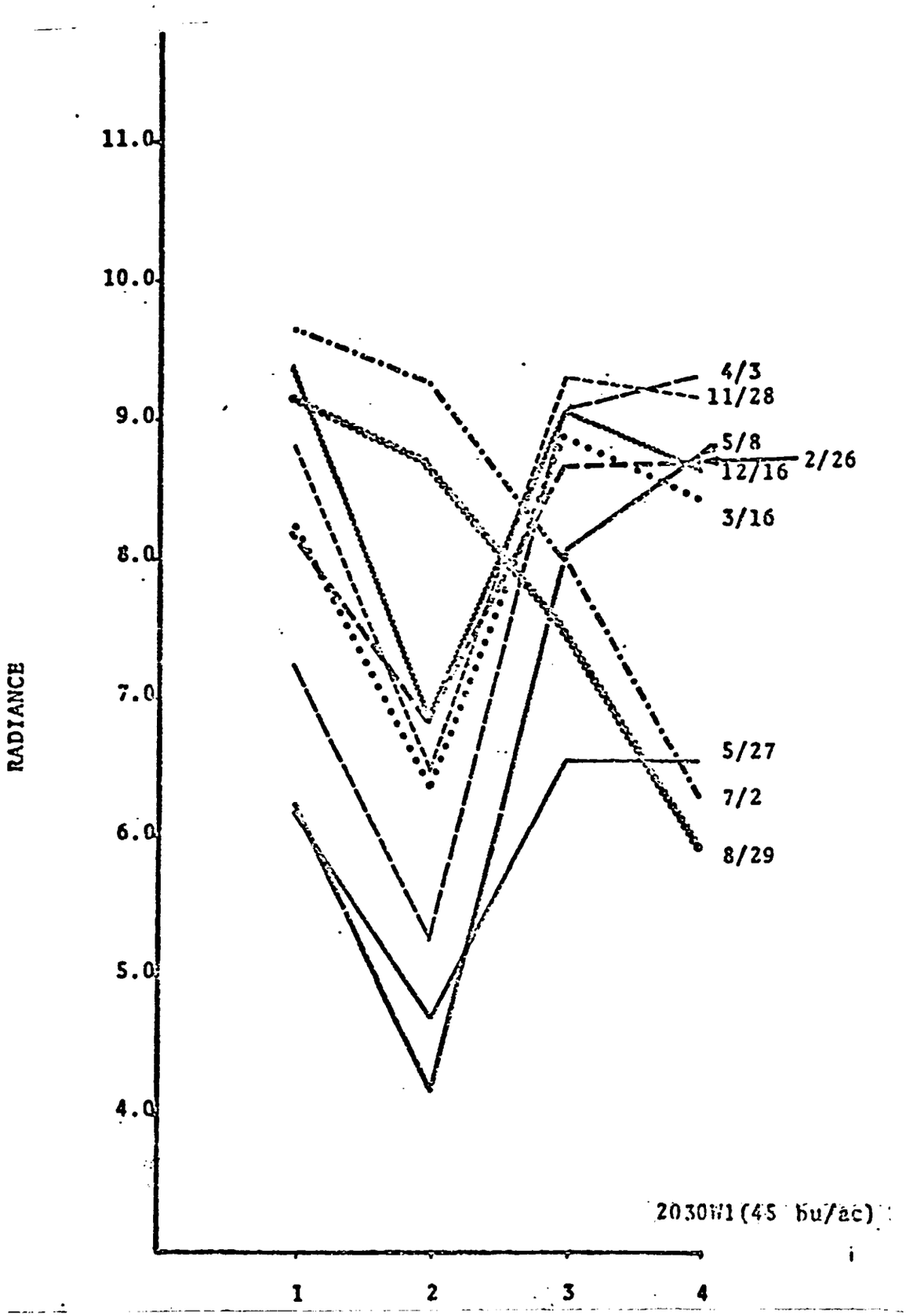
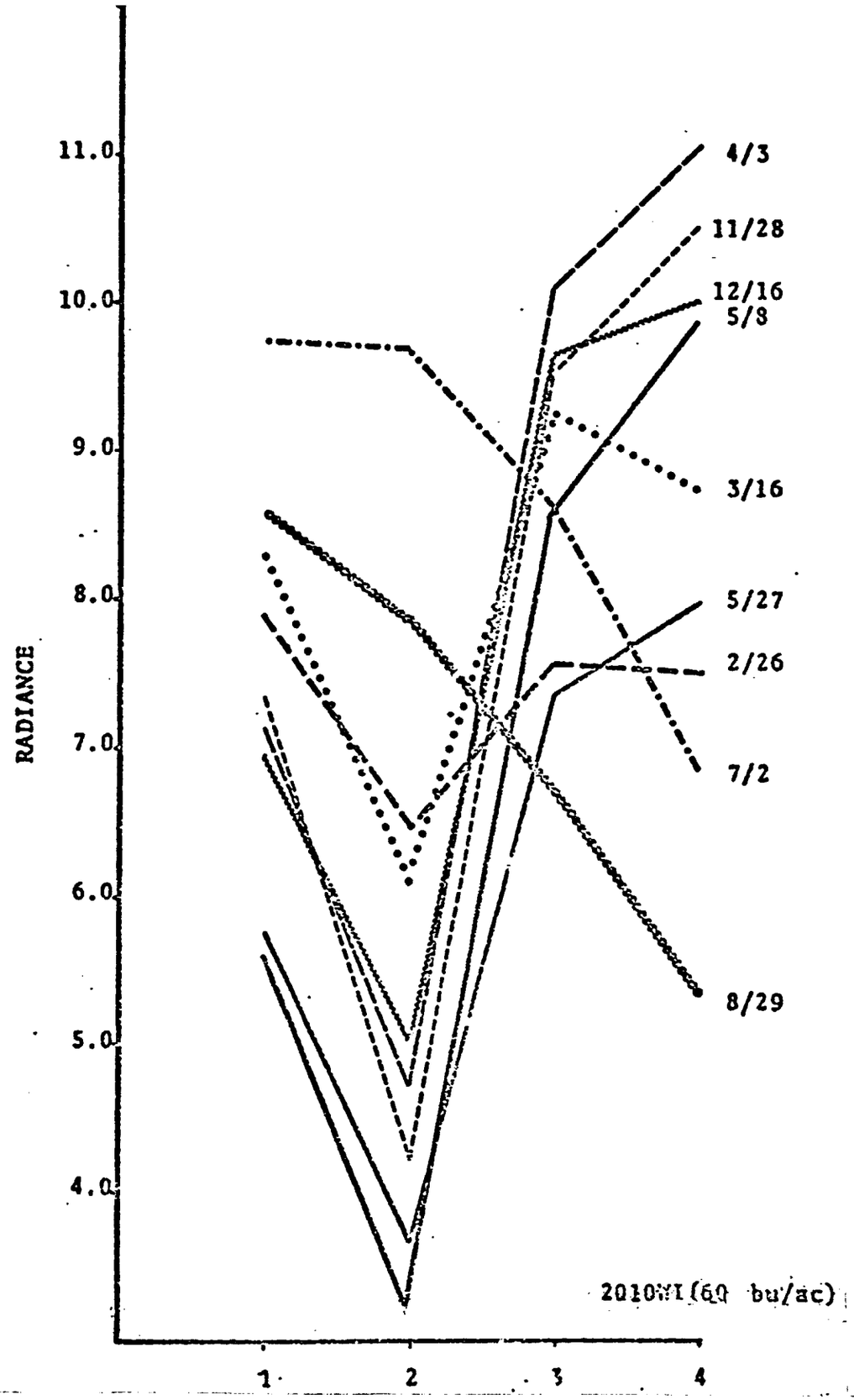


Figure 3-3. Radiance Values for a Low Yielding Irrigated Wheat Field.


RADIANCE
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
1
2
3
4
4/3
11/28
5/8
2/26
12/16
3/16
5/27
7/2
8/29
2030W1 (45 bu/ac)


11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
RADIANCE
1
2
3
4
4/3
11/28
12/16
5/8
3/16
5/27
2/26
7/2
8/29
2010YI(60 bu/ac)

LANDSAT AND OTHER PROPOSED SENSOR BANDS

LANDSAT PLUS 2 OTHERS		THEMATIC MAPPER
1	0.50-0.60	0.48-0.53
2	0.60-0.70	0.53-0.60
3	0.70-0.80	0.62-0.68
4	0.80-1.10	0.74-0.91
5	1.15-1.30	1.55-1.75
6	1.45-1.75	THERMAL IR

FINNEY CO.

REGRESSION MODELS FROM SIMULATED TVI VALUES

R^2	NUMBER OF VARIABLES	NUMBER/NAMES OF BIOPHASES	ORDER OF EQUATION
0.767	4	3/TILLERING (3/20/75) RIPENING (6/2/75) RIPENING (6/9/75)	3
0.703	4	2/TILLERING (3/20/75) RIPENING (6/9/75)	4
0.777	4	3/TILLERING (3/20/75) RIPENING (6/2/75) RIPENING (6/9/75)	4

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.

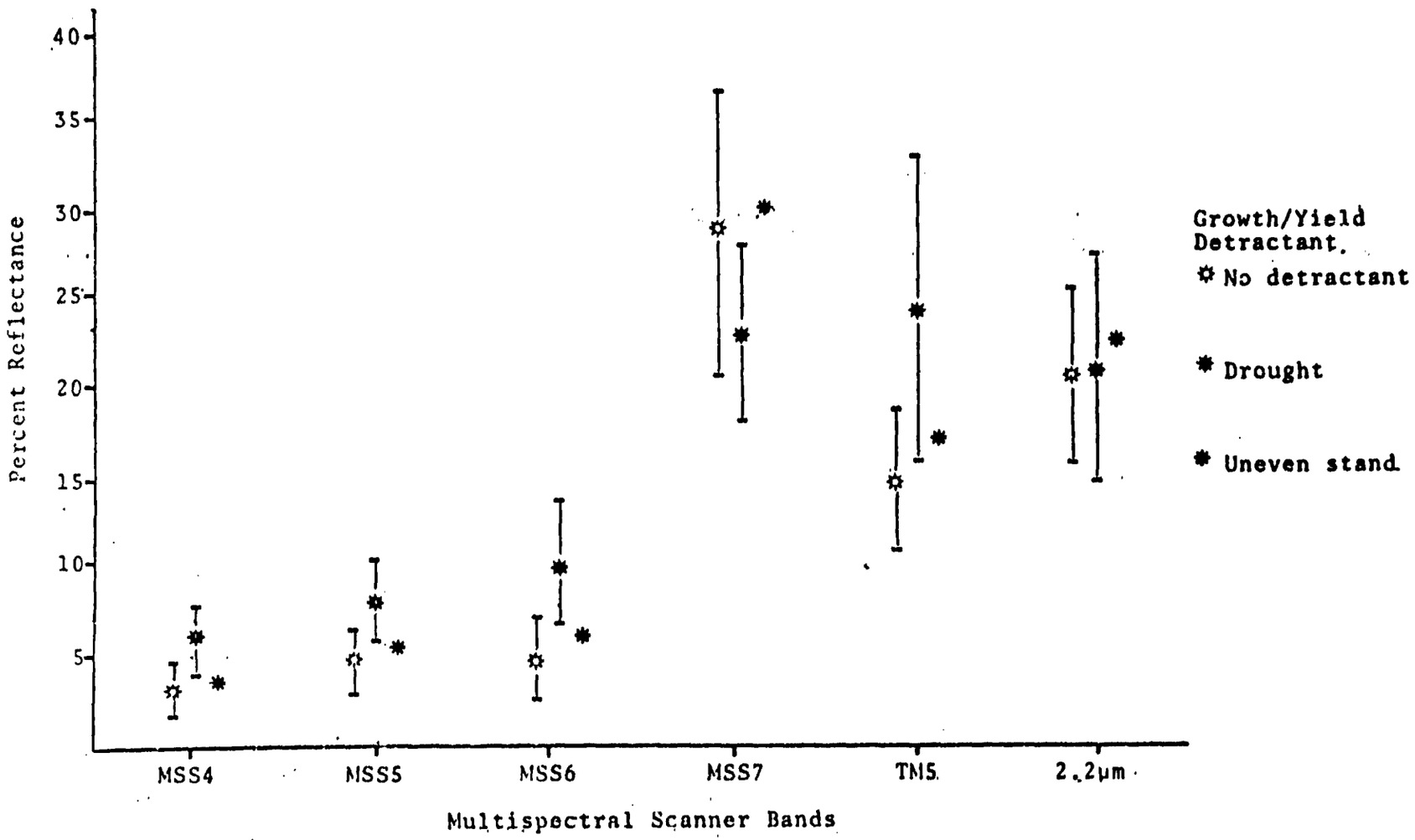
1975 & 1976 KANSAS WINTER WHEAT: DEPENDENCIES OF SPECTRAL DATA ON GROUND DATA

SCANNER BAND	WITHOUT DETRACTANTS	WITH DETRACTANTS	
MSS 6	STAND QUALITY	DETRACTANTS	WEEDS, UNEVEN STANDS
MSS 7	STAND QUALITY	DETRACTANTS	
THERMAL (8.0 - 13.5 μM)	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 μM	STAND QUALITY	DETRACTANTS	
TVI7	CANOPY HEIGHT	DETRACTANTS, CANOPY HEIGHT	

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

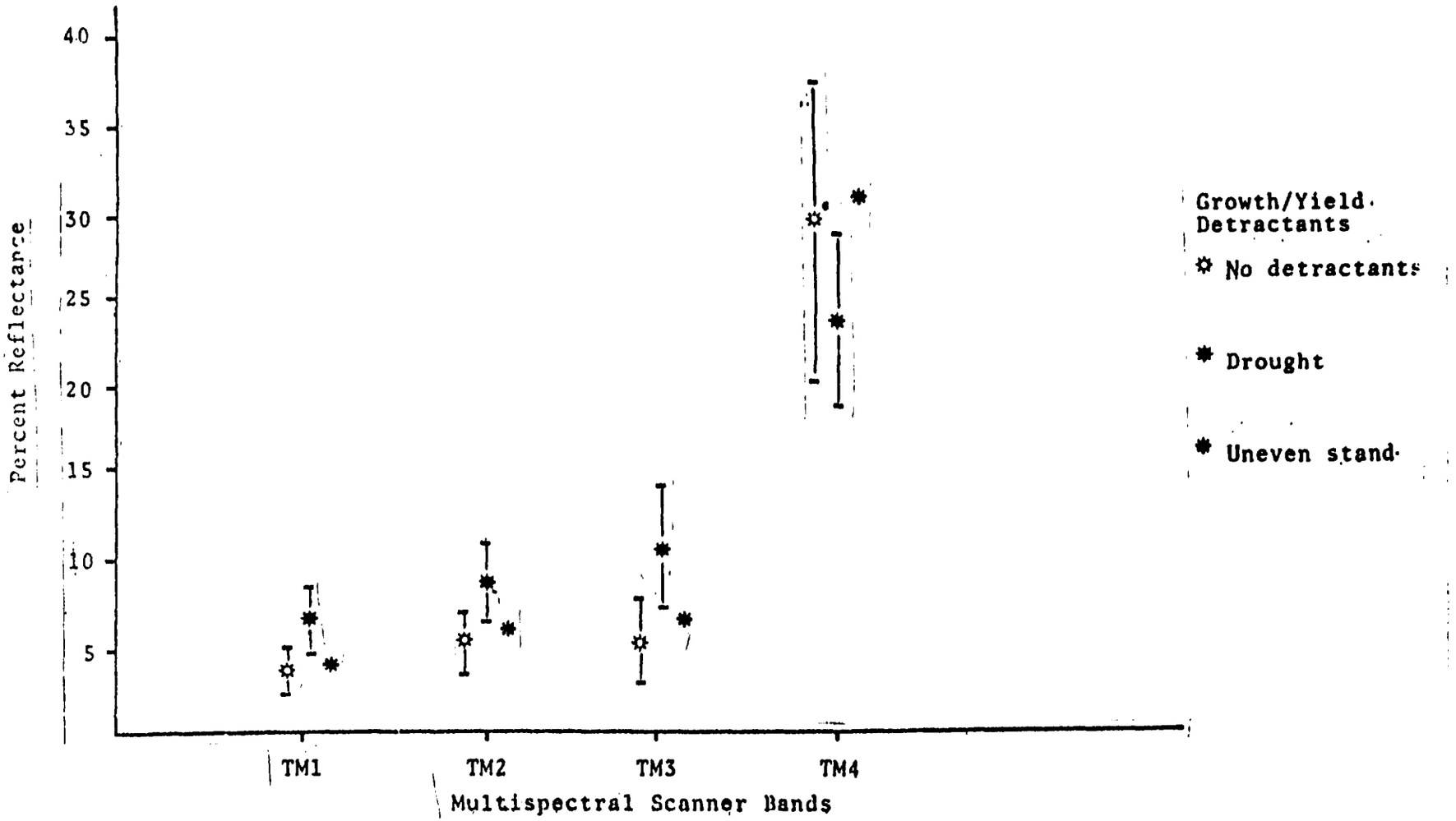
STAND QUALITY – 1 TO 6
GROWTH/YIELD DETRACTANTS – CODED
GROWTH STAGES – 1 TO 10
GROUND COVER – 1 TO 5 IN 20% INCREMENTS
CANOPY HEIGHT – IN INCHES

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



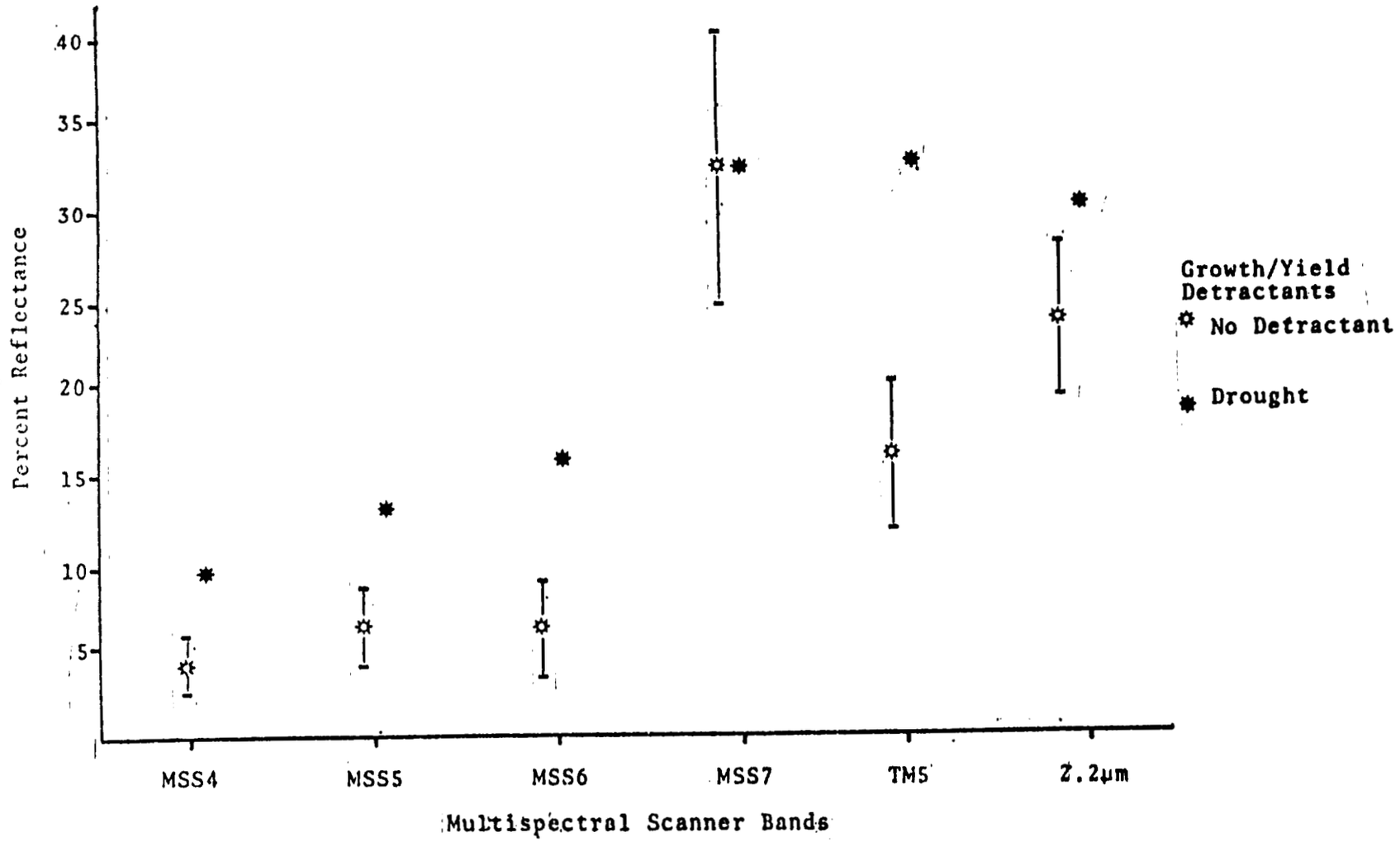
YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS

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



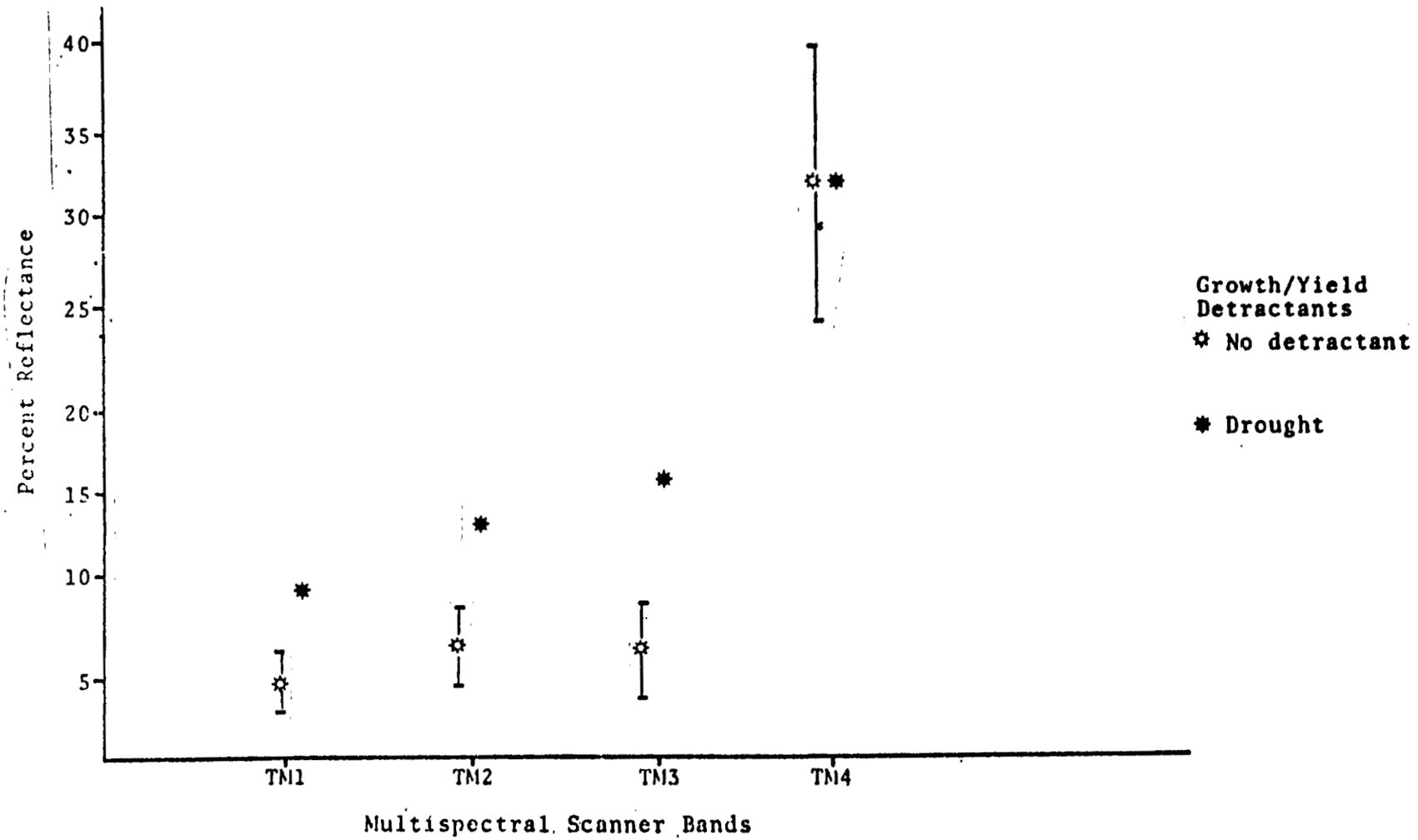
YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS

Winter Wheat, Kansas 1975. Growth Stage: Fully headed



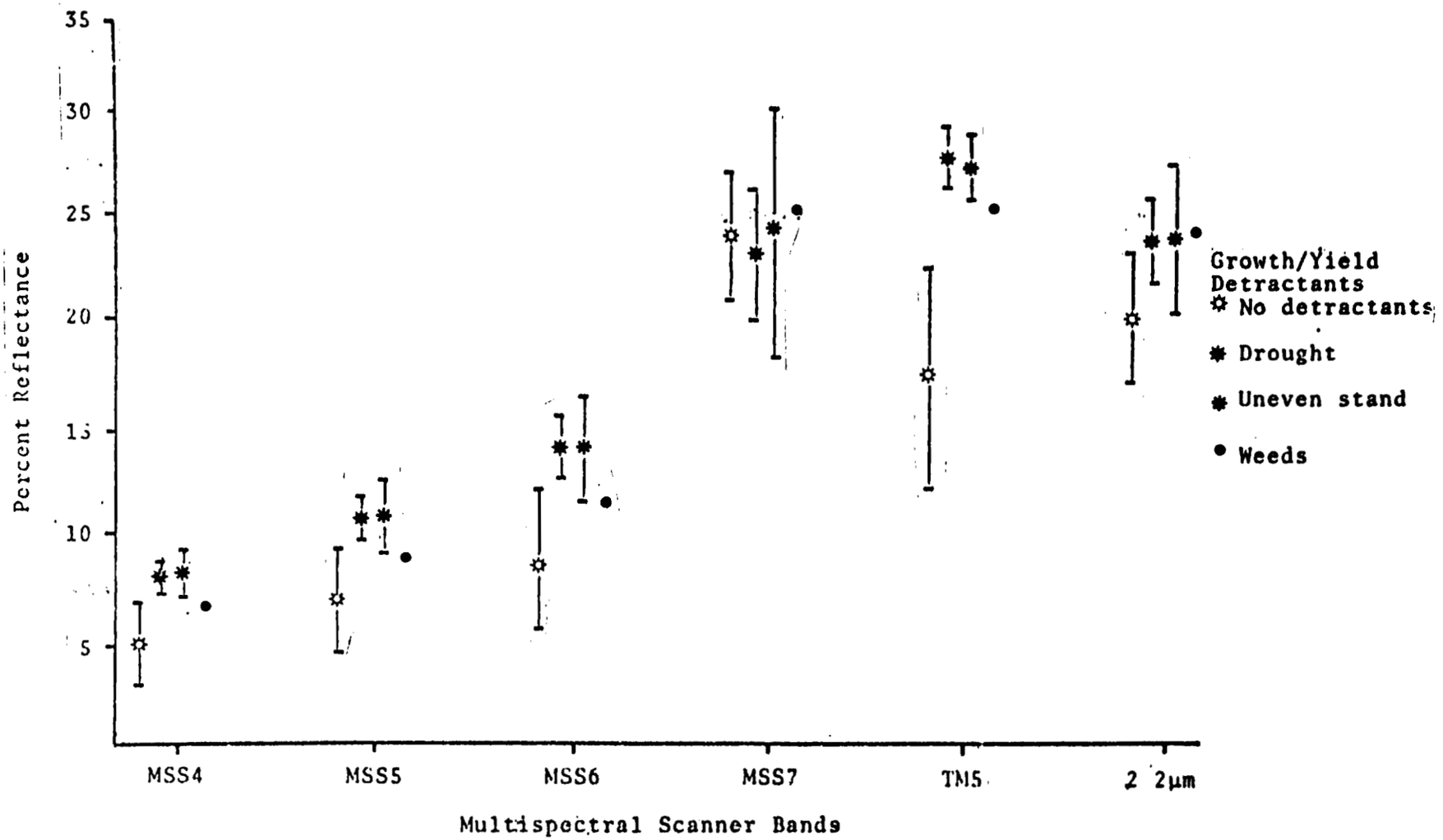
YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS

Winter Wheat, Kansas 1975. Growth Stage: Fully headed



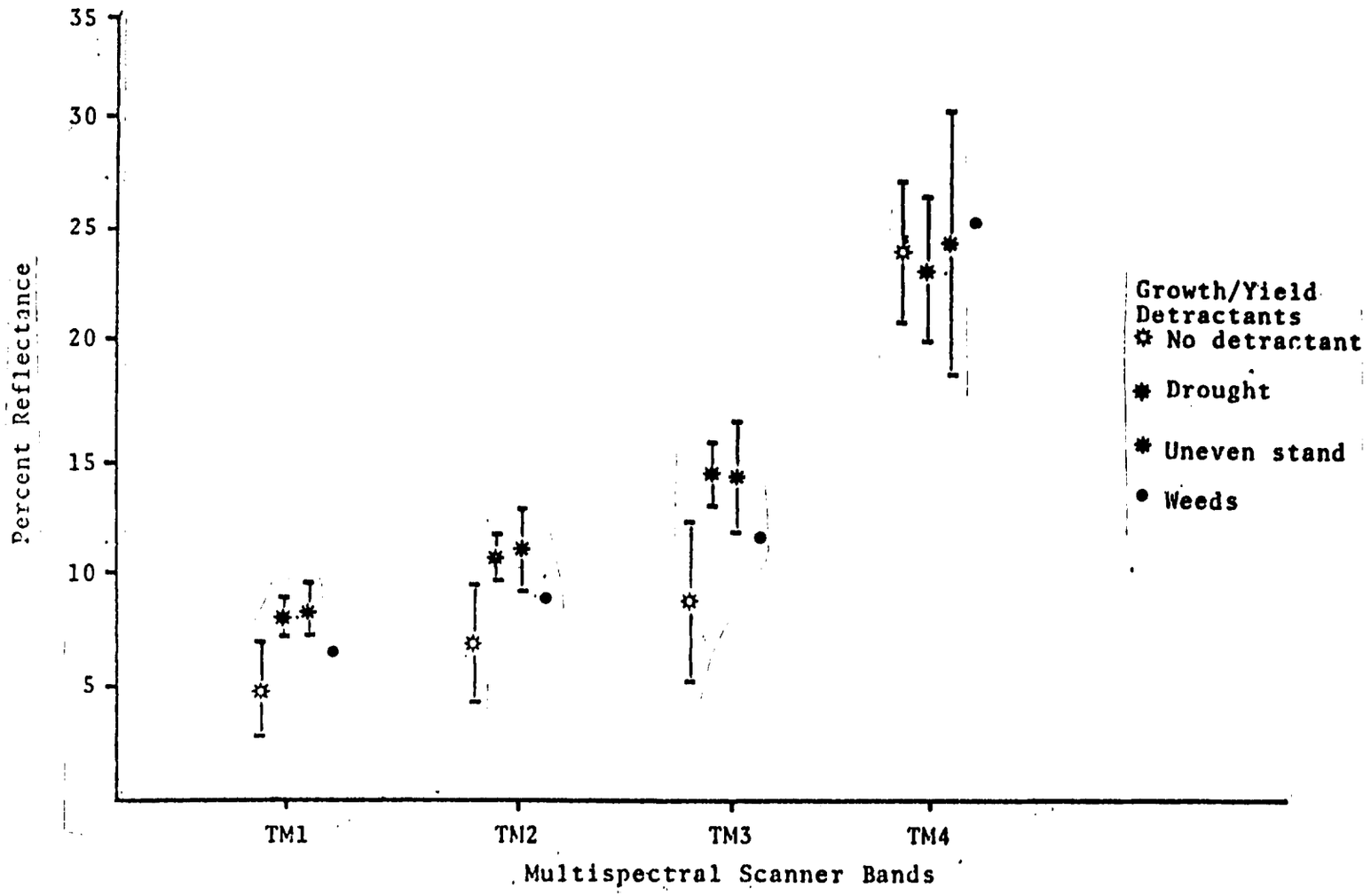
YIELD/GROWTH DETRACTANT CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNTER BANDS

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



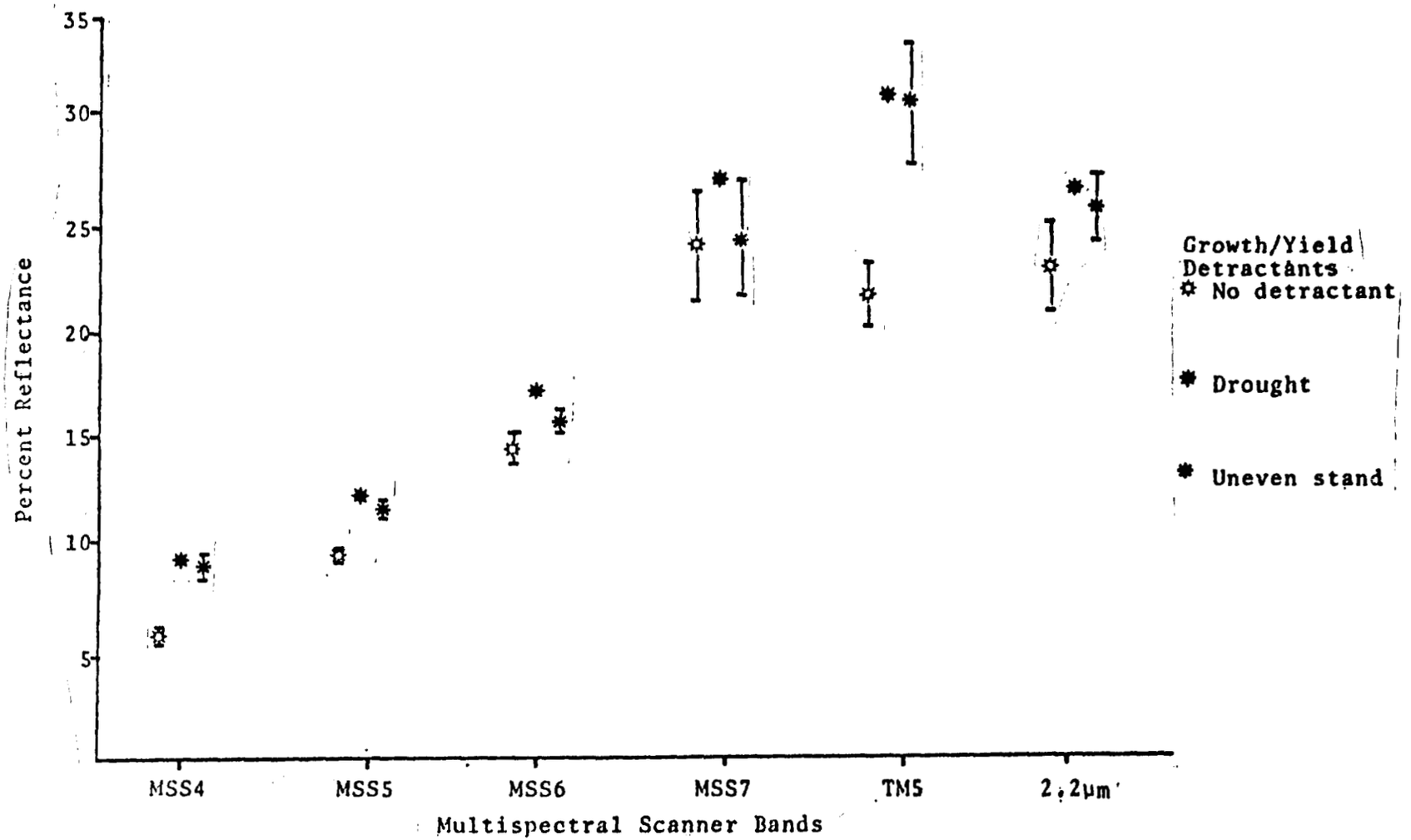
YIELD/GROWTH DETRACTANTS CLASS MEAN REFLECTANCE VALUES IN CERTAIN SCANNER BANDS

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



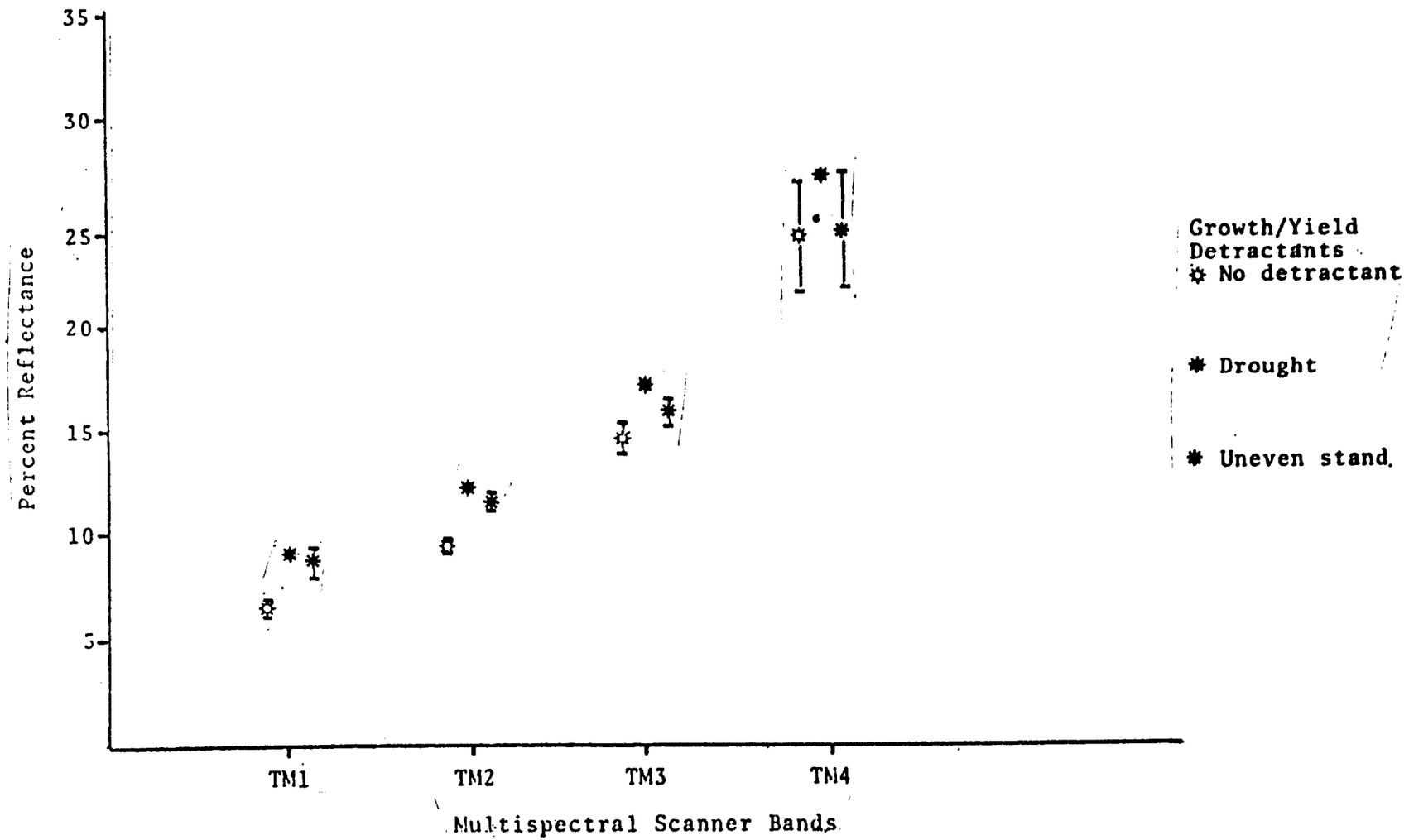
YIELD/GROWTH DETRACTANTS CLASS MEAN REFLECTANCE VALUES IN SELECTED SCANNER BANDS

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	

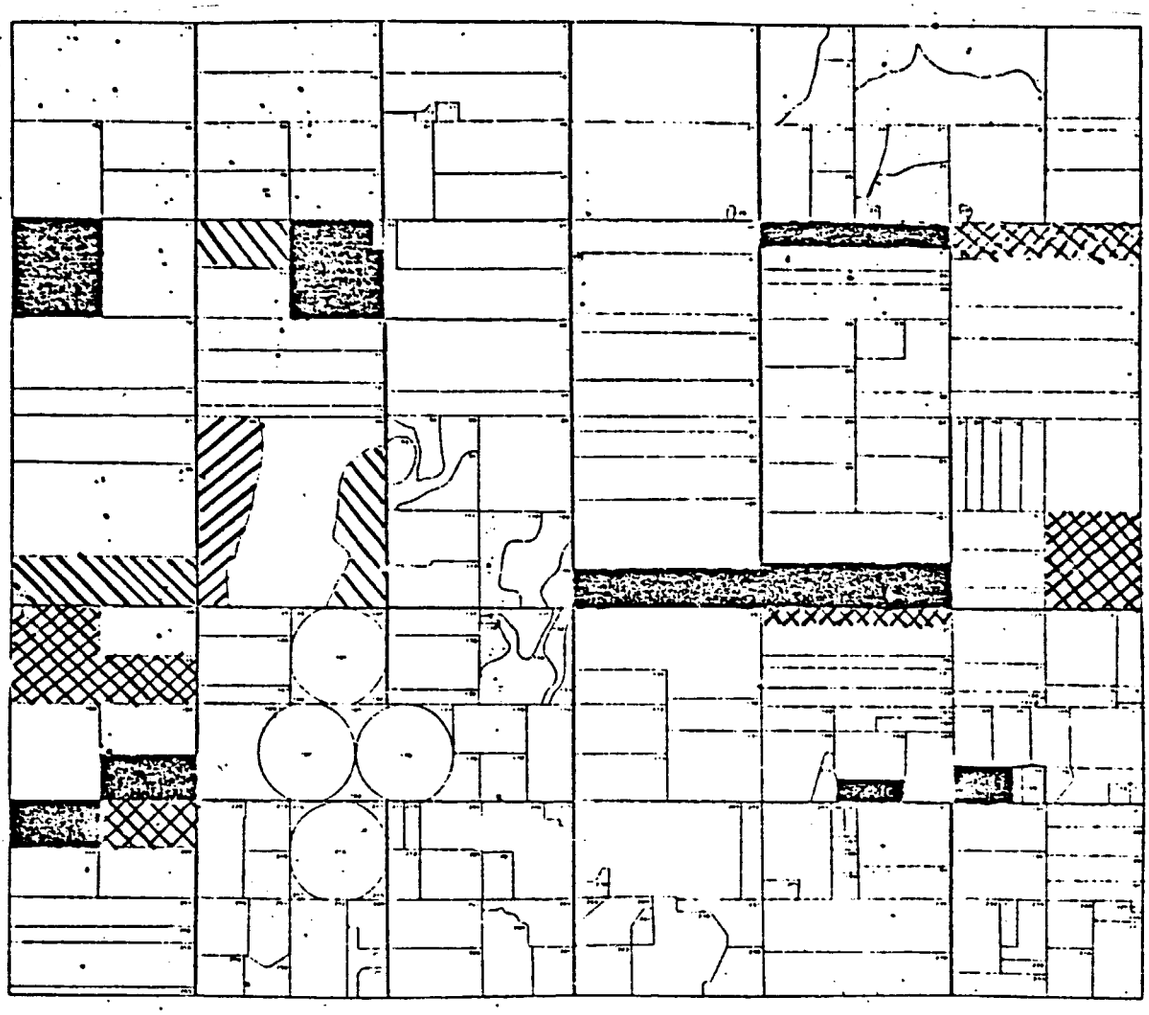
MAY 6, 1976

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 MW CM^{-2} $SR^{-1}\mu^{-1}$ x 10^{-1}. SPECTRAL BANDWIDTH IS 8.0 - 13.5 μM.

FINNEY COUNTY, KANSAS (SUPER SITE)

LACIE INTENSIVE STUDY SITE



Photography Acquired November 1975

Approximate Scale 1:24,000

Land Use Data Collected by The ASCS January 1976

Prepared by
FSO, 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

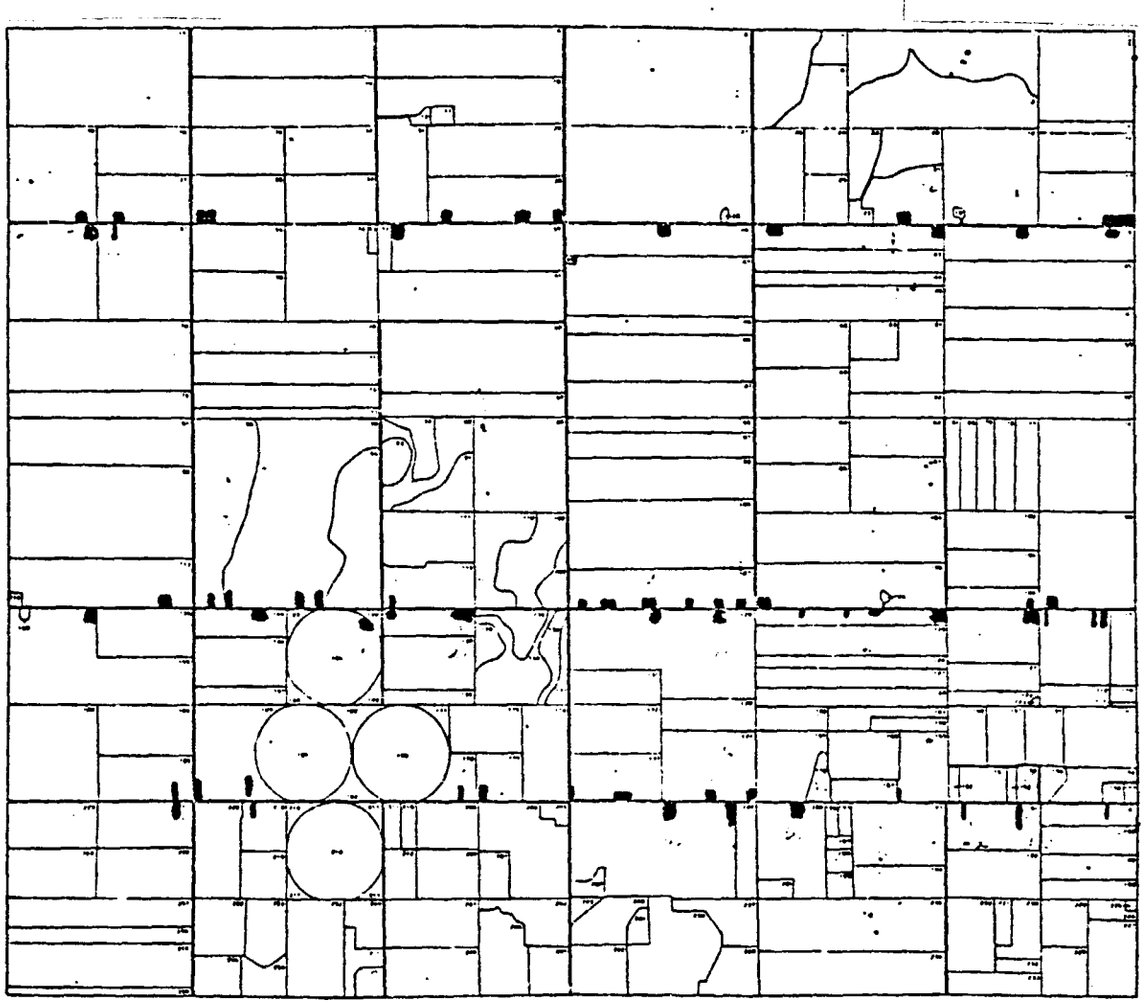
ORIGINAL PAGE IS
OF POOR QUALITY

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

ORIGINAL PAGE IS
OF POOR QUALITY

FINNEY COUNTY, KANSAS (SUPER SITE)

LACIE INTENSIVE STUDY SITE



Photography Acquired November 1975

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

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.

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*Presented 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

ERIM

OUTLINE

- Basic Philosophy
- Background
- Description of Sites Examined
- Types of Activities
- Issues Addressed
- Discussion of Results
- Conclusions
- Recommendations

ERIM

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

ERIM

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)

ERIM

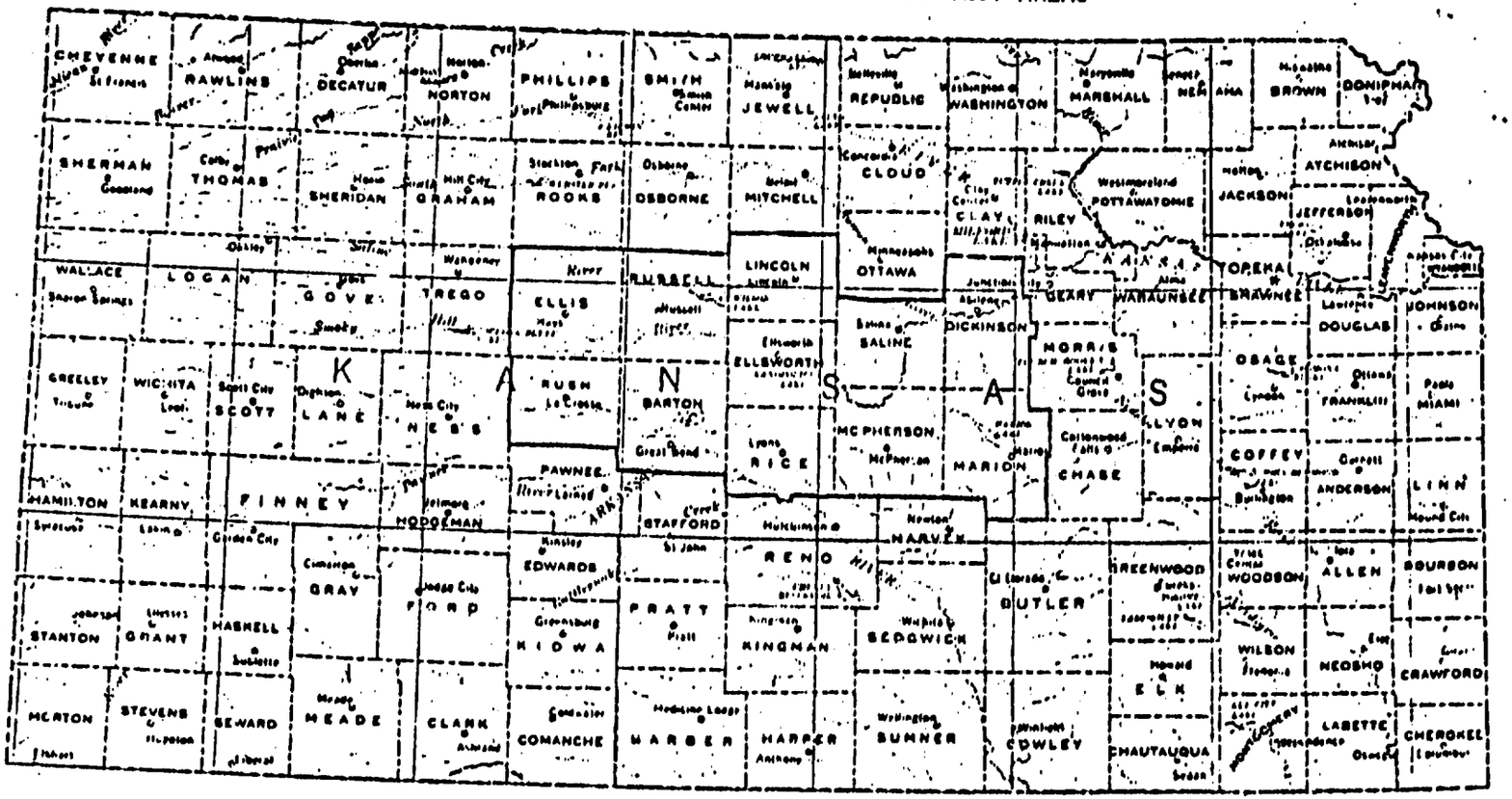
SITES EXAMINED

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

ERIM

LOCATION OF WHEAT FORECAST TEST AREAS



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OF POOR QUALITY

ACTIVITIES

- Field Measurements and Sample Collection
- Laboratory Measurements
- Data Reduction and Analysis
- Model Calculations and Analysis
- Landsat Data Processing and Analysis

ERIM

ISSUES ADDRESSED IN SATISFYING INVESTIGATION OBJECTIVES

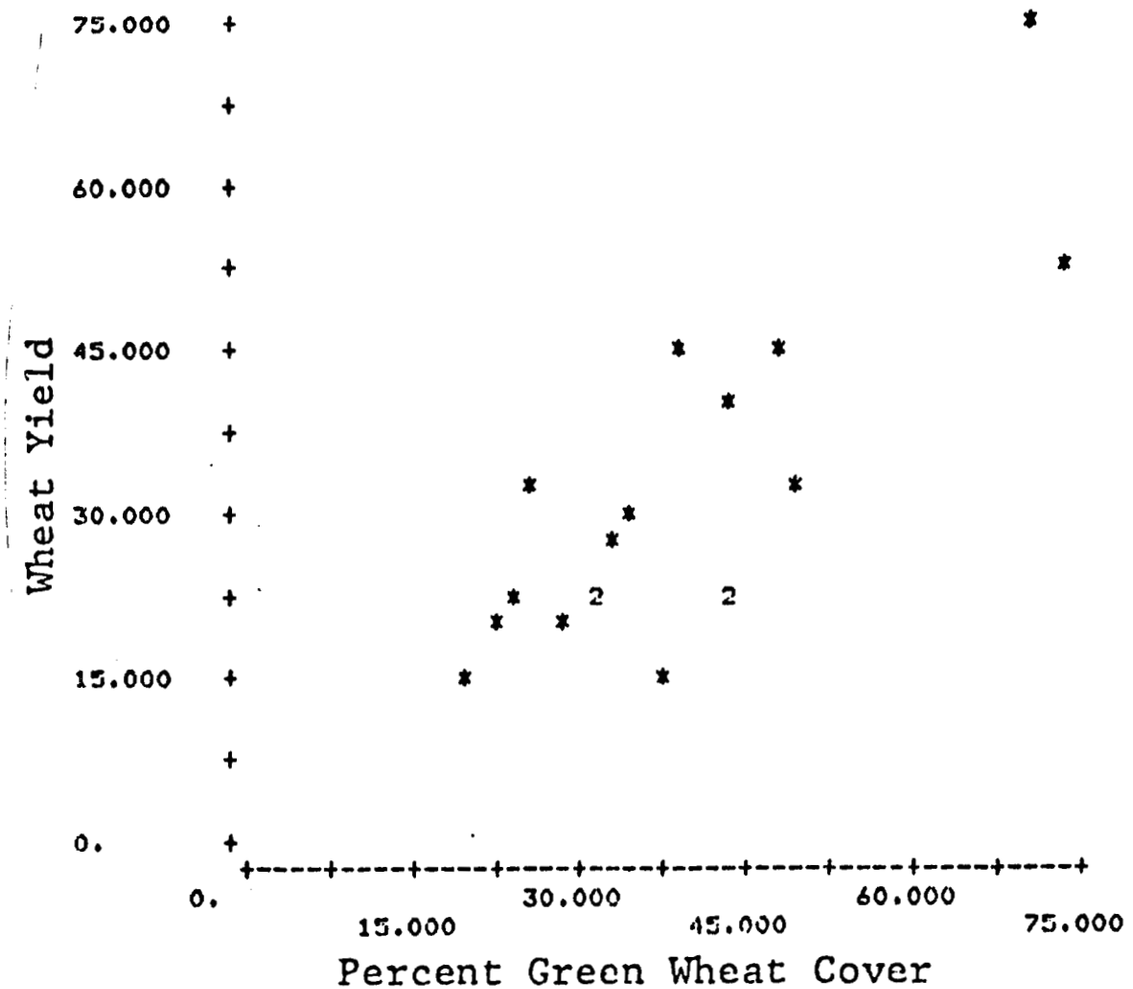
- Optimum Single Time (near heading)
- Landsat Green Indicators
- Comparison With Alternate Approaches
- Importance of Various Cultural Factors
- Model Extension (Geographically and Temporally)
- Data Screening
- Direct Production Forecasts

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

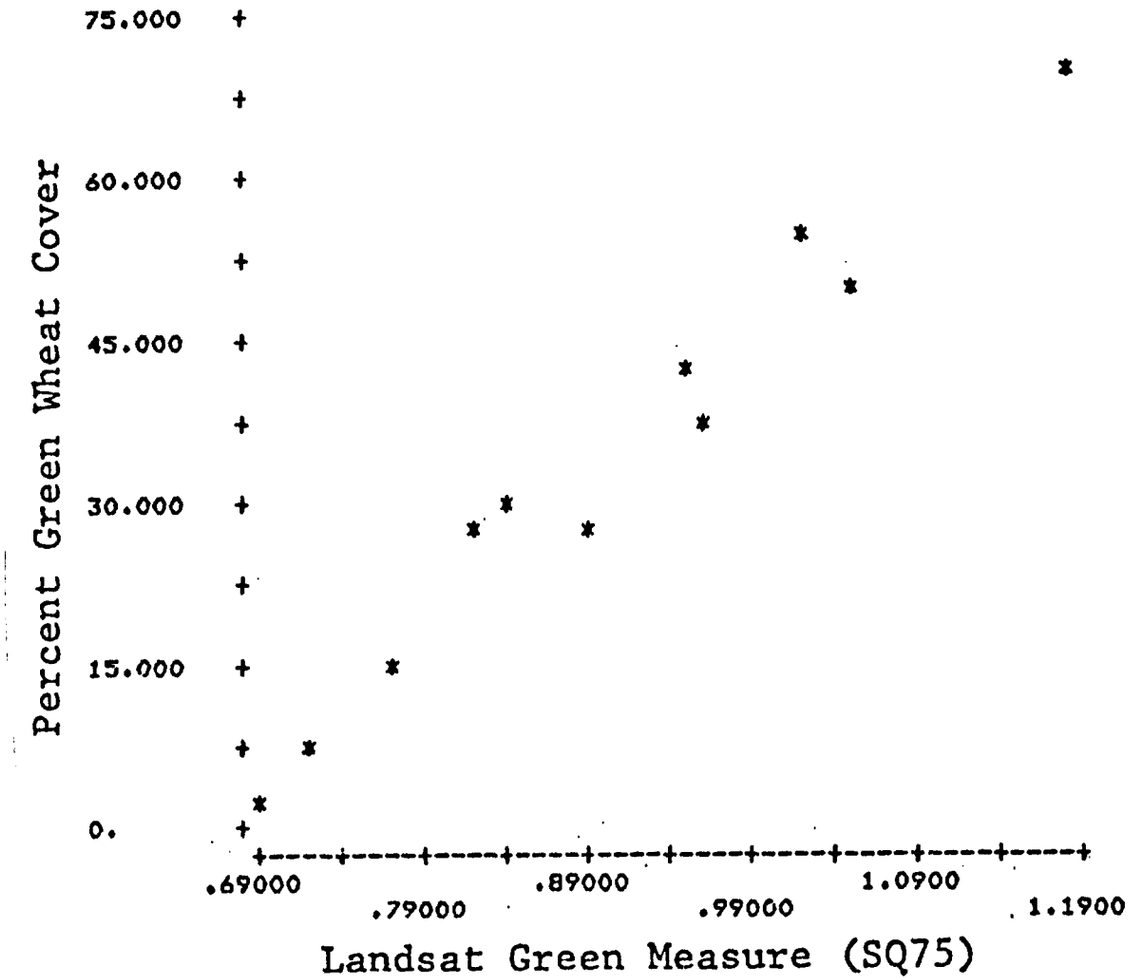
ERIM



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

FINNEY ITS
2 YRS. 9 FIELDS EACH
MID-MAY

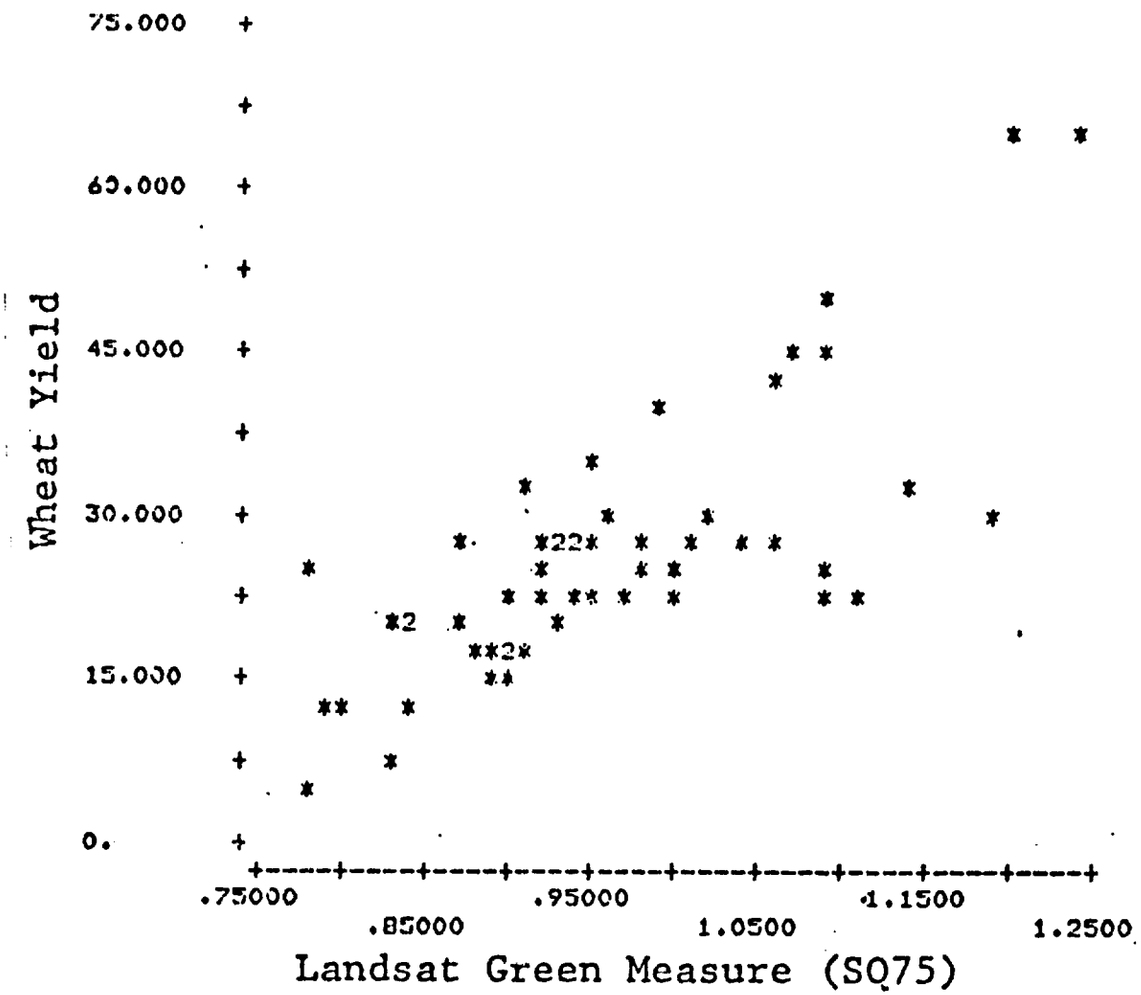
ERIM



LANDSAT GREEN MEASURE VS ERIM MEASUREMENTS OF PERCENT GREEN WHEAT COVER

CORRELATION = .98

ERIM



LANDSAT GREEN MEASURE VS WHEAT YIELD
CORRELATION = .8
1 SITE/DATE
1 PT/FIELD
LATE APRIL-EARLY MAY

ERIM

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

Yield Estimator	Site A	Site B	Site C	Average
FCIC*	0.95[1]	0.26[1]	0.74[1]	0.65
Stand Quality**	0.47[1]	0.78[1]	0.89	0.71
Landsat (4 Bands)	0.94[2]	0.80[4]	0.79[3]	0.84
Landsat (TVI)	0.93[2]	0.79[4]	0.64[3]	0.79

Dates when estimators were available:

[1]Pre-harvest (mid-late June); [2]15 April; [3]21 May; [4]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

Cultural Factors	Percent of Variance
Planting Date	0.1
Wheat Variety	10.6
Fallow Previous Year (yes/no)	55.8
Irrigation (yes/no)	56.3
Fertilization (yes/no)	55.0
Amount Fertilization (lb/acre)	57.4

ERIM

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

VARIABLES	PERCENT VARIANCE	STANDARD ERROR
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
2 = IRRIGATION
3 = FERTILIZATION
4 = PLANTING DATE
5 = CROPPING
6 = AMOUNT FERTILIZER
7 = SQ75 (MAY 6)
8 = SQ75 (JUNE 2)
9 = SQ75 (JUNE 12)
10 = SQ75 (APRIL 18)

ERIM

TWO TESTS OF EXTENSIONS OF LANDSAT WHEAT YIELD PREDICTION

From	To	Landsat Predictor	RMS Error[1] Local	RMS Error[1] Non-Local	Bias[2]
21 May	20 May	4 Bands	4.40	6.70	-5.00
Site A	Site A	SQ75[3]	5.24	5.08	0.00
		TVI[4]	5.03	4.88	0.02
18 April	18 April	4 Bands	7.41	9.10	-0.23
Site A	Site B	SQ75[3]	8.12	10.18	2.15
		TVI[4]	7.98	9.29	1.17

[1] On field by field basis, in bushels.

[2] Average difference between actual and predicted yield, in bushels.

[3] $\sqrt{MSS7/MSS5}$

[4] $\sqrt{(MSS7-MSS5)/(MSS7+MSS5)+0.5}$

ERIM

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

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

ERIM

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

ERIM

INITIAL RESULT FROM ERIM DIRECT WHEAT PRODUCTION FORECAST PROCEDURE
(Two LACIE Intensive Test Sites)

Site	Landsat Overpass	True Production	ERIM Production Forecast	Error (%)
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

ERIM

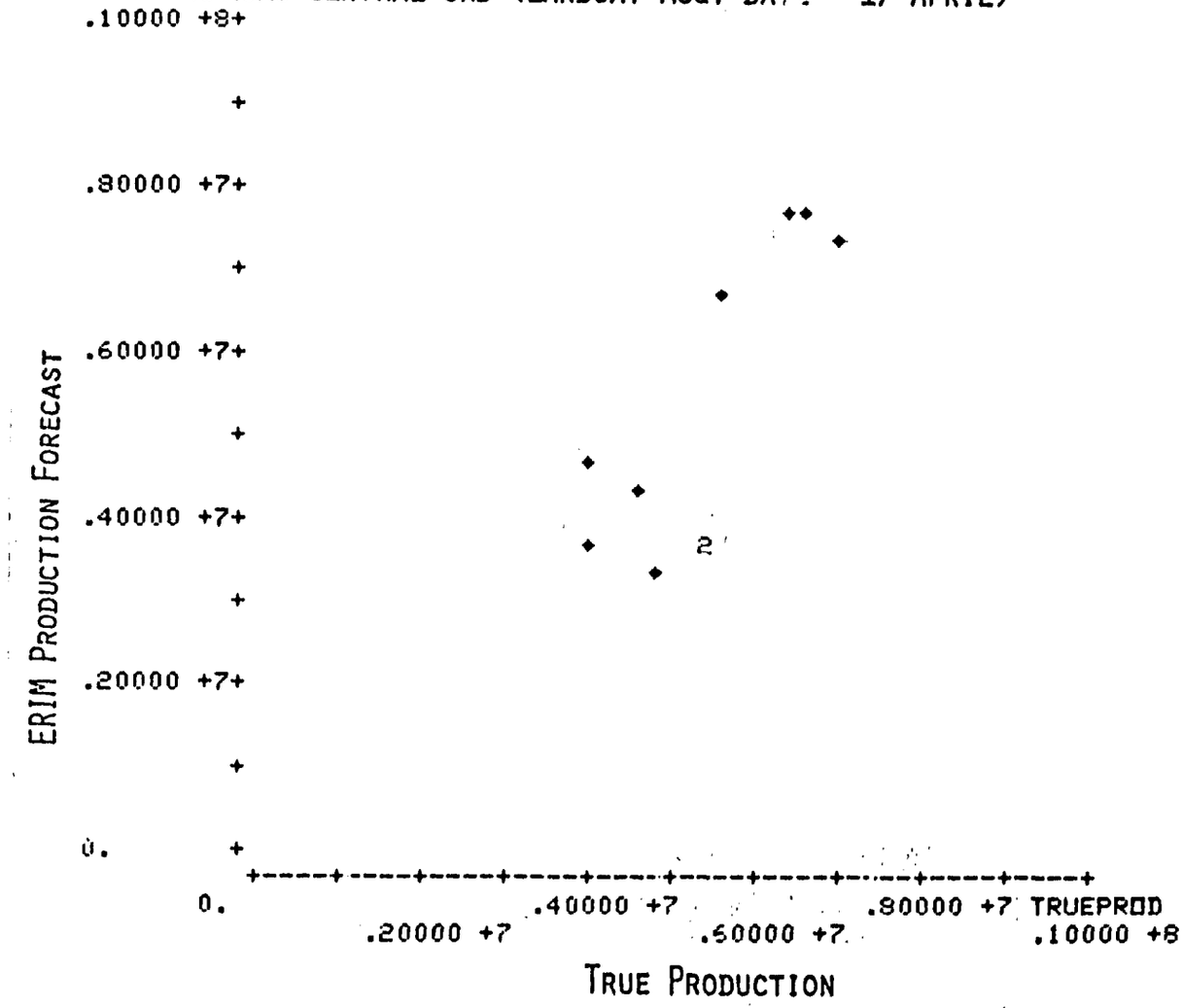
FURTHER RESULTS FROM ERIM DIRECT WHEAT PRODUCTION FORECAST PROCEDURE
(TEN COUNTIES OF KANSAS CENTRAL CRD)

2 ITS + 3 BLIND SITES

LANDSAT OVERPASS	TRUE PRODUCTION	ERIM PRODUCTION FORECAST	ERROR (PERCENT)
17 APR 76	5.38×10^6 BUSHELS	5.24×10^6 BUSHELS	2.6

ERIM

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



ERIM

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 LANSAT 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

ERIM

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

ERIM

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 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 (≥ 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 α 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]

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

$X^2 = 7.07$ 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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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.

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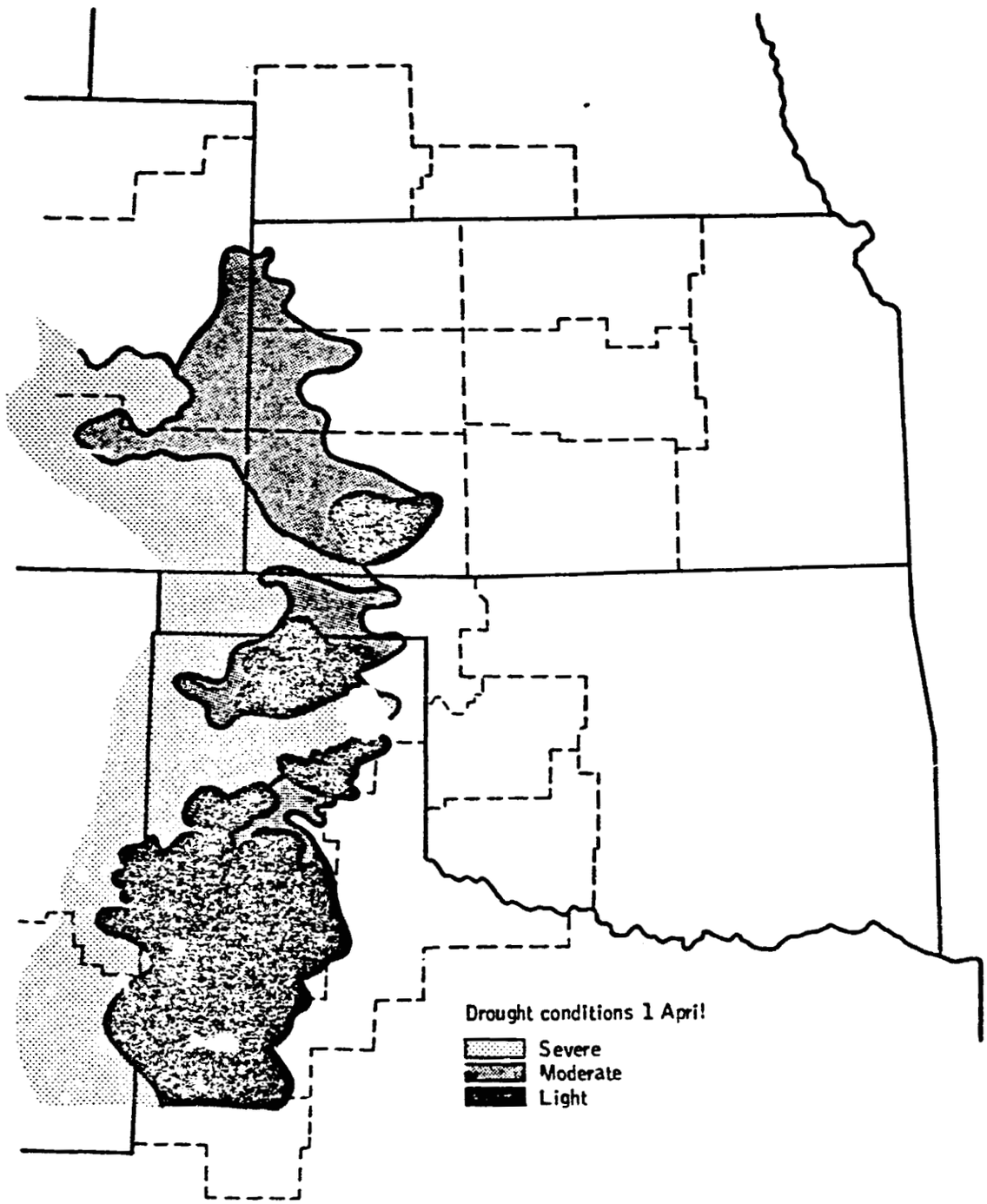

FIGURE 1. AREAL EXTENT AND EFFECT OF DROUGHT ON APRIL 1, 1976.
[From reference 5.]

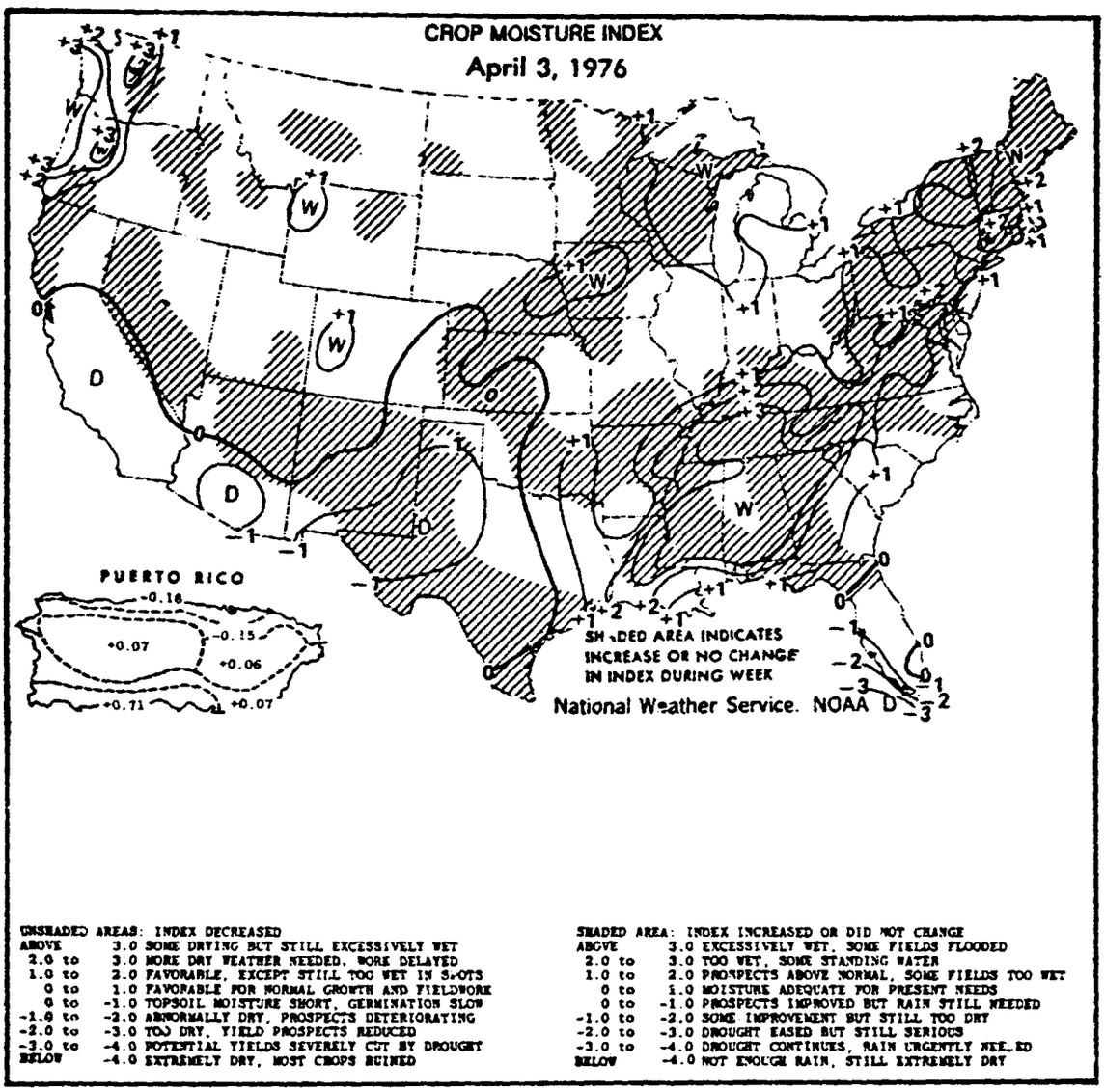

FIGURE 2. CROP MOISTURE INDEX FOR APRIL 3, 1976.
[From reference 7.]

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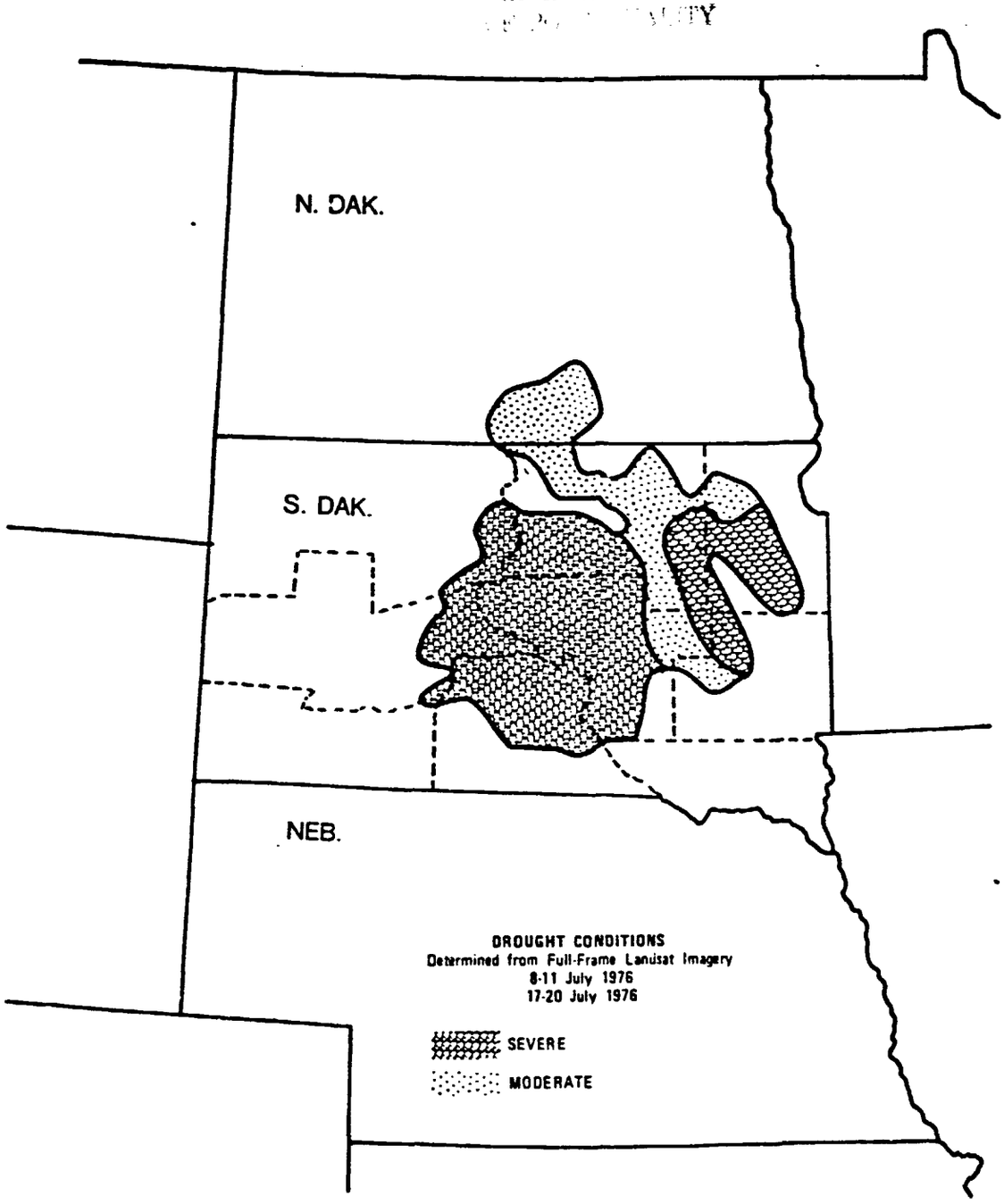

FIGURE 3. DROUGHT-AFFECTED AREA AS DETERMINED FROM LANDSAT FULL-FRAME IMAGERY FOR JULY 8 TO 11 AND JULY 11 TO 20, 1976. [From reference 4.]

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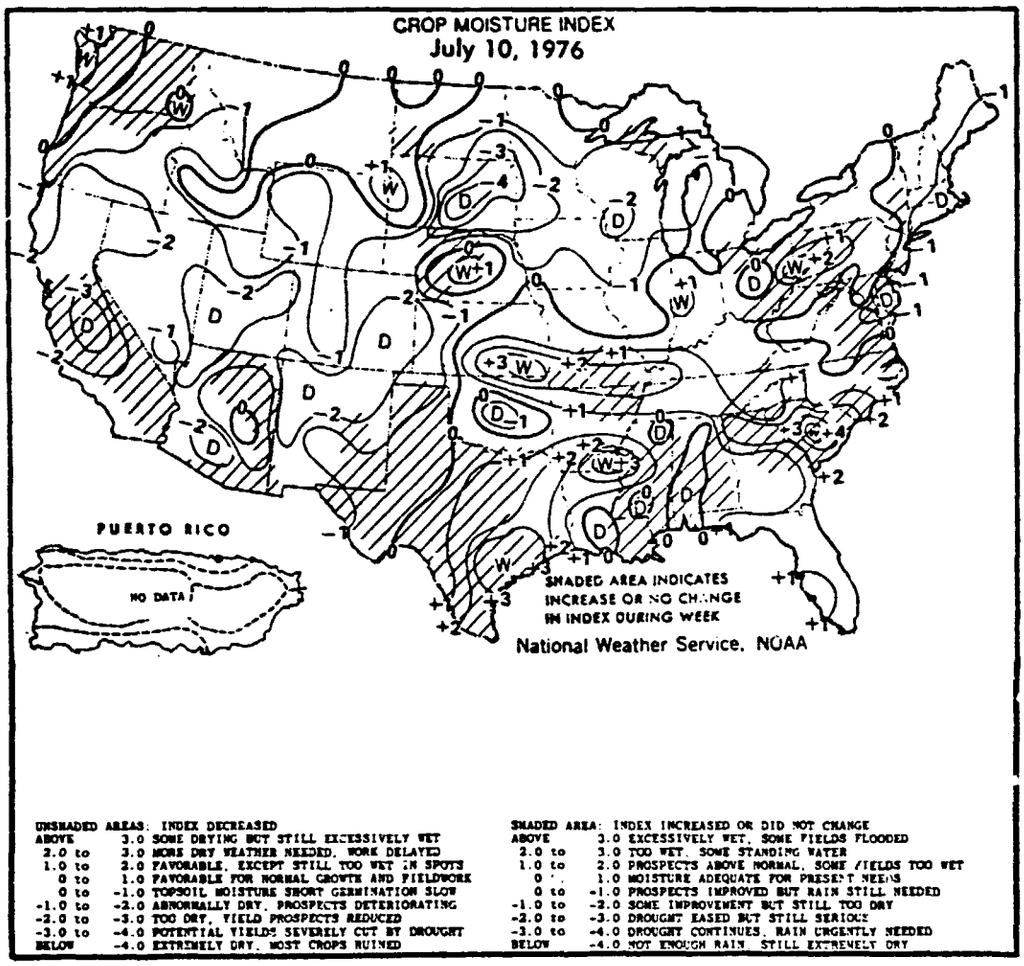

FIGURE 4. CROP MOISTURE INDEX FOR JULY 10, 1976.
[From reference 8.]

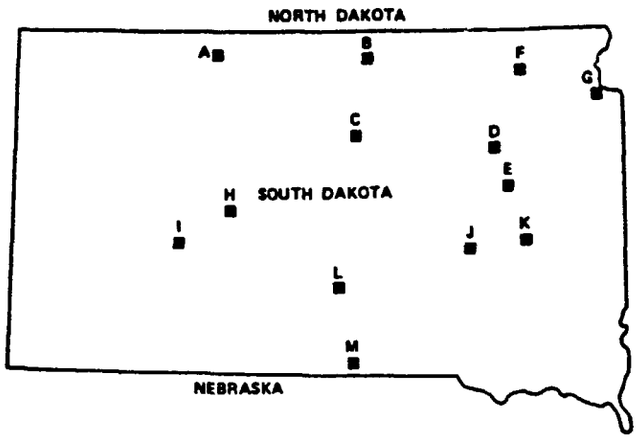

FIGURE 5. SEGMENT LOCATIONS. Map of South Dakota showing locations of LACIE 5- by 6-nautical-mile sample segments. [From reference 6.]

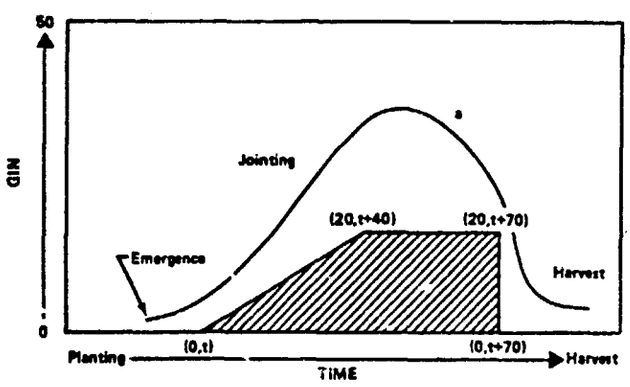

FIGURE 6. PLOT. GIN versus time for a normal, predominantly wheat segment. [From reference 6.]

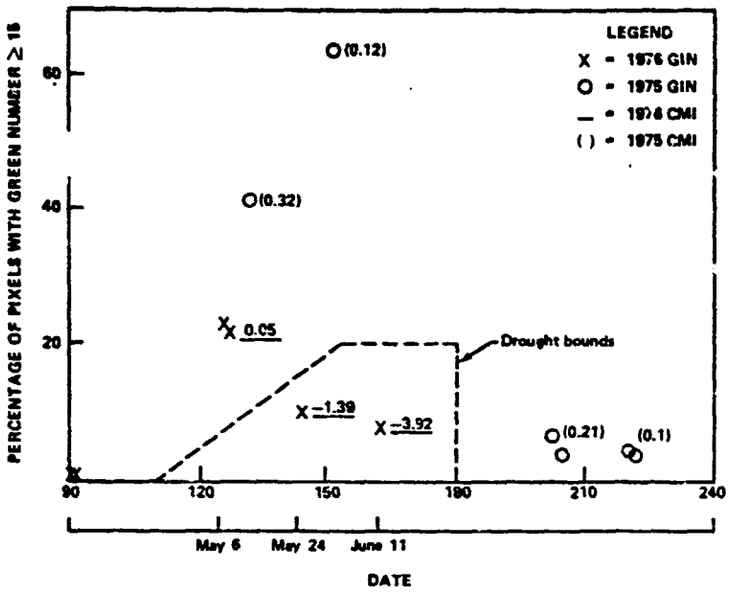

FIGURE 7. GRAPHIC PLOT. GIN versus time with CMI values for segment J. [From reference 6.]

- 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.

C-2

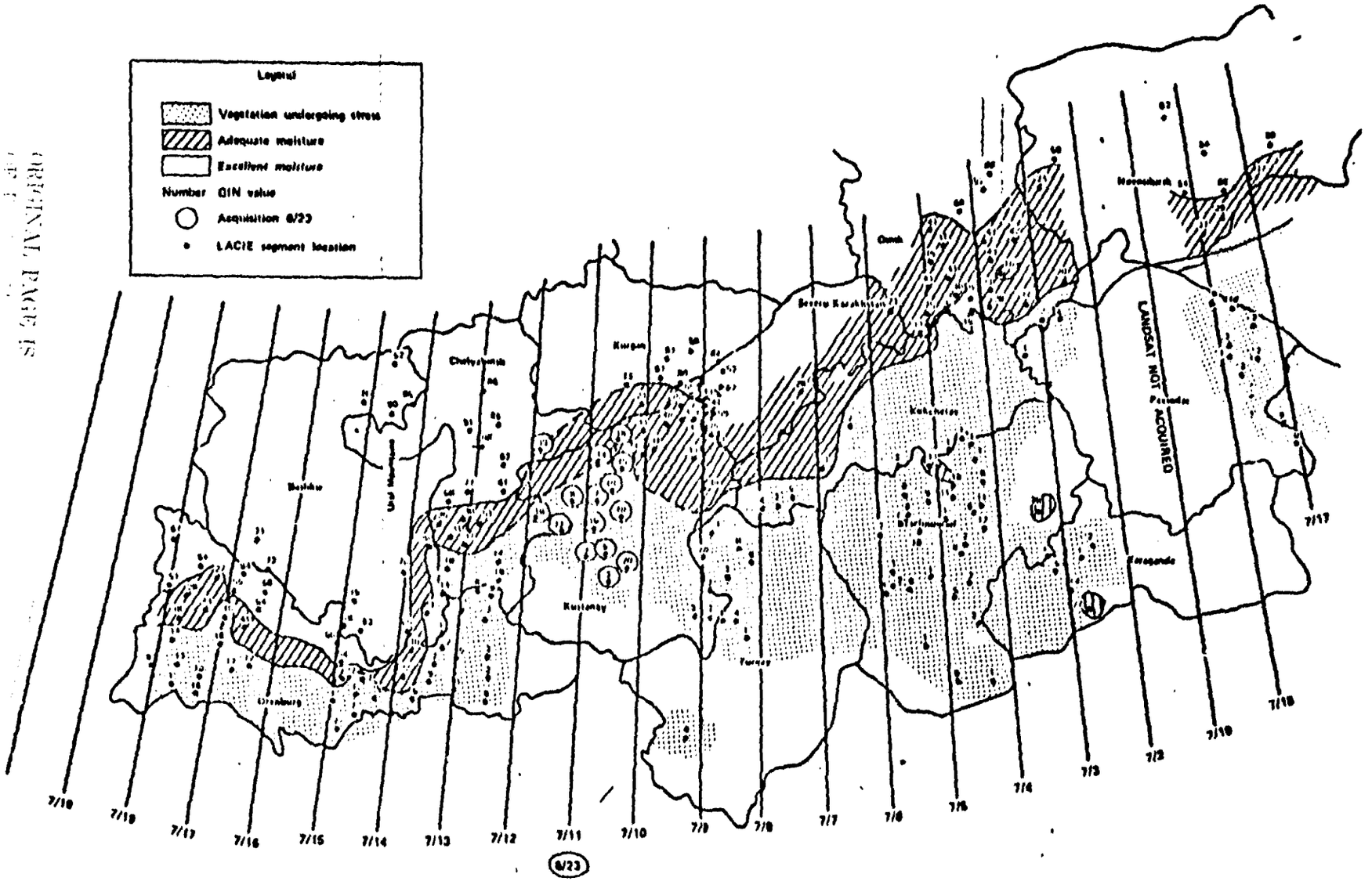

Figure 8.– Moisture conditions over U.S.S.R. spring wheat from the LACIE Green Index Number (GIN) monitoring program (Landsat data acquired June 23, 1977, and July 2 through July 19, 1977).

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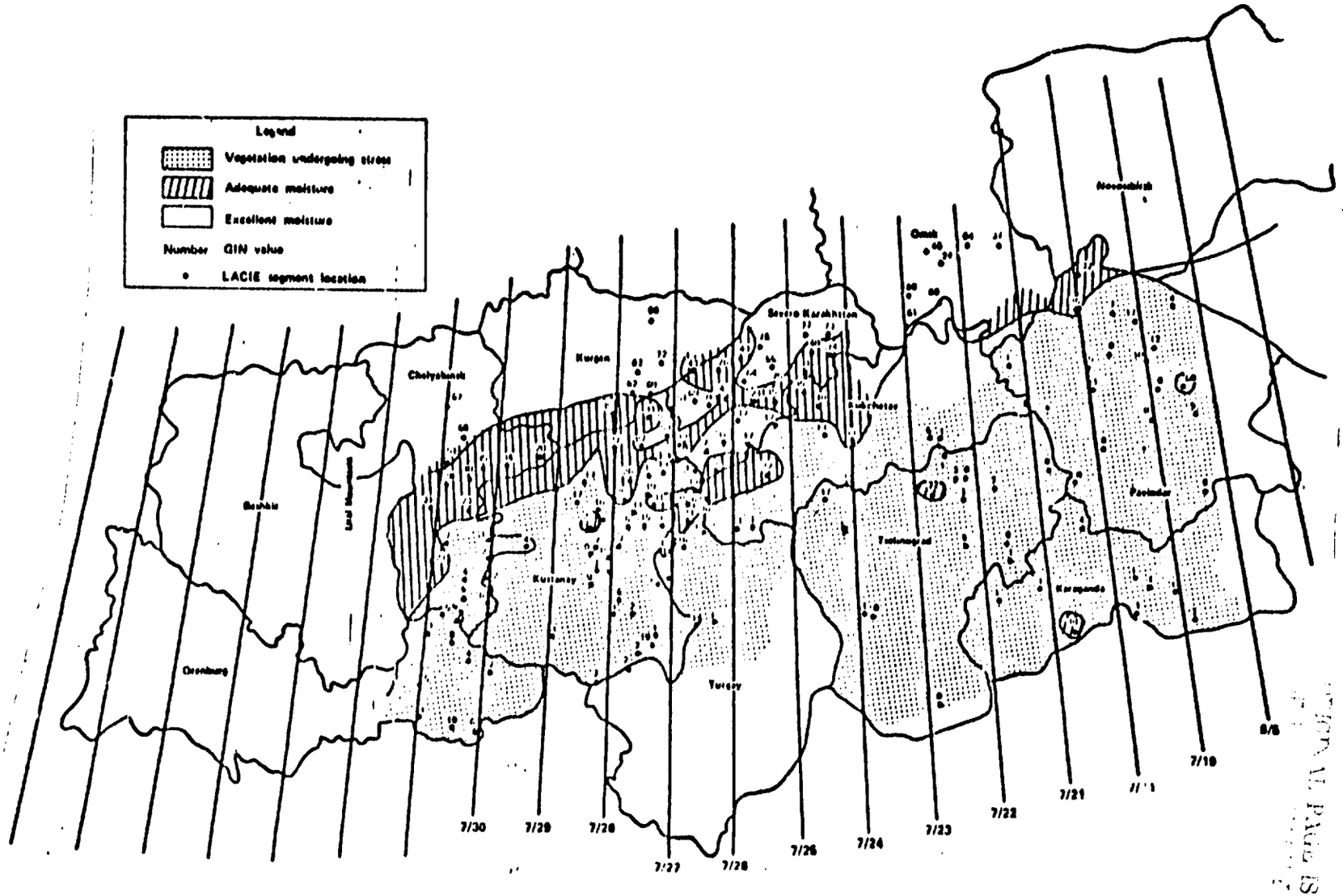

Figure 9.— Moisture conditions over U.S.S.R. spring wheat from the LACIE GIN monitoring program (Landsat data acquired July 19 through August 4, 1977).

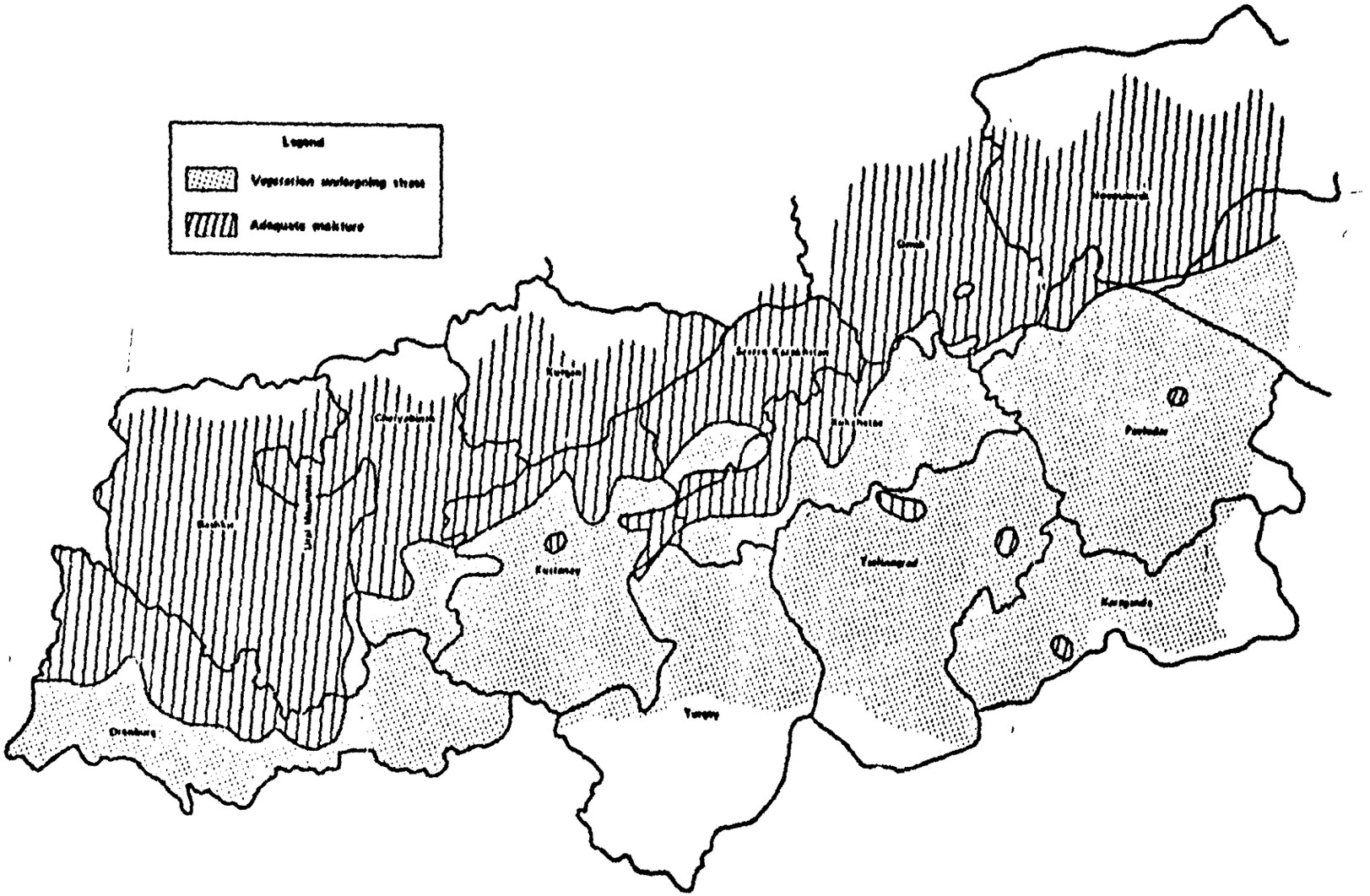

Figure 10.– Moisture conditions over U.S.S.R. spring wheat from the LACIE GIN monitoring program for July 1977.

- LANDSAT CORRELATION TO YIELD MAY BE DIFFICULT BECAUSE:
  - BIOLOGICAL SYSTEM IS DYNAMIC
    - THE CROP CONDITION WHEN LANDSAT PROVIDES BEST CORRELATION TO YIELD MAY NOT BE MAINTAINED TO HARVEST
      - TABLE 1
    - LANDSAT ACQUISITIONS MAY NOT BE SYNCHRONIZED WITH CRITICAL GROWTH STAGE
  - VARIATIONS EXIST AMONG AND WITHIN FIELDS
    - SPECTRAL
      - FIELD CENTER PIXELS
      - BOUNDARY PIXELS
    - GROUND TRUTH
      - COLLECTED IN SMALL AREAS AND MAY NOT REPRESENT ENTIRE FIELD
        - TABLE 2
      - FIELDS SHOULD BE DISPERSED TO IMPROVE ACQUISITION PERCENTAGE
        - TABLE 3
      - DIFFERENT PROCEDURES FOR DETERMINING YIELD VARY CONSIDERABLY
        - TABLE 4

- VARIATIONS AMONG ACQUISITIONS
    - HAZE
    - SUN ANGLE
    - SOIL AFFECTS
    - GROUND TRUTH SAMPLING

- LANDSAT IS CORRELATED TO PLANT PROPERTIES THAT INFLUENCE YIELD (TABLE 5)
    - GROUND COVER
    - PLANT HEIGHT
    - STAND QUALITY

- LANDSAT IS MORE CORRELATED TO YIELD AT SPECIFIC GROWTH STAGES (TABLE 4)
    - JOINTING-HEADING (DAY 107-127 IN EXAMPLE)

TABLE 1

SUBSET OF ARS GROUND TRUTH DEPICTING CHANGES IN YIELD COMPONENTS AFTER OPTIMUM PERIOD FOR SPECTRAL SIGNATURE CORRELATIONS TO YIELD

	Potential Head Sites/M^2			No. Leaves/M^2					
LOCATION	5/17	6/1	7/23	5/17	6/1	6/14	Bu/A	Seed/Head	Seed Wt/ 1000
10	157	278	264	583	948	809	20.3	21.1	2.43
1A	238	229	176	757	862	405	14.8	17.5	3.01
6	378	370	346	1231	1814	918	28.5	23.0	2.44
2	540	441	340	1836	1674	1071	30.4	18.0	3.23
1B	819	730	408	2688	2563	1958	34.9	21.2	2.66

TABLE 2

ARS GROUND TRUTH SHOWING YIELD VARIATION WITHIN FIELDS

LOCATION	YIELD (Bu/A) SAMPLE A	SAMPLE B
1a	14.8	27.6
1b	34.9	30.9
2	30.4	21.5 wild oats
3	24.4	25.0
4	37.9	42.3
5	24.8	28.6
6	28.5	42.6
7	32.2	25.7
8	24.0	29.0
9	36.2	38.2
10	20.3	

TABLE 3

EXAMPLE OF ACQUISITION HISTORY

	ACQUISITION DATES				
LOCATION	21 OCT.	8 NOV.	7 MAY	24 MAY	29 JUNE
1A	x			x	
1B	x			x	
2	x		x	x	x
3	x			x	x
4	x			x	x
5	x	x	x		
6	x	x			
7		x		x	x
8		x		x	x
9		x		x	x
10	x	x			x

TABLE 4 — CORRELATION (R) OF GREEN NUMBER TO:

ITS	DATE	YIELD ASCS	YIELD FARMER	YIELD FCIC	NO. FIELDS
1962	75311	.3639	-.19		5, 21
1963	75311		.7934		8
1961	76002	-.1961	.5812	-.1961	8, 5, 8
1962	76053	.2528	-.2246		5, 19
1962	76107	-.0159	.6825		5, 21
1963	76108		.9303		8
1988	76109	.7516	.6169	.3993	23
1962	76125	-.2408	.4908		5, 21
1964	76127	.4473	.0715	.5767	30
1988	76127	.7256	.6704	.2170	23
1962	76162	-.4855	.0796		5, 21
1964	76162	-.0128	.042	.2681	
1962	76197	-.2984	.0658		5, 21
1963	76198		-.4538		8
1961	76200	.3729	-.0508	.3729	8, 5, 8
1961	76234	-.5077	-.5388	-.5077	8, 5, 8

TABLE 5 — CORRELATION (R) OF GREEN NUMBER TO:

SEGMENT/ DATE	PLANT HEIGHT	GROUND COVER	GROWTH STAGE	SURFACE MOIS-TURE	WEEDS	FIELD OPNS	GROWTH/ YIELD DETRAC-TANTS	STAND QUALITY	YIELD ASCS	YIELD FARMER	YIELD FCIC	NO. FIELDS
3 Acqs. 1964-76127 1988-76109, 16127	.5416	.676	.4804	-.1984	.2131	-.0775	.0163	.575	.6194			76
1964 76127	.2848	.2554	.3301	.3253		0	-.1286	.3526	.4473	.0715	.5767	30
1988 Finney 76109	.4502	.7696	0	.4534	.0002	-.2671	.0177	.7970	.7516	.6169	.3993	23
1988 76127	.2548	.7011	.0044	.2632	.2632	.0135	.1617	.5704	.7256	.6764	.2170	23
1988 76109-76127	.5367	.7688	.464	-.2057	.2836	-.0775	.2993	.6302	.6441	.5621	.2566	46

SUMMARY

- LANDSAT CAN PROVIDE INFORMATION ON CROP CONDITION
  - AREAL EXTENT OF MOISTURE STRESS FROM FULL FRAME
  - SUBJECTIVE RATINGS OF STRESS FROM FULL FRAME CAN BE MADE
  - LANDSAT DIGITAL DATA CAN BE USED TO INDICATE WHEN AGRICULTURAL VEGETATION IS UNDERGOING MOISTURE STRESS
- LANDSAT MAY BE A TOOL TO HELP EXTRAPOLATE PRECIPITATION BETWEEN METEOROLOGICAL STATIONS
- LANDSAT DATA MAY BE USEFUL IN ESTIMATING SOIL WATER HOLDING CAPACITY
- LANDSAT IS SOMEWHAT CORRELATED TO PLANT PROPERTIES THAT INFLUENCE YIELD
  - GROUND COVER
  - PLANT HEIGHT
  - STAND QUALITY
- LANDSAT APPEARS TO BE CORRELATED TO YIELD AT SPECIFIC GROWTH STAGES
- ASSESSING YIELD FROM LANDSAT APPEARS FEASIBLE: HOWEVER, MORE RESEARCH IS NEEDED

SECTION 6

ESTIMATING WINTER WHEAT YIELD FROM CROP GROWTH PREDICTED BY LANDSAT

E. T. Kanemasu
Kansas State University

September 27, 1977
NASA Headquarters

PREFACE

The objective of this study is to (1) develop an evapotranspiration (ET) model for winter wheat; (2) develop a relationship between Landsat data and leaf area index; (3) develop a growth model for winter wheat; and (4) develop a yield model using ET and growth models.

Field data were gathered from commercial fields and plots in Riley, Ellsworth, Finney and Thomas counties in Kansas. Data included leaf area index, soil moisture, growth stage, and yield.

Evapotranspiration and growth models required inputs of solar radiation, maximum temperature, minimum temperature, precipitation, and leaf area index. Meteorological data were obtained from National Weather Service. Leaf area indices were obtained from Landsat computer compatible tapes. Yields were estimated from the ET model; however, further testing and evaluation of the yield model are required.

1.0 Introduction

This report summarizes the work completed under NASA Contract NAS9-14899.

Yields are, to a large part, dependent upon solar radiation, temperature, and soil moisture. Evapotranspiration and precipitation play important roles in soil moisture. In order to estimate evapotranspiration one requires information as to the vegetative cover. Landsat offers a method of assessing vegetative cover on repetative basis. Therefore, relatively simple weather data supplemented with Landsat estimates of ground cover offer one approach to large area yield forecasting.

2.0 Evapotranspiration (ET) Model

2.1 Model Development

The daily inputs into the model are solar radiation, maximum-minimum temperature, precipitation and leaf area index (LAI). Fig. 1 schematically shows the inputs. Potentially, meteorological satellites may be used to estimate solar radiation, temperature, and precipitation in areas where weather data are not available. Landsat data can be used to estimate LAI.

The evapotranspiration model described by Kanemasu et al. (1976) requires both soil and crop factors to estimate maximum evapotranspiration (ET_{max}) and transpiration. ET_{max}—the energy-limited ET occurring from a well-watered surface under nonadvective conditions--is given by Priestley and Taylor (1972) as

$$ET_{max} = \alpha[s/(s + \gamma)R_n \qquad [2.1]$$

where α is a constant for a particular crop and climatic situation; γ is the psychrometer constant (mb/°K) at mean temperature; and R_n is the 24-hr net radiation (mm/day). We evaluated α from lysimetric observations during periods of full canopy cover and wet soil surface (α = 1.35). When R_n was not measured, we estimated it from solar radiation, R_s (mm day^{-1}), using

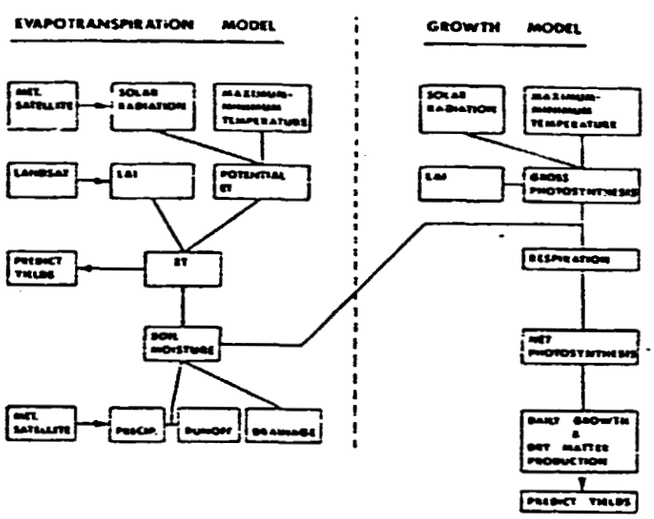

Fig. 1. Flow diagram of evapotranspiration (ET) and growth models. Potential use of meteorological satellites are shown. Winter wheat yields are predicted from ET and dry matter production estimates.

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the regression equations:

$$R_n = .959\ R_s - 3.61 \qquad [2.2]$$

and

$$R_n = .926\ R_s - 2.70 \qquad [2.3]$$

where [2.2] was developed for growth stages up to jointing and for the remainder of the season [2.3].

Evaporation from the soil surface is limited by energy supplied during the constant rate stage; therefore, an energy transmittance term (τ), based on leaf area index, is required. The daily evaporation rate during the constant rate stage can be estimated by

$$E_o = (\tau/\alpha)ET_{max} \qquad [2.4]$$

where $\tau = \exp(-.737\ LAI)$. Equation [2.4]was used until $\Sigma E_o = U$. Then the evaporation was calculated according to the falling rate phase equation

$$E_f = ct^{1/2} - c(t-1)^{1/2} \qquad [2.5]$$

where c(mm day$^{-1/2}$) depends upon the hydraulic properties of the soil and t is days after stage 1 evaporation. The soil factors U and c were obtained from lysimetric observations on bare soil or from weight changes from large soil-filled containers.

Transpiration was estimated by equations of the form given by Tanner and Jury (1976) and Kanemasu et al. (1976). When the available moisture content in the root zone was greater than 35% of field capacity, we used

$$T = \alpha_v(1-\tau)[s/(s + \gamma)]R_n$$

crop cover < 50% [2.6]

and

$$T = (\alpha-\tau)[s/(s + \gamma)]R_n$$

crop cover > 50% [2.7]

where $\alpha_y = 1.56$.

When the available soil moisture (θ_a) was less than 35% of the maximum available moisture (θ_{max}), equations [2.6] and [2.7] were multiplied by K_s, given by

$$K_s = \theta_a / .35(\theta_{max}) \qquad [2.8]$$

Therefore, at θ_a less than .35 θ_{max} transpiration was linearly reduced as the available water decreased (Fig. 2). The maximum available water content of a soil should be determined in the field.

Soil moisture in the root zone (0-150 cm) was estimated from a water balance of evapotranspiration, precipitation, runoff, and drainage. Runoff was estimated according to the amount of rainfall (R) and moisture content in the surface 30 cm:

$$\text{Runoff} = 0 \qquad R < 2.5 \text{ cm} \qquad [2.9a]$$

$$\text{Runoff} = R^{.75} \qquad R > 2.5 \text{ cm} \qquad [2.9b]$$

where R is the rainfall in inches. The surface 30 cm was allowed to hold 15 cm of water. Therefore, the rainfall could fill the 30 cm layer to 50% by volume, then the remaining rain must be runoff. The soil profile was divided into 5 layers (5, 25, 30, 30, and 60 cm) and each layer was allowed to hold 50% water for two days before draining to field capacity (obtained from field measurements). The amount of water drained from the 5th layer (below 150 cm) was identified as drainage.

2.2 Procedure

The evapotranspiration (ET) model was tested on several fields over a two year period at Manhattan, Kansas. Daily estimates by the model were compared with lysimetric observations. Leaf area index (LAI) was measured by optical planimeter and/or leaf length and width calculations. Soil

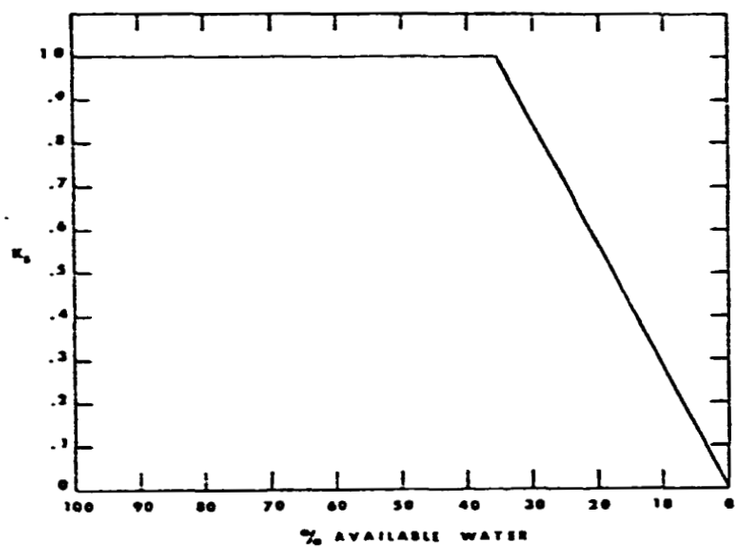

Fig. 2. Water stress factor (Ks) as a function of available water in the root zone. Ks linearly declines at 35% available water.

moisture estimates by the model compared favorably with neutron attenuation and gravimetric estimates.

LAI obtained from ground measurements are extremely tedious. Landsat data were used in the ET model by estimating LAI. Multiple regression equation was developed from Landsat coverage of Kansas sites (Colby, Ellsworth and Manhattan, Table I). Shown in Fig. 3 is the comparison of Landsat-predicted LAI with observed LAI. Figs. 4 and 5 show the season trends in observed and Landsat-predicted LAI. When Landsat predicted LAI curves were used in the ET model instead of observed LAI, seasonal ET estimates by Landsat were usually within 3.0 cm of the ET estimates from observed LAI measurements.

3.0 Soil Moisture Estimates from ET Model

For the 1975-76 winter wheat growing season, we obtained sample statistics for 22 sample segments in five Great Plains states (Kansas, Texas, Oklahoma, Nebraska, and Colorado). Analyst interpreters selected several wheat fields in each segment (4 to 20 fields). Landsat data were analyzed for each useable overpass date on all fields. For each date, leaf area index was estimted for each field and then averaged to obtain an average LAI for the segment (Figs. 6 and 7). The ET model was run on each segment and estimates of soil water depletion (higher percent depletions are drier) throughout the growing season are predicted (Figs. 8, 9, 10).

4.0 Yield Estimates from ET Model

A yield model was developed from small plot yields and the output from the ET model.

$$\text{Yield(metric tons/ha)} = 0.192[\Sigma(T/ET_{max})]_1^{0.172} \cdot [\Sigma(T/ET_{max})]_2^{0.104} \cdot [\Sigma(T/ET_{max})]_3^{0.646} \qquad [4.1]$$

Table 1. Computer compatible tapes from Landsat multispectral scanner used in data analysis.

TAPES USED IN DATA ANALYSIS

AREA	DATE	TAPE I.D. #
Colby	8/20/75	5123-16310
	8/29/75	2219-16442
	9/07/75	5141-16300
	9/25/75	5159-16285
	10/22/75	2273-16440
	1/11/76	5267-16221
	2/25/76	2399-16421
	4/01/76	2435-16410
	4/10/76	5357-16161
	6/02/76	5410-16065
	6/03/76	5411-16123
	6/12/76	2507-16391
	6/20/76	5428-16053
	6/30/76	2525-16384
	7/09/76	5447-16095
	9/10/76	2597-16364
	10/16/76	2633-16353
	11/21/76	2669-16341

AREA	DATE	TAPE I.D. #
Manhattan	10/20/73	1454-16374
	3/31/74	1616-16344
	4/18/74	1634-16341
	5/24/74	1670-16331
	6/29/74	1706-16320
	7/17/74	1724-16313
	8/04/74	1742-16305
	9/09/74	1778-16293
	10/15/74	1814-16283
	11/20/74	1850-16272
	12/07/74	1867-16205
	3/25/75	1975-16161
	4/12/75	1993-16152
	4/30/75	5011-16142
	5/18/75	5029-16133
	6/06/75	5048-16181
	6/24/75	5066-16171
	8/16/75	5119-16082
	11/15/75	5210-16083
	12/03/75	5228-16073
	4/16/76	2540-16232
	5/04/76	2468-16225
	6/09/76	2504-16220
	6/17/76	5425-15483
	7/06/76	5444-15525
	9/06/76	2593-16135
	9/24/76	2611-16131
	10/12/76	2629-16124
	10/13/76	2630-16182

AREA	DATE	TAPE I.D. #
Ellsworth	9/23/75	5157-16173
	10/02/75	2253-16324
	10/11/75	5175-16163
	10/20/75	2271-16323
	10/29/75	5193-16152
	11/07/75	2289-16322
	11/16/75	5211-16141
	1/18/76	2361-16313
	3/12/76	2415-16301
	3/21/76	5337-16061
	3/30/76	2433-16294
	6/01/76	5409-16011
	6/10/76	2505-16274
	7/07/76	5445-15583
	10/14/76	2631-16240
	11/01/76	2649-16233
	11/19/76	2667-16224
	12/25/76	2703-16211

AREA	DATE	TAPE I.D. #
Manhattan	10/31/76	2648-16174
	11/17/76	2665-16112
	11/18/76	2666-16170
	12/24/76	2702-16153

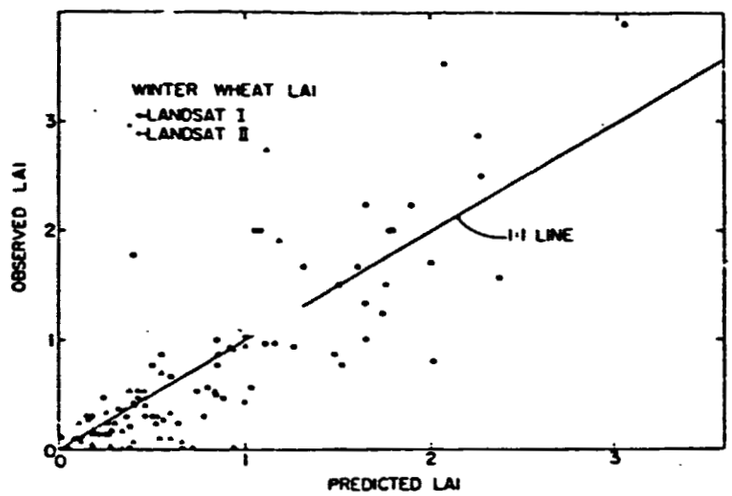

Fig. 3. Comparison of observed leaf area index (LAI) with Landsat-predicted LAI.

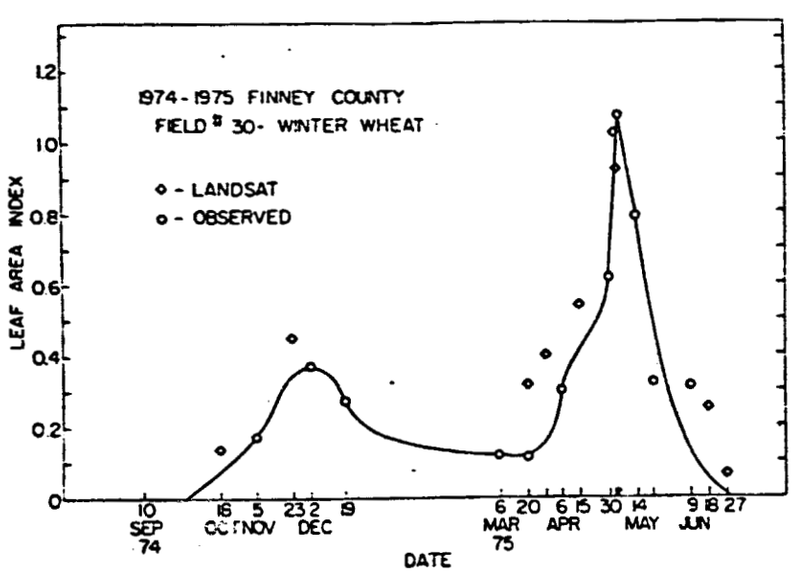

Fig. 4. Seasonal trends in observed leaf area index (LAI) in Finney County (solid line); square symbols indicate Landsat-predicted LAI.

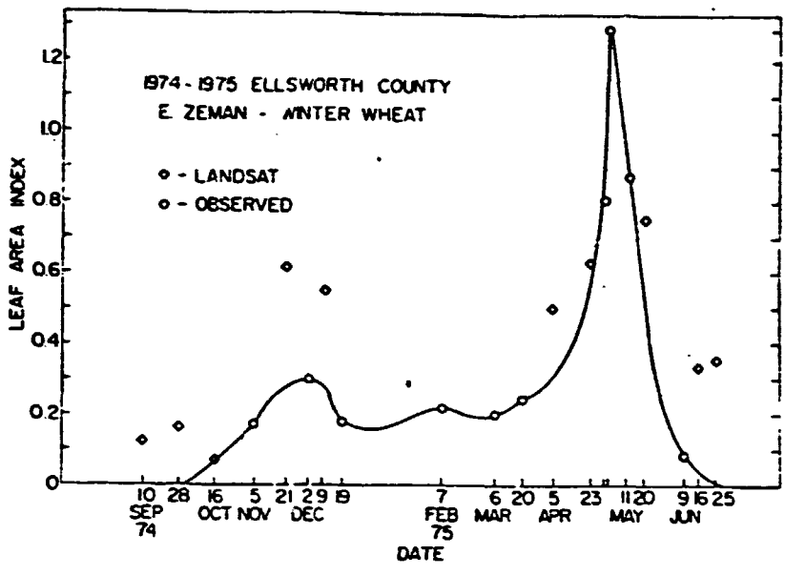

Fig. 5. Seasonal trends in observed leaf area index (LAI) in Ellsworth County (solid line); square symbols indicate Landsat-predicted LAI.

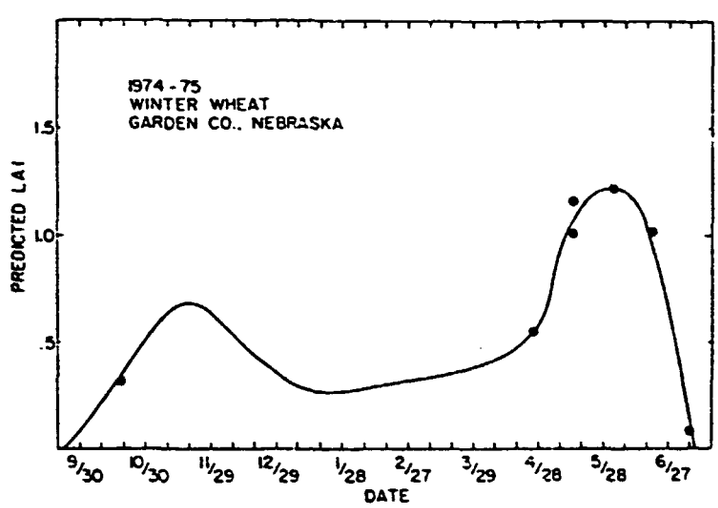

Fig. 6. Seasonal trends in Landsat-predicted leaf area index (LAI) for sample segment in Garden County, Nebraska, 1974-1975.

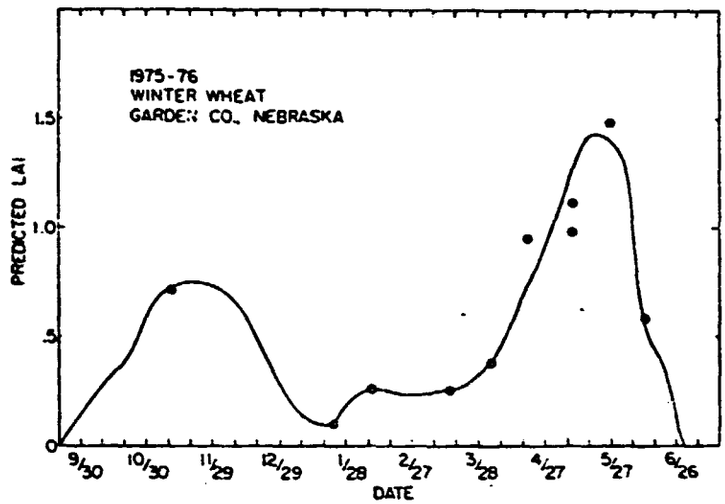

Fig. 7. Seasonal trends in Landsat-predicted leaf area index (LAI) for sample segment in Garden County, Nebraska, 1975-1976.

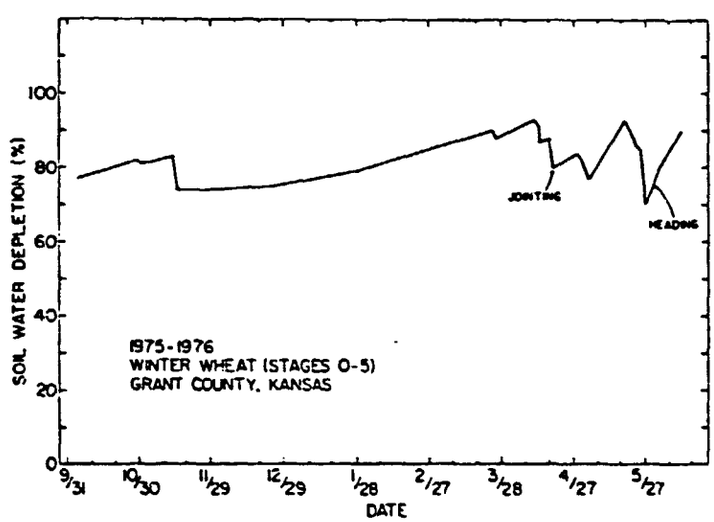

Fig. 8. Seasonal trends in soil water depletion in Grand County, Kansas, 1975-1976.

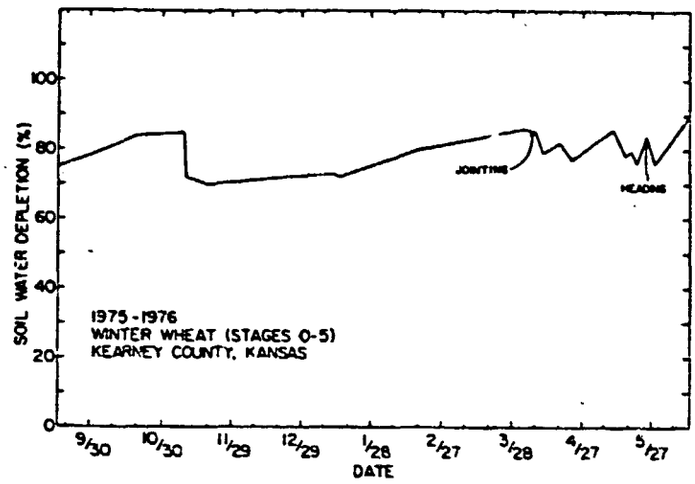

Fig. 9. Seasonal trends in soil water depletion in Kearney County, Kansas, 1975-1976.

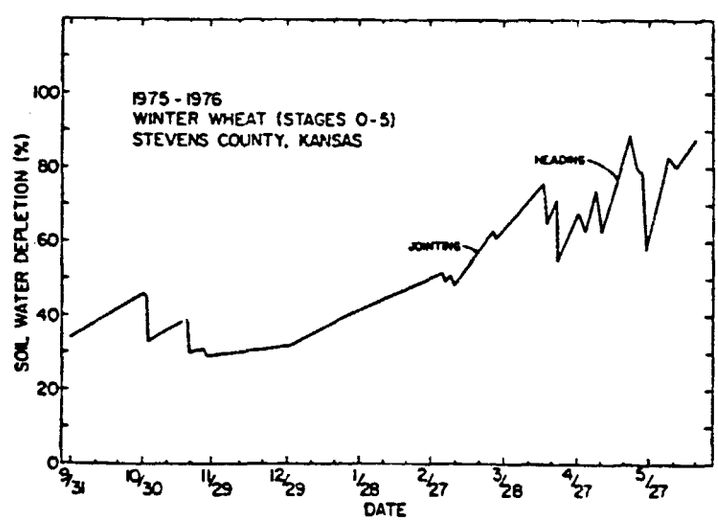

Fig. 10. Seasonal trends in soil water depletion in Stevens County, Kansas, 1975-1976.

where the subscripts 1, 2, and 3 are the respective growth stage intervals: emergence to jointing, jointing to heading, and heading to soft dough; T is the daily transpiration rate; ET_{max} is the energy-limiting evapotranspiration rate. Therefore, the yield model can be used on any field where the ET model can be applied.

Eleven wheat fields at Bushland, Texas presented an independent data set. Landsat and yield data were available (personnal communication with Dr. Clif Harlan, Texas A & M). The ET model was run using meteorological data and Landsat-predicted LAI. Yields were predicted from [4.1] and compared with observed yields (Fig. 11).

The soil moisture study over the 5 Great Plains states offered another data set; however, yields for individual fields were not measured. County yields were available from the Statistical Reporting Service (SRS). In addition, Feyerherm's KSU winter wheat model was run on the same data assuming a management and productivity (MAP) factor of 1 and summer fallow conditions. The root mean square error (RMSE) between the county yield and the ET yield model (eq. [4.1]) was 2.0 bu/acre while the RMSE between Feyerherm's yield model and the ET yield model was 1.5 bu/acre.

5.0 Growth Model

As shown in Fig. 1, the growth model uses the identical inputs as the ET model -- solar radiation, max-min temperature, precipitation, LAI. The major assumption in the growth model is that light and soil moisture are the primary limiting factors in plant growth. Other factors such as fertility, pest and disease influence growth and are reflected in the LAI term.

Photosynthesis is estimated from the amount of light that the canopy intercepts which is dependent upon the solar radiation and LAI. Soil

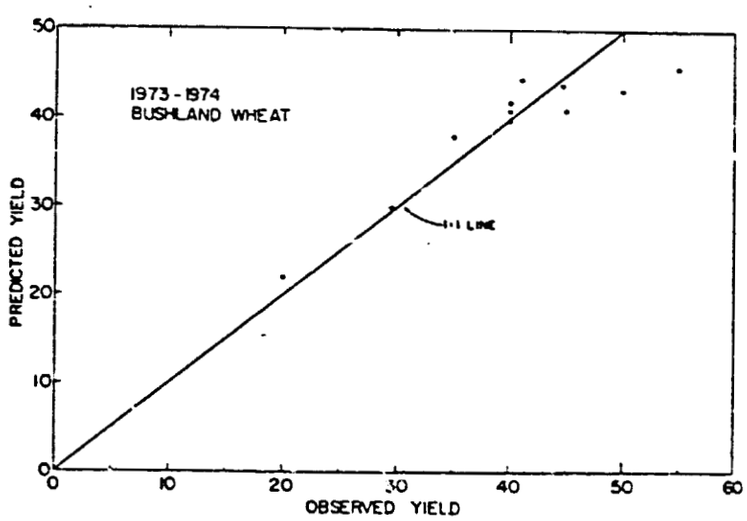

Fig. 11. Comparison between observed yields and predicted yield from evapotranspiration-yield model (r^2 = .9).

moisture decreases photosynthesis during high water depletion periods. Respiration is dependent upon LAI and temperature. The difference between photosynthesis and respiration is net photosynthesis which is the rate of dry matter production . The growth model simulated dry matter production on commercial fields in western, central and eastern Kansas using measured LAI. Fig. 15 shows the agreement in dry matter production estimated by the growth model using Landsat-predicted LAI and observed LAI.

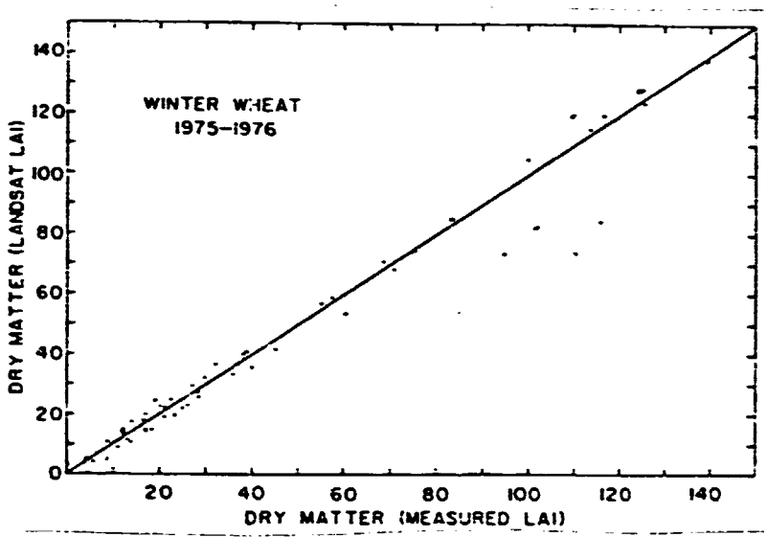

Fig. 15. Comparison of dry matter estimated by the growth model using measured leaf area index (LAI) and Landsat-predicted LAI.

SECTION 7

A STUDY OF LANDSAT DATA AND EARTHSAT SPRING WHEAT DATA FOR YIELD DETERMINATION

Executive Summary
Adapted from Contract NAS5-22950
July 1976 Goddard Space Flight Center

Prepared For

THE
LANDSAT CROP CONDITION
AND
YIELD BRIEFING

September 27, 1977

By

Earl S. Merritt
Vice President
Earth Satellite Corporation
7222 47th Street
Washington, D. C. 20015

EXECUTIVE SUMMARY - STATEMENT OF EARTHSAT INTERACTIVE YIELD ESTIMATE CONCEPT

The EarthSat Yield System has been developed as a modern alternative to the traditional weather regression approaches to crop yield estimates. The "System" has, furthermore, been designed from inception to permit the interactive use of yield-related information derived from remote sensor systems, either aircraft or satellite.

The EarthSat System is largely computerized. It operates on a globally-applicable two-level (25n.m. and 12.5n.m.) geobased grid-cell structure. The "System" processes meteorological data from first order ground meteorological observation stations and from meteorological satellites in order to define a dense network of real and synthesized plant weather information. In the 1975 upper Great Plain tests, weather station data and meteorological satellite data were entered into the "System" at six hourly intervals.

The objective of the basic diagnostic activities in the "System" is to define the weather influencing plant growth with sufficient detail that simulation models which describe plant growth, and define soil moisture profiles can be accurately operated. The goal of all system diagnostic activities is to define the spatial variations in plant yield clearly enough that such descriptions can be locally verified with either ground-based observer transects or by remote sensing techniques.

The "System" differs from traditional approaches in that the resulting synthesized and real weather diagnostic grid allows application of quasi-physiologically and fully physiologically-based plant yield models. These models either describe or infer plant processes, i.e., photosynthesis, gas exchange, dry matter accumulation and translocation,

water stress, etc., accurately enough to permit a very accurate and highly plant descriptive diagnosis.

The plant process descriptions over a 12.5n.m. geobased cell structure for the 1975 spring wheat crop season has been utilized to develop a functional relationship between LANDSAT observables and the stress factors described by the "System." This functional relationship, which includes a component of the short term plant stress as well as the long term stress history, has been utilized to enhance the spring wheat yield forecasts produced by the simulation model. These enhanced yield estimates were prepared after complete analysis of all LANDSAT frames taken between 15 May and 15 September over the four state upper Great Plains region.

The LANDSAT analyses were undertaken using a previously defined interpretive key which permitted a description of low, moderate or high stressed areas with an approximate 65 percent accuracy and low and high stress area with an accuracy of approximately 90 percent. The LANDSAT analyses were then coded for entry into the computerized geobase at a resolution of approximately 12.5n.m. Once entered into the data base they were readily available for interactive uses with the existing EarthSat "System" simulated data base.

The results achieved by the LANDSAT Interactive EarthSat System show definite promise. For example, at the four state aggregate level the error of yield estimate was reduced from an already reasonable 2.3% to 0.79%. At the state level the average error of approximately 5% was lowered to an average error of approximately 3%. Similar improvements were generally noted at the crop reporting district (CRD) level. The region-wide errors produced by NOAA's traditional regression models for the same area and time were 6.3%. Table E-1 presents these comparisons.

	EARTHSAT YIELD ESTIMATES BASED ON DATA THRU AUGUST 30 1975			NOAA CCLA	USDA SRS
	1975 FINAL MODEL YIELD ESTIMATE	LANDSAT * STRESS CORRECTED YIELD ESTIMATE	LANDSAT ** MOISTURE CORRECTED YIELD ESTIMATE	8/25/75 YIELD ESTIMATE	5/10/76 YIELD ESTIMATE
MONTANA	23.7	23.03	21.36	27.6	25.6
N.C.	25.0	24.31	21.96	29.5	27.2
N.E.	23.3	22.63	21.16	26.7	25.0
C.	---	21.65	21.94	---	25.6
S.C.	---	---	---	---	20.1
S.E.	---	21.37	19.64	---	23.7
SOUTH DAKOTA	17.0	13.33	17.35	20.7	13.0
N.W.	13.7	19.81	13.83	20.3	17.4
N.C.	15.9	17.32	16.23	14.5	19.0
N.E.	17.3	21.14	17.66	13.1	19.4
W.C.	---			---	13.7
C.	---	14.03	16.11	---	15.0
E.C.	---	19.61	13.72	---	17.9
S.W.	---	---	---	---	15.0
S.C.	---	---	---	---	15.3
S.E.	---	18.09	16.94	---	17.9
NORTH DAKOTA	27.1	26.42	26.45	23.5	25.9
N.W.	25.6	24.84	25.98	21.1	24.9
N.C.	26.2	24.74	24.49	20.2	24.4
N.E.	29.7	29.53	29.03	29.6	31.0
W.C.	---	24.94	26.36	---	24.6
C.	26.7	26.22	25.82	22.0	25.5
E.C.	30.7	29.41	29.33	30.1	28.8
S.W.	---	23.13	22.21	---	22.9
S.C.	---	23.26	23.92	---	21.2
S.E.	28.3	27.33	26.83	16.8	22.8
MINNESOTA	33.7	33.93	33.03	30.2	31.0
N.W.	36.2	34.85	34.30	30.5	33.7
N.C.	---	---	---	---	26.5
W.C.	29.5	32.44	30.65	31.4	27.0
C.	---	---	---	---	31.0
S.W.	---	29.82	27.71	---	33.0
S.C.	---	---	---	---	31.0
FOUR STATE ESTIMATE	26.0	25.6	25.2	23.8	25.4

* LANDSAT CORRECTED STRESS HISTORY MODEL

** INTERACTIVE SOIL MOISTURE AND LANDSAT CORRECTED STRESS HISTORY MODEL

TABLE E-1

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The LANDSAT analytical technique has been applied to winter wheat areas of Kansas and surrounding states in 1975 and 1976. In this period concern over a new "dust bowl" in northwest Oklahoma, southwest Kansas, northwest Texas and eastern Colorado was high in the late winter and early spring of 1976 since poor germination had been observed over much of the area. The resultant LANDSAT analysis accomplished in October 1975 and March through May 1976 indicated that, for the state of Kansas the fears of a "dust bowl" were only justified over southwest CRD of Kansas where extensive abandonment of dry land winter wheat fields occurred. All other areas of Kansas were reasonably good but they were be' their record 1975 yields. Total production was down nearly 71.5 million bushels over 1975.

The full EarthSat Interactive "System" was not operated over the winter wheat region. However, the system models were operated from planting to 1 April at selected ground observation points. These sample runs appear to confirm the applicability of the "System" diagnostic and predictive element in the winter wheat areas. Selected point average yield[1/] estimates are Dodge City 23bu/A, Topeka 24bu/A, Amarillo 14bu/A. These yield estimates are based on the use of a Technology Acceptance maximum yield value derived from the past 4 years of Kansas yield history and plant stress coefficients developed in the spring wheat region states.

The EarthSat Yield System concept has shown considerable promise in the spring wheat test in 1975. The use of LANDSAT interpretation generally appears to improve the "System" yield estimate. The application of all types of data in a common coordinate system is a very powerful concept. The combination of this concept with a highly disaggregated plant environment diagnostic and plant yield simulation (process) models

1/ Includes both dryland and irrigated area yields.

offer additional improvements in the future. It is anticipated that the greatest benefits from the EarthSat System will accrue to yield estimates made in anomalous years and in regions where the meteorological observing network is less dense than in the United States.

EarthSat CROPCAST™ System, a commercial crop forecasting venture, employs some aspects of the System studied in 1975 and 1976. CROPCAST is now in operation over Canada and the United States for corn, soybeans, wheat and cotton. Results to date are encouraging, e.g., comparisons of CROPCAST's forecasts of the USDA monthly (SRS) Crop Production Reports, issued approximately 4 weeks and two weeks prior to the USDA report, show the following accuracies:

All Crops	97%
Corn	98%
Soybeans	97%
Winter Wheat	99%
Spring Wheat	93%

The end-of-year comparisons are a few months away, but similar accuracies are expected.

CROPCAST is now available over the South American soybean and wheat areas in Brazil, and Argentina. Monitoring of Winter conditions is underway over several wheat growing regions.

CROPCAST has been designed to use Landsat when it is available in a timely manner. The future plans for 48 to 96 hour turn-arounds are very exciting. CROPCAST will continue to use Landsat in a confirmatory and interactive manner, rather than as a primary data source.

SECTION 8

SPECTRAL INDICATORS OF CROP DEVELOPMENT AND LEAF AREA INDEX FROM LANDSAT DATA

C. L. WIEGAND, H. W. GAUSMAN, A. J. RICHARDSON,
A. H. GERBERMANN, J. H. EVERETT, AND R. W. LEAMER

Abstract

Spectral indices such as the transformed vegetation index (TVI), the green number (GVI), and the perpendicular vegetation index (PVI) are significantly correlated with leaf area index (LAI), and green biomass (BIOM) during the crop development and grain filling stages. They also respond to growing conditions as LAI and BIOM do. Two of them take soil background into account, hence also help remove its variations in MSS data. By so doing, they offer the possibility of calibrating crops spectrally across years, thereby minimizing ground truth requirements and increasing the value of the indices where ground truth is unavailable. In addition, they and their temporal trajectories may be helpful in improving training sample selection, signature extension, and in classification procedures.

The evidence indicates that the vegetation indices can be used to estimate LAI needed for the evapotranspiration and photosynthesis subroutines in crop productivity models. Thus they can be used to help implement the models over large areas by either (a) providing input data for the models, or (b) feedback data to check on, and retrack the models, if necessary.

LANDSAT FOLLOW-ON FINAL REPORT

CONCLUSIONS

1. POP, PC, AND LAI ARE THE PLANT PARAMETERS MOST CONSISTENTLY RELATED TO LANDSAT MSS DIGITAL COUNTS (DC).
   - LAI CAN BE ESTIMATED SPECTRALLY.
   - LINEAR COMBINATIONS OF THE OTHER PLANT PARAMETERS (POP, PC, PH) ACCOUNT FOR 67 TO 90% (R^2X100) OF THE VARIATION IN LAI AND FROM 69 TO 89% OF THE VARIATION IN GRAIN YIELD.

2. LANDSAT SPECTRAL INDICATORS, SUCH AS PVI, RELATE TO GRAIN YIELDS OF SORGHUM FOR ABOUT A 60-DAY PERIOD--FROM GROWING POINT DIFDERENTIATION (GPD) TO HALFWAY BETWEEN 1/2 BLOOM (HB) AND PHYSIOLOGICAL MATURITY (PM) OF THE GRAIN.

3. OPTIMAL WAVELENGTHS FOR DETECTING CERTAIN STRESSES HAVE BEEN DETERMINED.

4. FORAGE PRODUCTION DIFFERENCES OF GRASSY RANGELANDS CAN BE MAPPED.

"SPECTRAL INDICATORS OF SORGHUM DEVELOPMENT AND THEIR IMPLICATIONS FOR GROWTH MODELING"

CONCLUSIONS

(TEMPLE, TX 1976 SORGHUM DATA)

1. VEGETATION INDICES DERIVED FROM LANDSAT DATA ARE RESPONSIVE TO GROWING CONDITIONS THAT AFFECT LAI AND BIOMASS.

   TVI, PVI, and GVI are about equally useful for monitoring seasonal crop development and vegetation density.

2. THE HIGH CORRELATIONS OBTAINED BETWEEN LANDSAT VEGETATION INDICES AND PLANT GROWTH MEASUREMENTS INDICATE THEY CAN BE USED OVER LARGE AREAS, EITHER AS

   a) INPUT DATA FOR PLANT GROWTH SIMULATION, OR

   b) FEEDBACK DATA TO CHECK ON, AND RETRACK GROWTH SIMULATION MODELS.

3. SPECTRAL VEGETATION INDICES CAN BE CALCULATED FOR AS MANY PIXELS, OR FIELDS, AS ARE OF INTEREST IN A GEOGRAPHICAL AREA. THUS, PLANT GROWTH MODELS CAN BE EXTENDED TO LARGE AREAS YET BE AIDED BY SPECIFIC FEEDBACK ON ACTUAL GROWING CONDITIONS IN INDIVIDUAL FIELDS.

4. THE IMPROVED ESTIMATES OF LEAF AREA INDEX AND BIOMASS THAT RESULTED FROM INCLUSION OF WEATHER DATA IN COMBINATION WITH VEGETATION INDICES IN ESTIMATING EQUATIONS INDICATE THAT GROWTH SIMULATION MODELS THAT MIMIC PLANT RESPONSE TO SOIL AND AERIAL ENVIRONMENTS WILL IMPROVE YIELD ESTIMATES* OVER THOSE ARRIVED AT FROM SPECTRAL DATA ALONE.

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* FARMER-REPORTED YIELDS ARE SUSPECT! (DISAGREE WITH BOTH GROUND SAMPLE DATA AND SPECTRAL INDICATORS.)

LANDSAT AND WEATHER MEASUREMENTS (X)	Sorghum Plant Growth Measurements							
	Leaf area index		Biomass (kg/ha)		Plant height (cm)		Plant cover (%)	
	R	Sy.x	R	Sy.x	R	Sy.x	R	Sy.x
PVI,	0.89**	0.39	0.79**	1224	0.88**	14	0.79**	13
TU,	0.92**	0.33	0.87**	1000	0.90**	13	0.83**	12
STU	0.92**	0.34	0.88**	957	0.90**	13	0.84**	12
I,	-0.67**	0.64	-0.71	1413	-0.63**	23	-0.64**	16
PVI, TU,	0.95**	0.28	0.88**	988	0.93**	11	0.85**	12
PVI, STU	0.95**	0.27	0.89**	945	0.93**	11	0.86**	11
PVI, I,	0.92**	0.34	0.86**	1038	0.90**	13	0.83**	12
PVI, I, TU,	0.95**	0.28	0.88**	991	0.93**	11	0.85**	12
PVI, I, STU	0.95**	0.28	0.89**	958	0.93**	11	0.86**	11
PVI, I, TU, STU	0.95**	0.28	0.90**	922	0.93**	11	0.88**	11
MAXIMUM	2.22		7199		107		73	
MINIMUM	0.06		43		18		11	
MEAN	1.02		1444		63		35	
STANDARD DEVIATION	0.84		1964		29		21	

LAI = -0.783 + 0.068 PVI + 0.003 STU + 0.001 I (1)

BIOMASS = -1544 + 101 PVI + 6 STU - 9 I (2)

PH = -3.04 + 2.27 PVI + 0.10 STU + 0.10 I (3)

PC = =1.41 + 1.23 PVI + 0.07 STU -0.02 I (4)

** Significant at the 0.01 probability level.

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"LEAF AREA INDEX ESTIMATES FOR WHEAT FROM

LANDSAT SPECTRAL DATA"

(Wiegand, Richardson, Kanemasu)

CONCLUSIONS

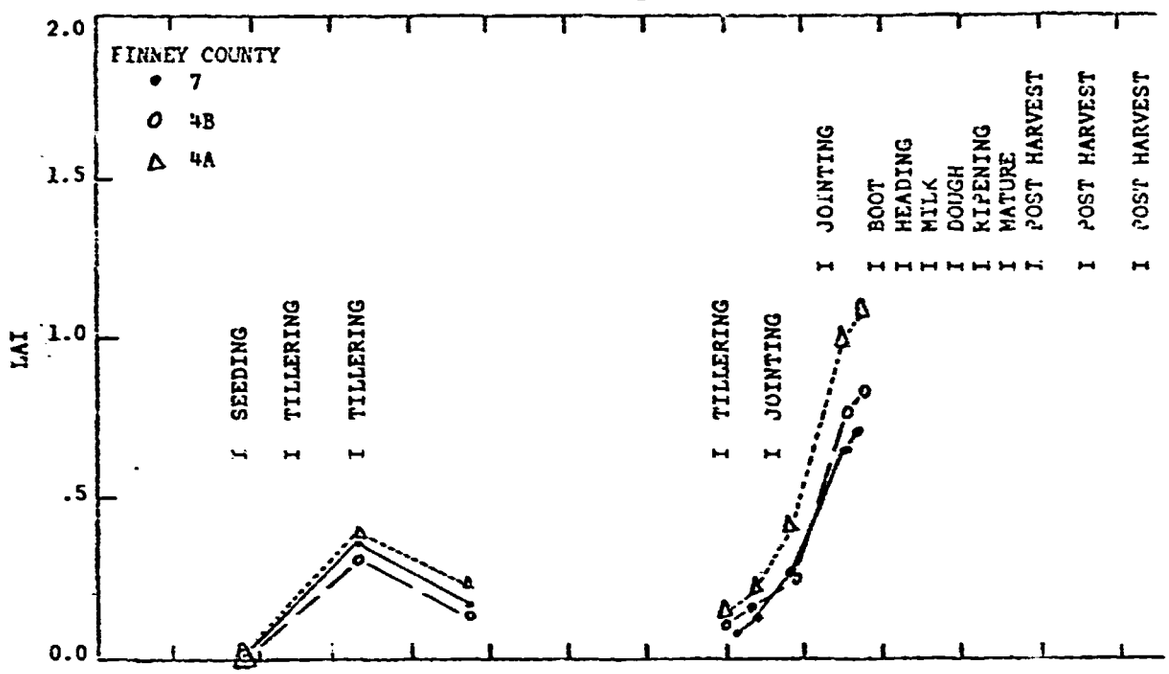
1. $PVI = \sqrt{(Rgg5 - Rp5)^2 + (Rgg7 - Rp7)^2}$

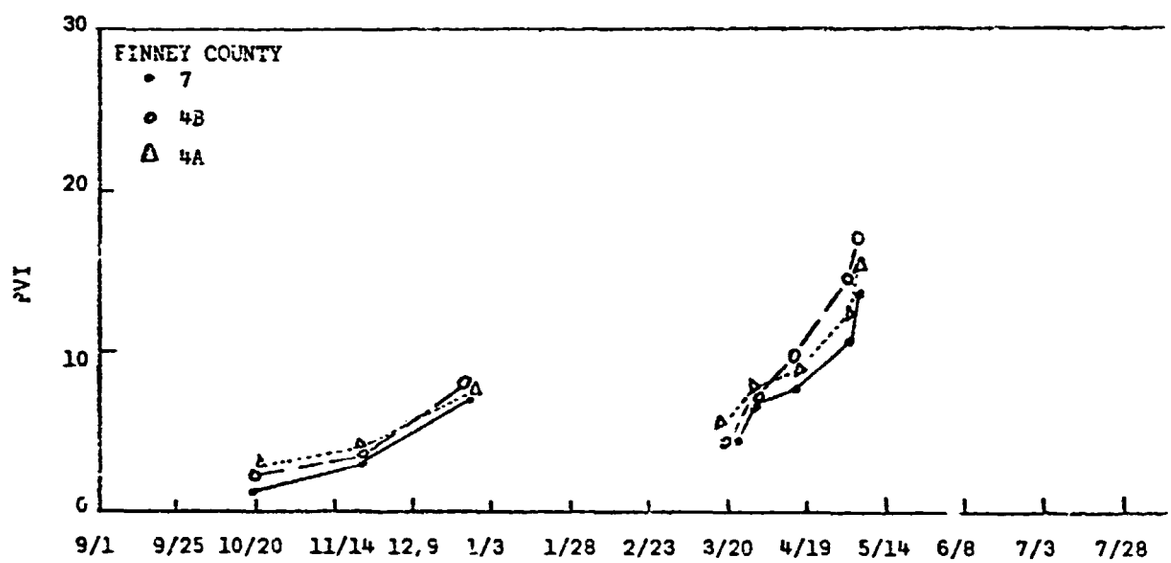
YIELDED EQUAL OR BETTER CORRELATION WITH GROUND-MEASURED LAI THAN DID

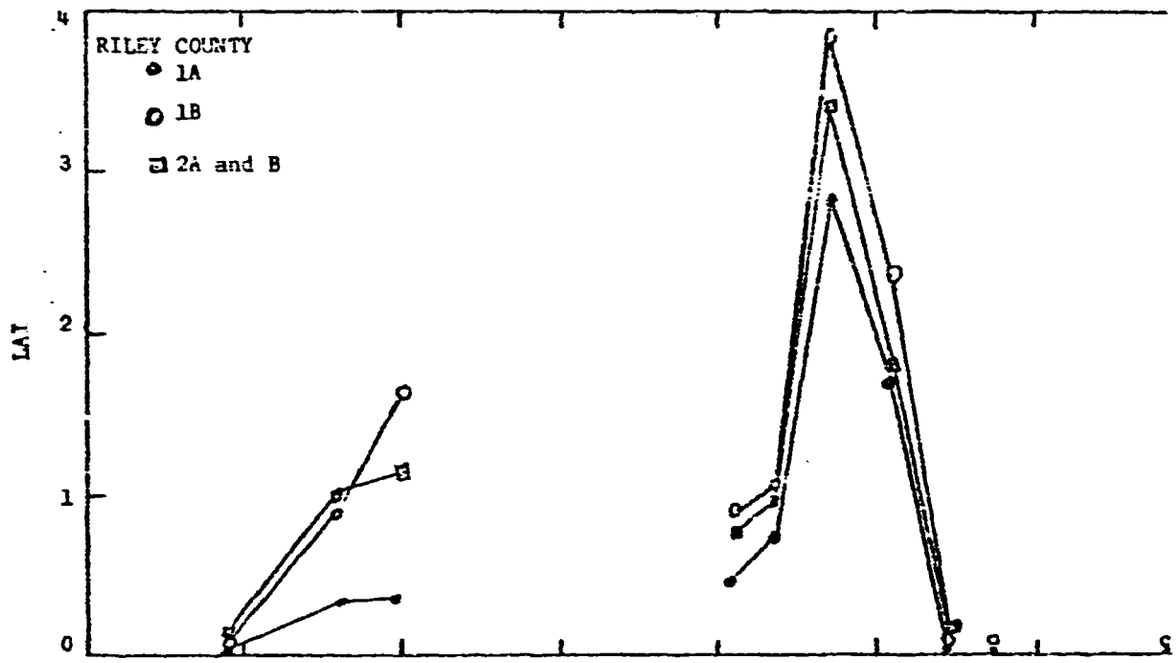
$$LAI = a_0 - a_1(MSS\ 4/5) - a_2(MSS\ 4/6) + a_3(MSS\ 4/2x7) + a_4(MSS\ 5/6) - a_5(MSS\ 5/(2x7)) + a_6[(MSS\ 4/5) - (MSS\ 4/(2x7)]\ MSS(4/5)$$

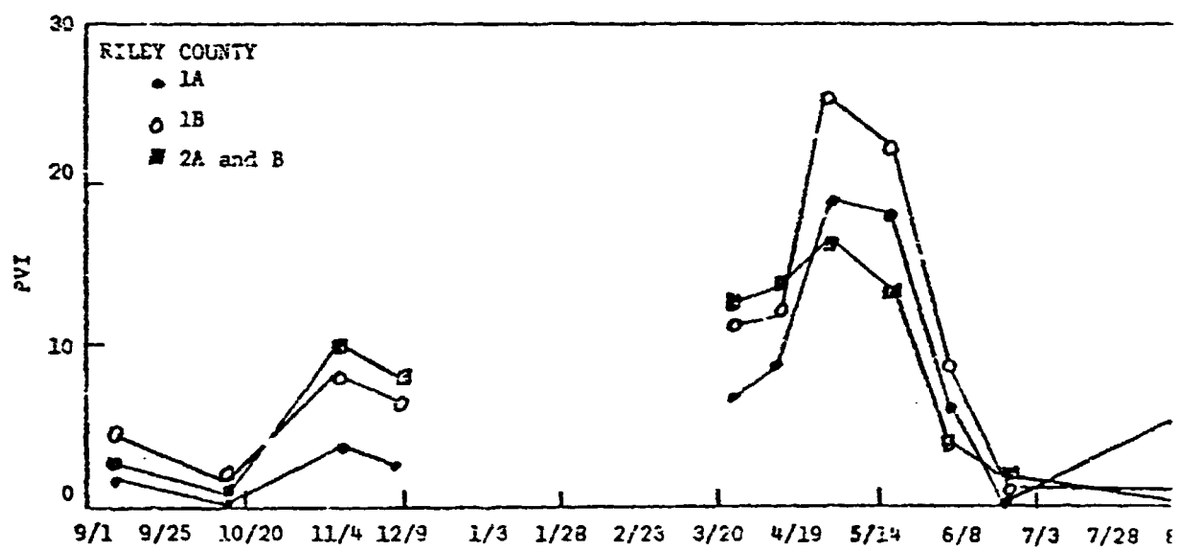
2. SPECTRAL VEGETATION INDICES SUCH AS PVI ARE APPLICABLE TO [illegible].

3. APPEARS POSSIBLE TO CALIBRATE WHEAT LAI IN TERMS OF PVI AND REDUCE GROUND TRUTHING TO SPOT CHECKS.

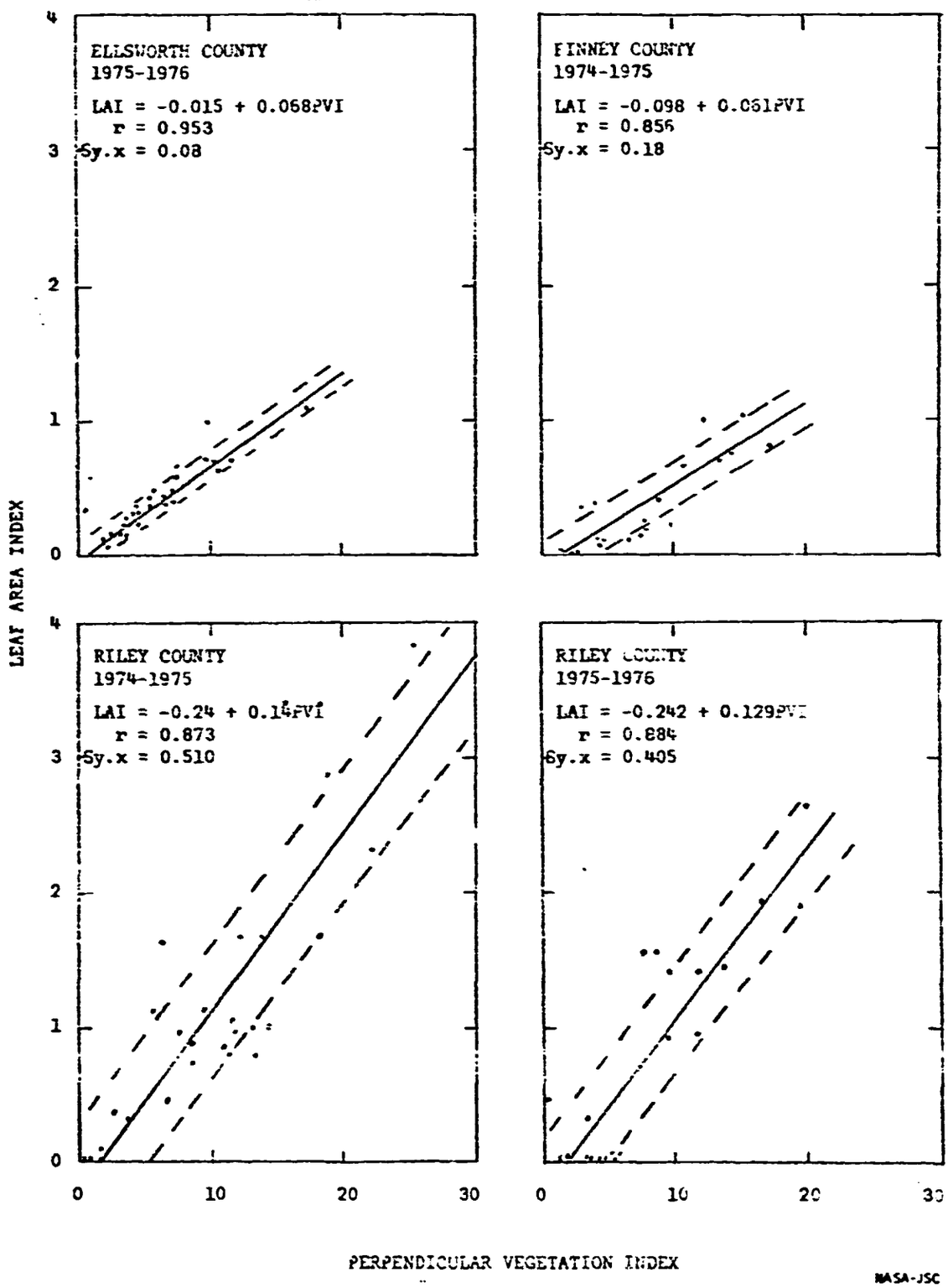

FINNEY COUNTY
7
4B
4A
LAI
2.0
1.5
1.0
.5
0.0
SEEDING
TILLERING
TILLERING
TILLERING
JOINTING
JOINTING
BOOT
HEADING
MILK
DOUGH
RIPENING
MATURE
POST HARVEST
POST HARVEST
POST HARVEST


FINNEY COUNTY
7
4B
4A
PVI
30
20
10
0
9/1
9/25
10/20
11/14
12,9
1/3
1/28
2/23
3/20
4/19
5/14
6/8
7/3
7/28
DATE, 1974 - 1975





DATE, 1974 - 1975


ELLSWORTH COUNTY
1975-1976
LAI = -0.015 + 0.068PVI
r = 0.953
Sy.x = 0.08
FINNEY COUNTY
1974-1975
LAI = -0.098 + 0.061PVI
r = 0.856
Sy.x = 0.18
RILEY COUNTY
1974-1975
LAI = -0.24 + 0.14PVI
r = 0.873
Sy.x = 0.510
RILEY COUNTY
1975-1976
LAI = -0.242 + 0.129PVI
r = 0.884
Sy.x = 0.405
LEAF AREA INDEX
PERPENDICULAR VEGETATION INDEX
0
1
2
3
4
0
10
20
30

NASA-JSC