- 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

LOCATION	Potential Head Sites/M^2 5/17	6/1	7/23	No. Leaves/M^2 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	YIELD (Bu/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

LOCATION	ACQUISITION DATES				
	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:

		YIELD			
ITS	DATE	ASCS	FARMER	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	.6764	.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 ($\alpha = 1.35$). When R_n was not measured, we estimated it from solar radiation, R_s (mm day^{-1}), using

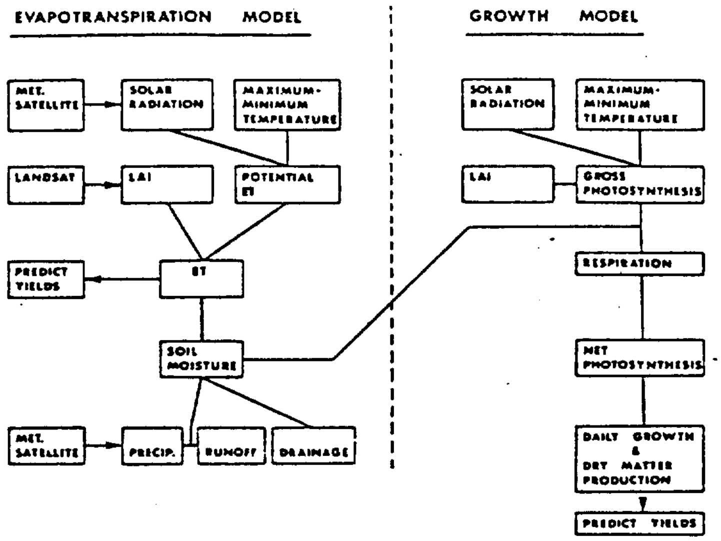

Fig. 1. Flow diagram of evapotranspiration (ET) and growth models. Potential use of meteorological satellites are shown. Winter wheat yields are predicted from ET and dry matter production estimates.

the regression equations:

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

and

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

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

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

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

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

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

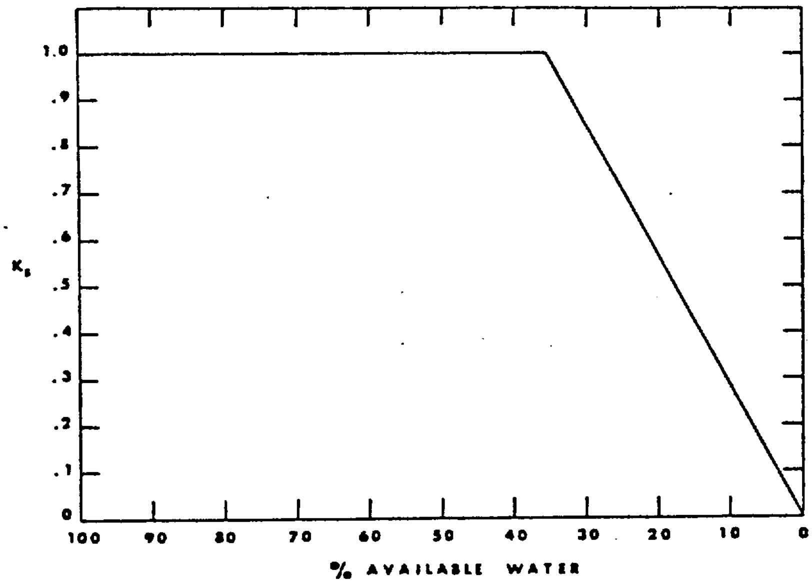

Fig. 2. Water stress factor (Ks) as a function of available water in the root zone. Ks linearly declines at 35% available water.

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.

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

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. #
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	10/20/73	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. #
Manhattan	10/31/76	2648-16174
	11/17/76	2665-16112
	11/18/76	2666-16170
	12/24/76	2702-16153

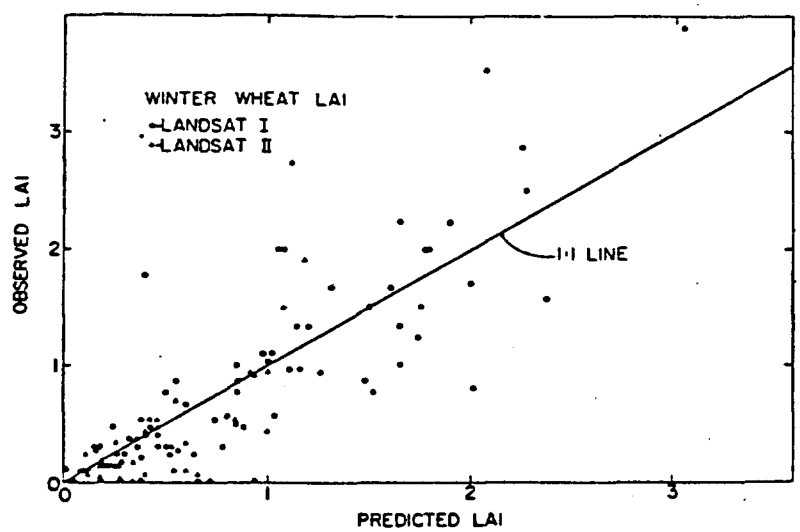

Fig. 3. Comparison of observed leaf area index (LAI) with Landsat-predicted LAI.

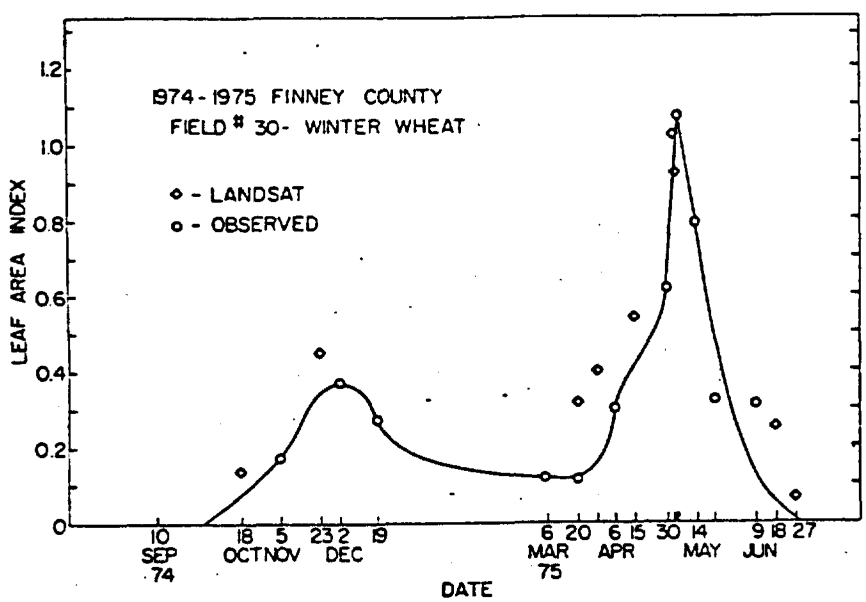

Fig. 4. Seasonal trends in observed leaf area index (LAI) in Finney County (solid line); square symbols indicate Landsat-predicted LAI.

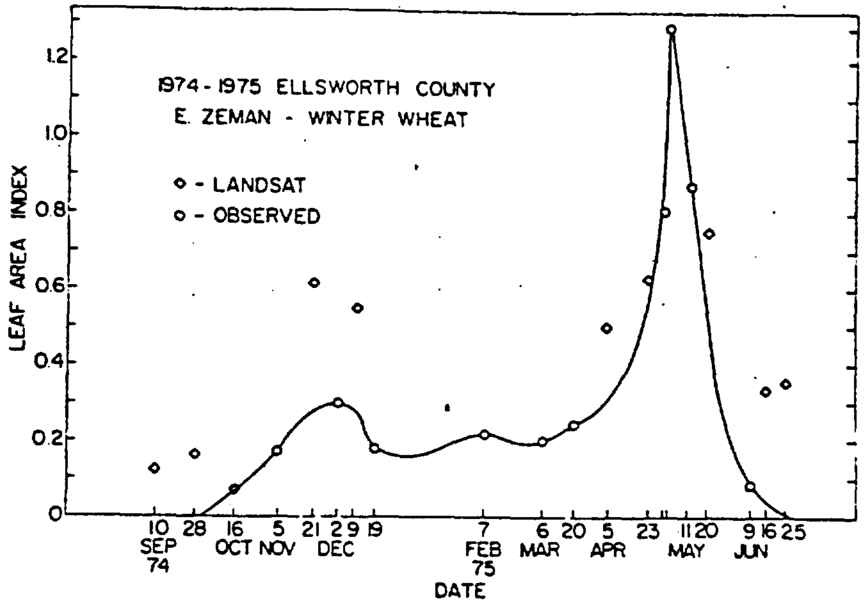

Fig. 5. Seasonal trends in observed leaf area index (LAI) in Ellsworth County (solid line); square symbols indicate Landsat-predicted LAI.

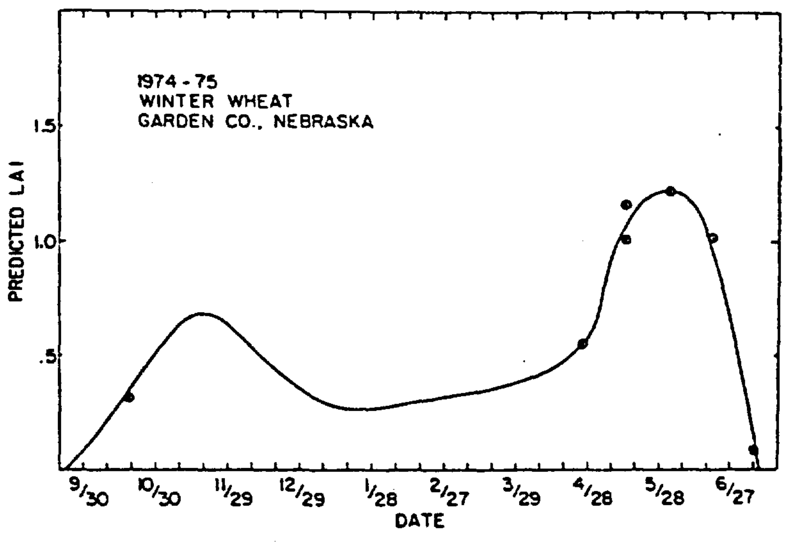

Fig. 6. Seasonal trends in Landsat-predicted leaf area index (LAI) for sample segment in Garden County, Nebraska, 1974-1975.

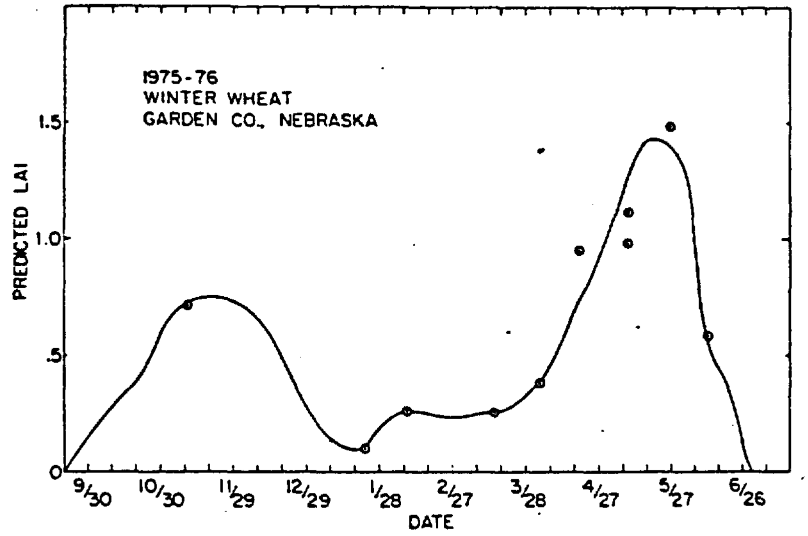

Fig. 7. Seasonal trends in Landsat-predicted leaf area index (LAI) for sample segment in Garden County, Nebraska, 1975-1976.

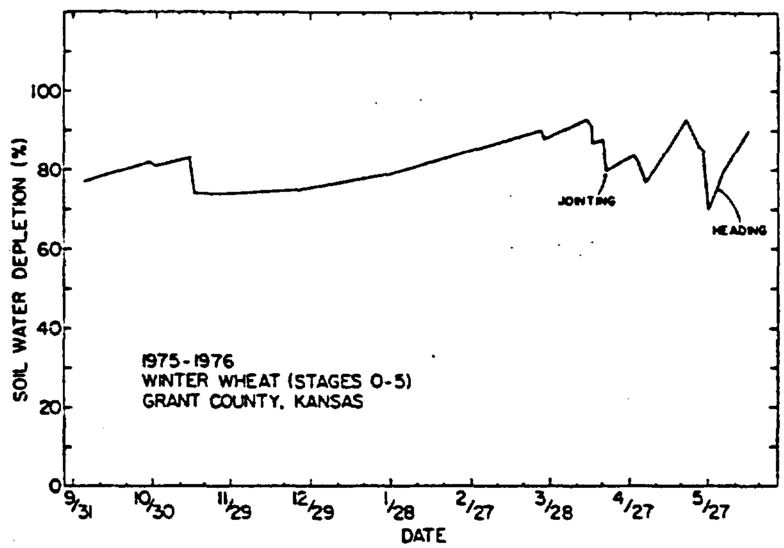

Fig. 8. Seasonal trends in soil water depletion in Grand County, Kansas, 1975-1976.

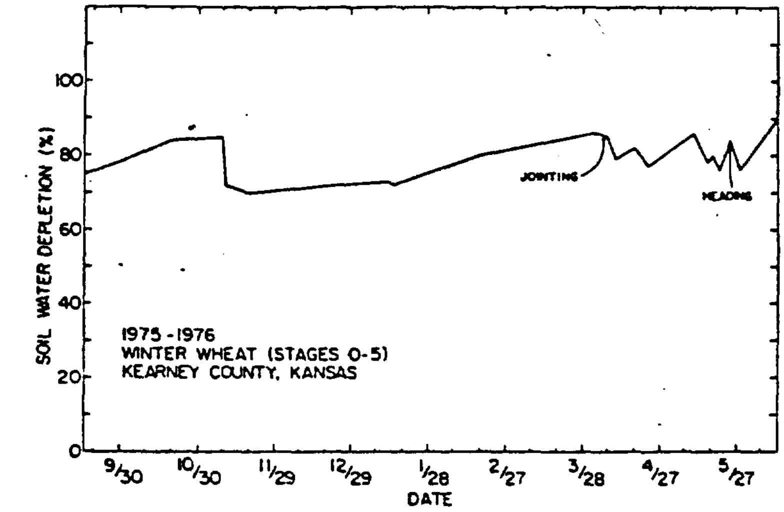

Fig. 9. Seasonal trends in soil water depletion in Kearney County, Kansas, 1975-1976.

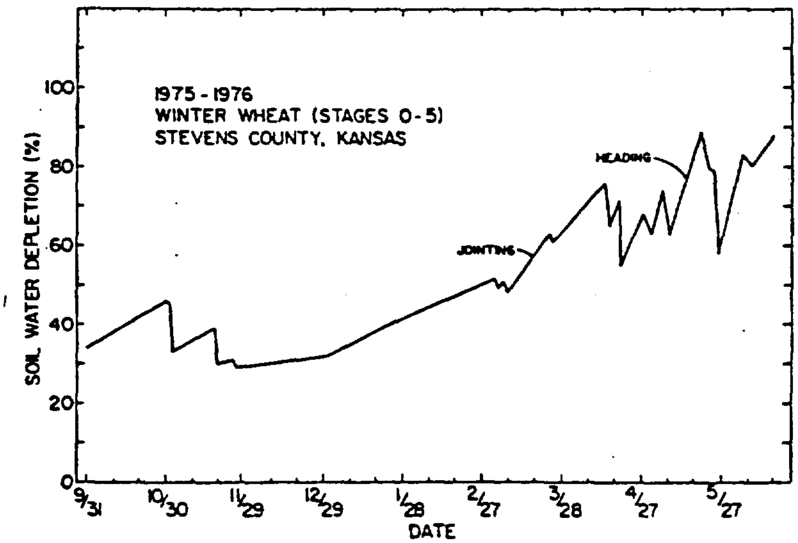

Fig. 10. Seasonal trends in soil water depletion in Stevens County, Kansas, 1975-1976.

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, and 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

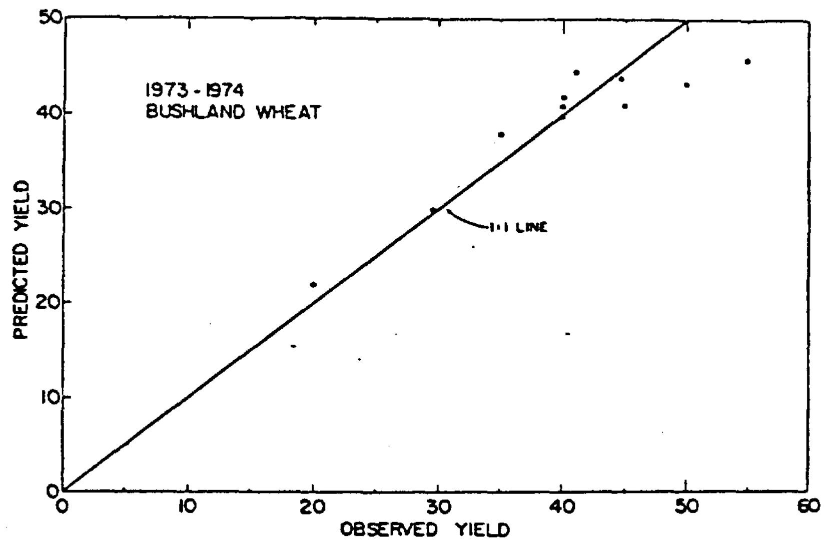

Fig. 11. Comparison between observed yields and predicted yield from evapotranspiration-yield model ($r^2 = .9$).

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.

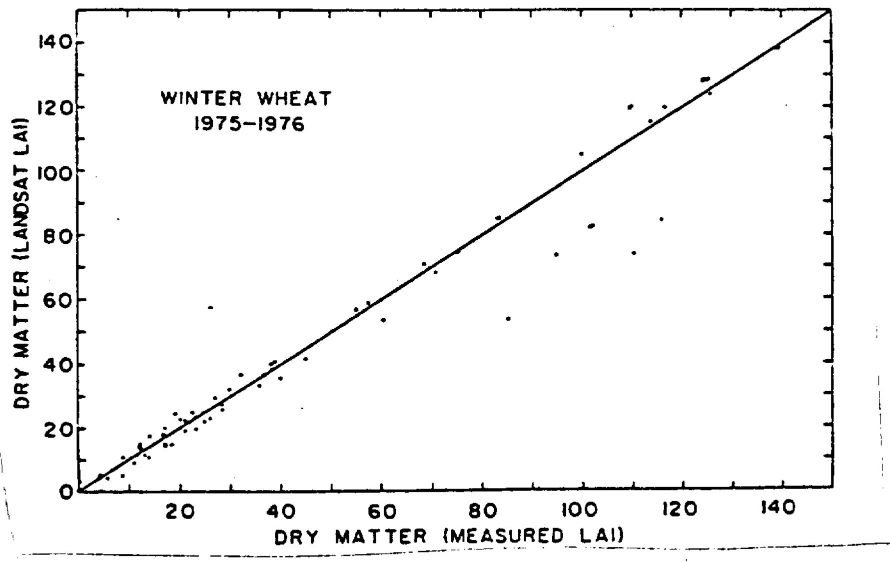

Fig. 15. Comparison of dry matter estimated by the growth model using measured leaf area index (LAI) and Landsat-predicted LAI.

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

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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

	1975 FINAL MODEL YIELD ESTIMATE	LANDSAT * STRESS CORRECTED YIELD ESTIMATE	LANDSAT ** MOISTURE CORRECTED YIELD ESTIMATE	NOAA CCEA 8/25/75 YIELD ESTIMATE	USDA SRS 3/10/76 YIELD ESTIMATE
MONTANA	23.7	23.03	21.34	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	18.33	17.05	20.7	18.0
N.W.	18.7	19.81	18.88	20.3	17.4
N.C.	15.9	17.32	16.23	14.6	19.0
N.E.	17.3	21.14	17.66	18.1	19.4
W.C.	---			---	13.7
C.	---	14.08	16.11	---	15.0
E.C.	---	19.61	18.72	---	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	23.4	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.	---	23.18	22.21	---	22.9
S.C.	---	23.26	23.92	---	21.2
S.E.	28.3	27.83	26.88	16.8	22.8
MINNESOTA	33.7	33.98	33.05	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

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 below 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

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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.

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	1416	-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	

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

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

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

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

** Significant at the 0.01 probability level.

"LEAF AREA INDEX ESTIMATES FOR WHEAT FROM
LANDSAT SPECTRAL DATA"

(Wiegand, Richardson, Kanemasu)

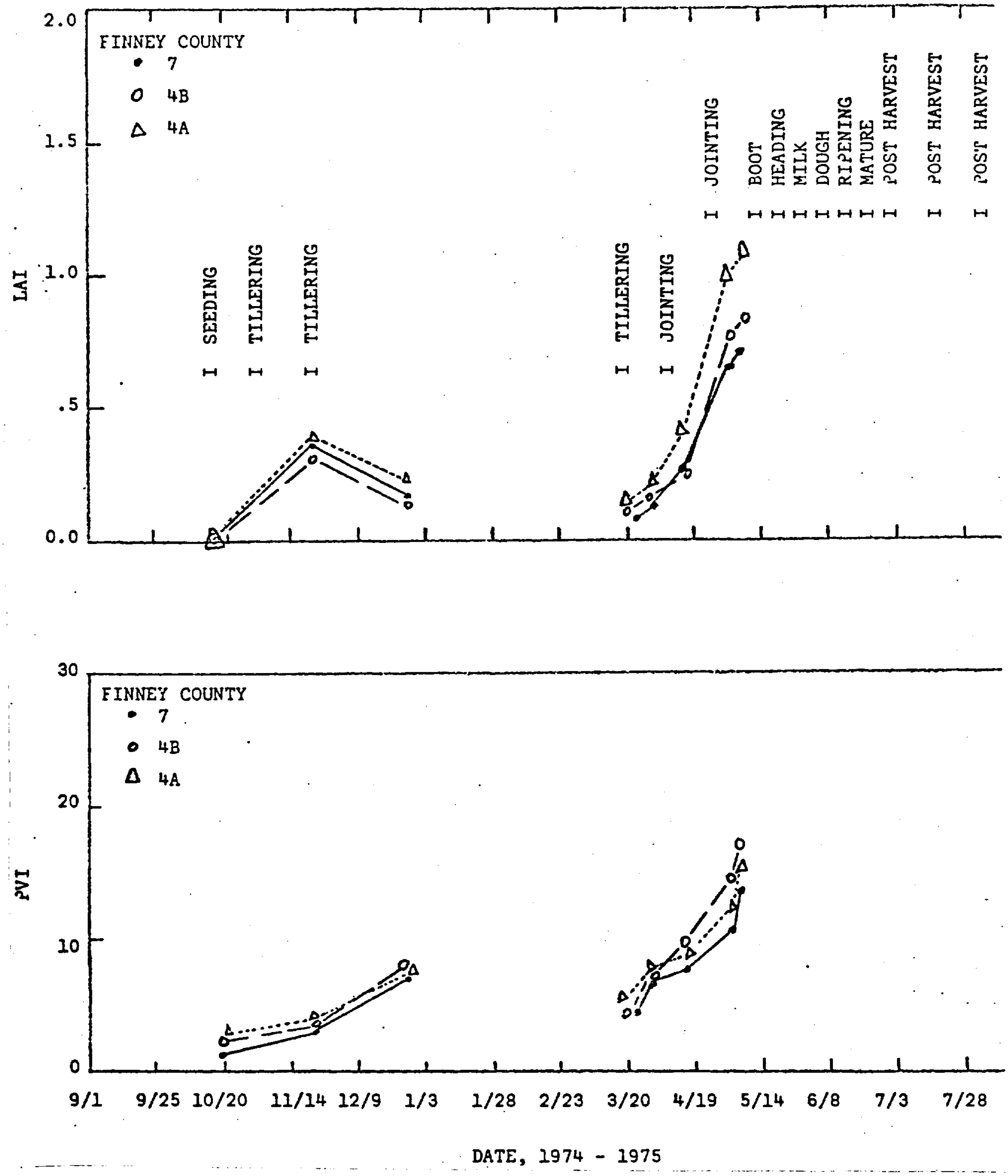
CONCLUSIONS

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

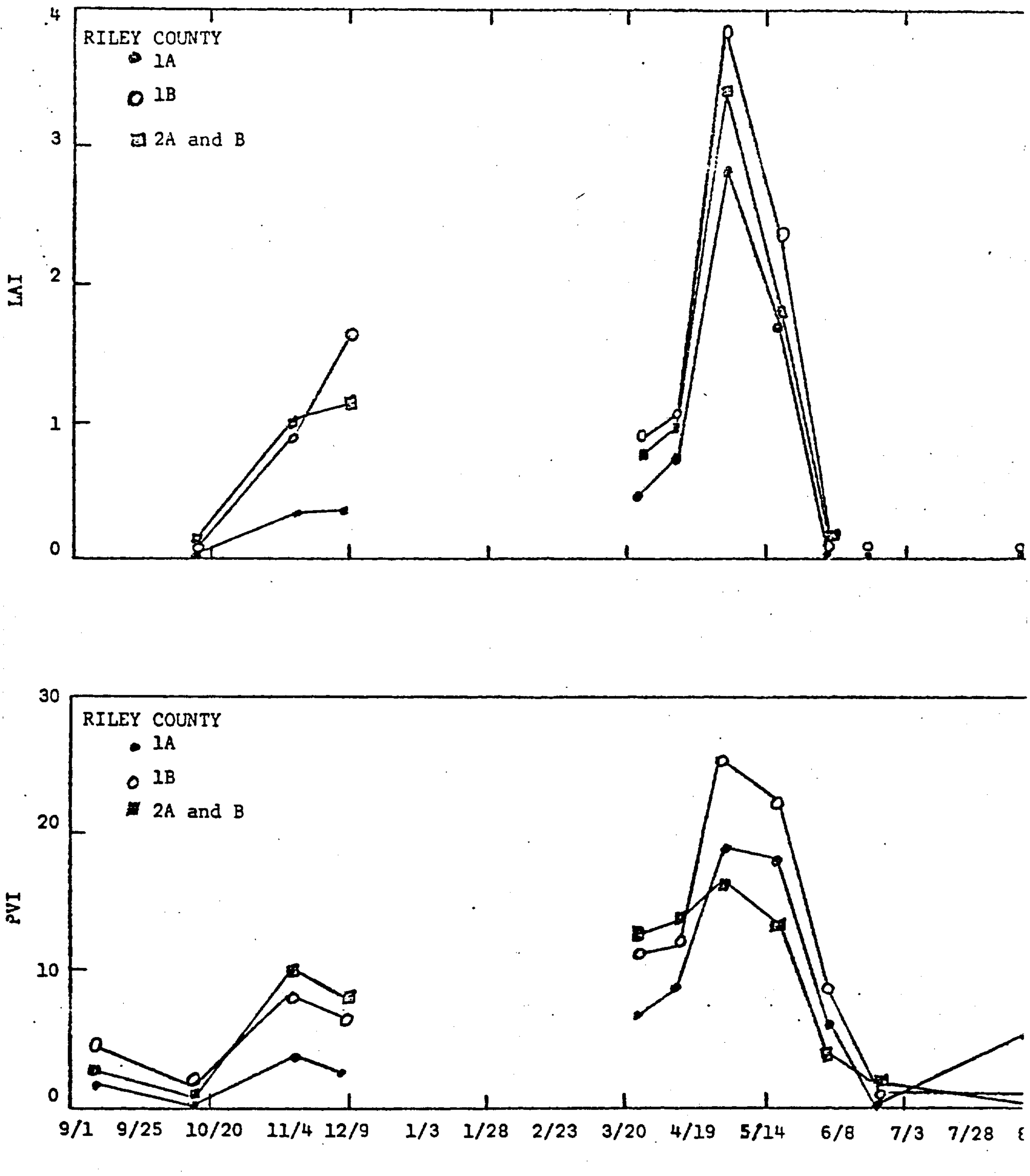
YIELDED EQUAL OR BETTER CORRELATION WITH GROUND-MEASURED LAI THAN DID

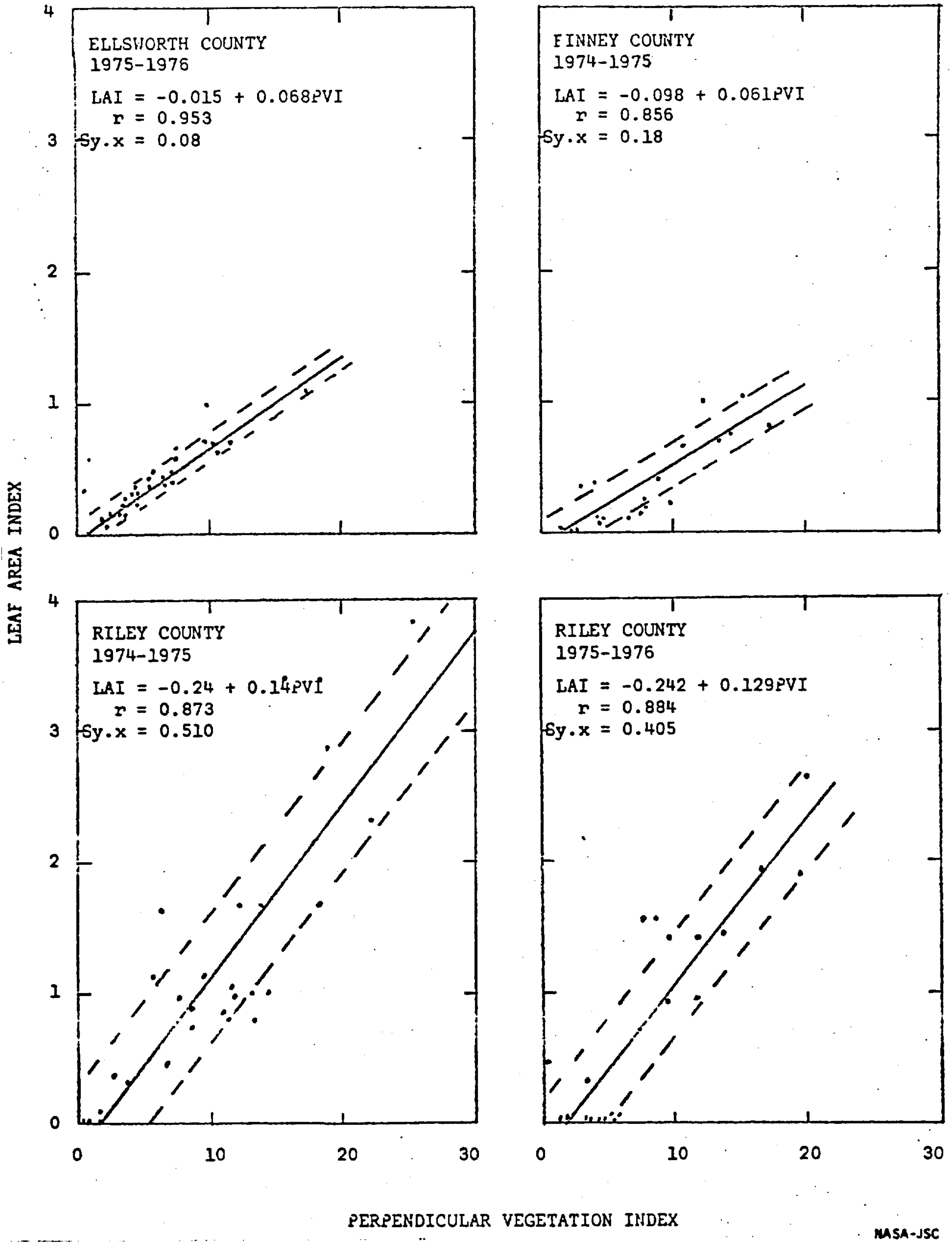
$$LAI = a_0 - a_1(MSS\ 4/5) - a_2(MSS\ 4/6) + a_3(MSS\ 4/2x7) + a_4(MSS\ 5/6) - a_5(MSS\ 5/(2x7)) + a_6[(MSS\ 4/5) - (MSS\ 4/(2x7)]\ MSS(4/5)$$

2. SPECTRAL VEGETATION INDICES SUCH AS PVI ARE APPLICABLE TO WHEAT.
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


RILEY COUNTY
1A
1B
2A and B
LAI
0
1
2
3
4
RILEY COUNTY
1A
1B
2A and B
PVI
0
10
20
30
9/1
9/25
10/20
11/4
12/9
1/3
1/28
2/23
3/20
4/19
5/14
6/8
7/3
7/28
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
10
20
30

NASA-JSC