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FINAL REPORT -- PHASE ONE

"Integration of Environmental and Spectral Data for Sunflower Stress Determination"

Contract NAS 9-16427
During the Period
August 24, 1981 - September 30, 1982

Submitted to

Early Warning/Crop Condition Assessment Project of AgRISTARS
c/o Victor Whitehead
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center/Mail Code SH3
Houston, Texas 77058
(713) 483-5244

by

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Weekly ground observations (acquired in 1980 and 1981) have been analyzed in concert with large scale aerial photography and concurrent Landsat data. Using multidate supervised and unsupervised classification procedures, it has been found that all crops grown in association with sunflowers in the study area are spectrally separable from one another. Under conditions of extreme drought, severely stressed plants were differentiable from those not severely stressed, but between-crop separation was not possible.

The environmental analysis has involved the use of both detailed field surveys from the University of Minnesota Crop Pest Management (CPM) program and USDA-SRS yield statistics for Minnesota counties. Initial regression analyses to estimate sunflower seed yield showed a sensitivity to environmental stress during the flowering and seed development stages. One of the most important biological factors related to sunflower production in the Red River Valley area was found to be the extent and severity of insect infestations.

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CONTENTS

INTRODUCTION

This report is submitted in fulfillment of the reporting requirements of Contract NAS 9-16427 and covers the research performed thereunder during the period from August 24, 1981 to September 30, 1982. This research is being conducted in support of the Early Warning/Crop Condition Assessment Project of AgRISTARS and is aimed at integrating spectral and environmental data to facilitate early determination of stress. The final product of this two-year effort will be a mathematical model based on the physiological response of sunflowers to their environment and on the manifestations of this response in the appearance of the crop that strives to estimate the degree of stress experienced by the crop.

This report covers only the first year of work to be performed during the planned two-year effort. The objectives during the first year were to: 1) analyze existing data sets that contain information on the response of sunflowers to their environment, and effects of disease, insects and yield losses, 2) continue acquisition of field data to incorporate with existing data sets, 3) acquire and analyze aerial photographic and Landsat data to document spectrally the field conditions observed during the current year, and 4) prepare for the second year of study wherein the aforementioned data will be synthesized and field spectral radiometry will be initiated as necessary and appropriate.

Substantive progress has been made in the pursuit of all of the aforementioned objectives during the past year. The effort to date has been coordinated mutually between the authors of this report with Lillesand leading the photographic and Landsat spectral work and Seeley leading the collection and analysis of the environmental data sets. The structure of this report reflects this division of effort and is therefore organized such that we treat progress to date in the spectral analysis area in Section I, followed by discussion of the environmental data analysis activities in Section II.

I. SPECTRAL ANALYSIS ACTIVITIES

1.1 OBJECTIVE/REFERENCE DATA SOURCES

The western and northwestern districts along Minnesota's Red River Valley are responsible for over 90 percent of the state's sunflower production. The primary objective of the spectral component of our first year of study has been to assess the spectral separability of sunflowers from the other crops grown in this area. In pursuit of this objective we have taken an integrated approach of analyzing available Landsat MSS data, supporting aerial photography, and ground reference data covering the 1980 and 1981 growing seasons. Our emphasis has been on data collected during 1981 (when this study began) in that data from 1980 were less available and of lower quality, and 1980 was a year of extreme drought. Ground reference data for the 1981 growing season were provided from several sources, yielding locations of nearly 400 fields (>80 acres) including: sunflowers, potatoes, small grains, sugar beets, pinto beans, and several miscellaneous crops of lesser acreage. The University of Minnesota Extension Service Crop Pest Management program (CPM) provided detailed information on the condition of approximately 150 fields of sunflowers, potatoes, and small grains. Centrol, a farm management cooperative, provided us with the location of a number of fields of sugarbeets, pinto beans and other miscellaneous crops during 1981. The 1980 data set included some 50 potato and 50 sunflower fields derived from the CPM program.

The CPM program involves field scouts based out of Crookston, Minnesota, in the northwest and Morris, Minnesota, in the west. The counties covered from each of these district offices are shown in Figure 1. (Also shown are the limits of coverage for the three Landsat scenes needed to cover the CPM districts). The information on crop condition monitored by the CPM program is included in a computerized data base maintained at the University of Minnesota and includes weekly information on the condition of each field, including the presence and degree of infestation of various pests, such as insects, weeds, etc. Location, crop history, and management practice information for each field is also included in the data base. In short, this data base has proven to be an invaluable aid in our analysis of the Landsat data, particularly when analyzed in concert with the aerial photography acquired as part of this study. This photo coverage has taken the form of large scale (1:10,000) 70mm color and color infrared images of a subset of 60 of the ground-monitored fields. The photographs have provided a bridge between the Landsat and ground observations and have aided in our substantiation and understanding of anomalous conditions appearing in these data sets. The geographic distribution of the photo coverage is shown in Figure 2. Figures 3 and 4 depict a representative sample of the photography.

1.2 LANDSAT DATA ANALYSIS PROCEDURES

The Landsat data samples being used in the study are 240x240 pixel segments of full scenes which are displayed on an interactive image analysis system. This allows the analyst to view the Landsat data in contrast enhanced color, electronically magnify the image to observe the full detail in the data, and to outline ground areas over which reference data have been collected. Forty image segments or "windows" have been analyzed over three Landsat scenes in 1980, at three times during the growing season, and 46 windows have been analyzed for two dates in 1981. In the remainder of this section of this discussion we will highlight the procedures used to analyze the Landsat data. In the next section we will summarize the results obtained by analyzing the 1980 and 1981 data sets, respectively.

1.2.1 Supervised Analysis Procedure

The 1980 Landsat scenes were analyzed using only a supervised training technique, while both supervised and unsupervised training were employed to analyze the 1981 data. The University of Minnesota Image Processing Software (UMIPS) system was used to carry out both analyses. In the supervised approach, the operator used ground-determined field locations and ½-inch to the mile county highway maps to carefully outline polygons on the interactive display corresponding as closely as possible to the corresponding ground derived information. Since the images were geometrically corrected, a grid overlay showing mile square segments (Public

Land Survey sections) was very useful in locating a desired field in relation to easily identifiable natural and cultural features on the base map and display. In delineating the polygon to represent the ground conditions in a given field the operator used his judgement as to the exact boundaries of the field and avoided edge pixels to the extent possible. If anomalous conditions existed within a field as viewed on the interactive system, the operator would create a polygon both with and without the anomaly. If aerial photographs were available for a field in question they were used to help decide the shape and position of the polygon to best represent the ground observation. The aerial photographs were found to be extremely useful in this regard.

Using the vertices that defined each polygon, the spectral data for each field were extracted from the appropriate Landsat tape. To "clean" the data base before further analysis, a histogram/range plot was compared for all polygons representing the same crop type. Those polygons that were noticably different from the rest within their respective groups were investigated in an attempt to create representative crop groupings. Samples with fewer than 30 pixels were deleted due to their lack of statistical reliability. Fields which exhibited high variability, or multimodality in one or several bands were also deleted if reference information confirmed that they were indeed atypical fields. Once the file editing process was completed, fields were grouped and named as to their crop type, condition, time of year, etc., and a new set of statistics was then created. Two-dimensional scatter plots of each Landsat band vs. all others were then prepared and the pairwise transformed divergence values among all fields were computed.

Divergence is a measure of the statistical separability of two spectral data sets, and thus, an indicator of the probability of error in discriminating between them. Divergence is computed from

$$D_{ij} = \tfrac{1}{2}\mathrm{tr}\ [(\Sigma_i - \Sigma_j)(\Sigma_j^{-1} - \Sigma_i^{-1})] + \tfrac{1}{2}\mathrm{tr}\ [(\Sigma_i^{-1} + \Sigma_j^{-1})(V_i - V_j)(V_i - V_j)^T]$$

where D_{ij} is the divergence between class i and j; tr represents the trace of the indicated matrix; Σ is the covariance matrix for the indicated class; and V is the mean vector for the indicated class. As computed in the UMIPS software, divergence is scaled to range between 0 and 2000. Generally, if the divergence value between any given pair of spectral responses is in excess of 1500 the responses are considered separable spectrally. Lower divergence values indicate overlapping spectral reflectances and consequent "confusion" between cover types.

1.2.2 Unsupervised Analysis Procedures

In order to more fully explore the spectral characteristics of the test areas and simulate an operational crop inventory system, an unsupervised classification was performed on a subset of the Landsat windows for 1981. A UMIPS algorithm which is a variation of the SEARCH program developed by the NASA Earth Resources Laboratory was used for this purpose. This algorithm passes a 3x3 pixel moving window over the data set. Any window falling below a user-defined maximum variance threshold is analyzed. (This operation reduces the occurrence of "edge effect" spectral classes).

These sets are accumulated and combined down to a user-defined maximum number of spectral classes, with 18 classes being found to be an appropriate number with which to work. Once these spectral classes were defined the various windows were classified using a scaled distance algorithm. (A scaled distance measure is used because covariance data are not generated for the spectral classes in the algorithm). Ground reference data were then used to identify and combine spectral classes into information classes on the interactive display. With the aid of the UMIPS software, colors were assigned to each spectral class on the display using the previous supervised training information as well as the 70mm CIR aerial photography, county highway maps, and information acquired directly from farmers in the area.

1.3 LANDSAT DATA ANALYSIS RESULTS

1.3.1 Results from Analysis of 1980 Data

The dates of analysis for 1980 were June 26, July 23, and September 6. (The June 26 image was not available for the northern scene). Again, extremely dry conditions prevailed during 1930, causing crops to vary widely in their condition. For the mid-summer scene analysis it was therefore necessary to stratify each of the sunflower and potato fields into two sub-classes based on their infrared reflectance. The sub-groups were created using two major criteria. The first was their appearance on the interactive display. Highly infrared reflective fields appeared red or pink, while those of low infrared reflectance appeared cyan. Subsequent analysis of the variance, range of the digital numbers, transformed divergence values, and bispectral plots of each field demonstrated the validity of the separate grouping. Due to the extremely dry conditions represented in the data set it is entirely possible that the "sunflower" or "potato" fields in the low infrared reflectance groups were fields under severe stress and/or were simply bare. With this in mind, we adopted the same field grouping for the spring and fall scene analyses. Although we can show separability between types of fields (stressed/bare vs. productive) within both potatoes and sunflowers, there was no differentiability between these classes by crop type, even on a multitemporal basis.

1.3.2 Results from Analysis of 1981 Data

The supervised and unsupervised analysis of the 1981 data has been completed for only two dates (July 9 and September 19) and for only the two most northerly Landsat scenes shown in Figure 1. Due to the extremely cloudy conditions realized during the 1981 growing season, these images were the only scenes available for analysis. It goes without saying that many of the mid-season comparisons we were expecting to make were not obtainable due to the poor Landsat coverage--i.e., one date of mid-season imagery over only two-thirds of our study area.

We have found for the July 9 image that, in general, sunflowers are separable from potatoes, wheat, barley, alfalfa, and pinto benas. However, the separability of sunflowers from sugarbeets on this single date is questionable. It should be noted that the number of fields of alfalfa and pinto beans was limited in this study due to inadequate ground information and the low percentage of these crops grown in the study area. Therefore, our comparisons of sunflowers with these crops are based on a small number of samples which were often located in a limited geographic area.

In addition to showing separability from several other crops, sunflowers also manifested some interesting spectral subclasses. Sunflower fields were grouped into geographic regions and growth stages in an attempt to account for this spectral separability among subclasses of sunflowers. Since each of the windows extracted from the Landsat tapes were approximately 8.5 square miles in dimension and were chosen from all major sunflower growing areas contained within the Landsat scenes, the windows were used as strata to compare sunflowers among various geographic areas. Using these groupings, sunflowers within a specific window were indeed separable from sunflowers in many other geographic areas. As expected, a north to south gradient was found to exist within a single scene. Possible causes for these gradients include a range of soil types, precipitation variations, etc. For a limited number of fields the CPM program provided the growth stages for sunflowers on or within a few days of July 3. When fields that had the same growth stage were grouped together it was found that several of the different growth stage groups were separable from one another. Whereas July 9 is fairly early in the growing season for sunflowers and there was not complete ground cover by the plants at this date, it 's suspected that soil reflectance could be influencing our spectral analysis. In short, combining the sunflower fields in the above two manners did not create completely homogeneous groupings. In either grouping there was general, not complete, separability of subgroups. Insufficient data at this time was contained within the CPM data base to try to check the condition of the crops within the growth stages studied. It is hoped that when this information is entered into the data base that this will help explain some of the within-group stage variability.

To summarize the results of the July 9 analysis, under "normal" mid-season growing conditions sunflowers were found to be separable from small grains, alfalfa, potatoes, and pinto beans, but were found to be confused with sugarbeets. The latter confusion, however, was not a problem in the analysis of the September 19 image data.

We have found that for the September 19 image that, in general, sunflowers are separable from sugarbeets, alfalfa, pinto beans, and corn. However, the separability of sunflowers from potatoes at this time is questionable. As in the summer, the number of fields of alfalfa, pinto beans and corn was limited. However, the divergence values of these crops vs. sunflowers indicate that these crops are separable, since virtually all of the pairwise divergence values are greater than 1500. It must still be kept in mind, however, that the fields of alfalfa, pinto beans, and corn are few in number and limited in their geographic distribution.

The separation of potatoes from sunflowers is much less straightforward in the fall. Around half of the divergence values between potatoes and sunflowers fall below 1500, indicating that they are not clearly separable. It is difficult to say why they are not more clearly separable, but perhaps it is due to their senescence. Both sunflowers and potatoes "dry down" at this time of the year, thus they may be losing the characteristics that earlier in the summer rendered them separable. In addition, many farmers use chemicals to artificially dry down both sunflowers and potatoes. This may also explain their lack of separability. We do not have the information needed to answer this problem fully. It is an interesting problem, however, since the spraying of crops would change the spectral "signature" very rapidly. (Remember that potatoes and sunflowers were separable in the July 9 data set).

Small grains were harvested by the September 19 image date so these fields were probably bare, contained stubble, or replanted to something else. In any case, the field locations that were small grains in the July 9 image were again separable from sunflowers in the September 19 image regardless of what may have been done to those fields.

Variability still existed within the sunflower data sets themselves for the fall imagery. It was noted that relatively higher infrared reflectance was received from plants grown in the northern part of the state. Although geographic blocking helped to account for some of the variability within sunflowers it again did not account for all of it. This is of interest because this "unaccounted for" variability may be due to stress.

The bottom line from the spectral analysis performed to date then is that all crops that are commonly grown in association with sunflowers in our study area are spectrally separable from one another when at least mid-season and fall images from a "normal" year are utilized. Both the supervised and unsupervised analyses supported this conclusion. Further work is needed to document the spectral manifestation of stress in sunflowers under normal growing conditions. Under drought conditions it was shown that severely stressed plants are differentiable from those not severely stressed, but between-crop separation is not possible.

II. FIELD DATA, ENVIRONMENTAL ANALYSES, AND INITIAL MODELING EFFORTS

- LITERATURE REVIEW
- DATA
- MODELS

2.1 LITERATURE REVIEW

Sunflower (Helianthus annus L.) production has rapidly increased in the U.S. over the past 15 years. Prior to 1970, the acreage planted to this crop was but a few thousand, hardly significant when compared to other agronomic commodities. Sparked by rapidly developing markets for vegetable oil, sunflower acreage expanded to over four million by 1980. Most of this increase in acreage has been in the oilseed varieties, which are grown as a source of oil and meal. According to Beard (1), in many environments, the sunflower yields more oil per unit area of land than any other crop. Seed yields generally vary from 1100 kg/ha to 2200 kg/ha, but many exceed 3000 kg/ha under irrigation and top management. About 40 percent of the seed is oil of high quality.

The world's primary producers of sunflowers are the USSR, USA, Argentina, Australia, and Canada, and the agricultural researchers of these countries have contributed most significantly to the development of improved hybrids and agronomic practices. Since the early 1970's, the acreage planted to open-pollenated varieties has been declining, as plant breeders in these countries have developed better hybrids. Today, over 80 percent of the U.S. sunflower acreage is hybrid seed. Hybrid seed has lead to the following major improvements in sunflower production: (a) higher seed yield; (b) greater oil content; (c) more uniform attainment of seed maturity within individual plants; (d) disease resistance; (e) easier combining at harvest; (f) and tolerance to increasing plant populations. All of these factors have contributed to the strong positive trend in production statistics over the past decade. They likewise confound any efforts to model or predict production of sunflower based on historical data. For this reason, a general review of the literature on this crop was focused on defining the physiological, ecological, and management characteristics that might best direct a screening of important physical and biological variables which could be used as predictors of seed yield.

This review will describe research findings in the following 4 categories: (1) general agronomic and ecological variables important to sunflower production; (2) methods used to score the rate of growth and development of this crop; (3) relationships between sunflower phenology and Growing Degree Days (GDD); and (4) the crops response to irrigation and moisture deficits.

Agronomic and Ecological Considerations

In the mid northern and southern latitudes, sunflowers are grown where moisture and/or length of season characteristics may severely limit the production of other crops. According to Robinson (22), sunflowers are most commonly in rotation with soybeans and small grains. Though not considered a drought resistant crop, sunflowers will often produce satisfactorily when other crops are seriously damaged by moisture deficits. Lindstrom et al (16) report that characteristics accounting for this response include: (1) an extensive and heavily branched taproot system exceeding 2 m in depth which can extract greater amounts of soil water than some other crops; (2) growth and development characteristics which allow tolerance of short periods of drought; and (3) a relatively short critical moisture period for seed yield.

In the past yields have been limited by problems with weeds, diseases, insects, and birds. Both Beard (1) and Cobia and Zimmer (5) report significant improvements in weed control and disease resistance. However, because of the morphological characteristics of the floral head, the crop remains highly susceptible to yield losses from insects and birds. In the northern latitudes, blackbirds and gold finches can consume significant amounts of seed. Universities recommend reducing bird depredation by avoiding bird-prone areas, utilizing various scaring devices, or spraying a chemical bird-repellent. Cutworms, sunflower midge, sunflower moth, and seed weevils are major insects which account for yield losses in the northern latitudes. Table 1 shows a typical sunflower insect monitoring schedule for Minnesota. Tillage, weed control, and crop rotations are used to keep infestations at low to moderate levels. In recent years, the majority of yield losses have been caused by sunflower midge and/or seed weevil. According to McBride and Oseto (18), damage to individual fields may range from negligible to total loss. Chemical control of these and other insects is difficult. Frequently, they feed on areas of the plant that are not readily exposed to chemical sprays. Secondly, chemical sprays are used at the risk of disrupting or killing needed pollenators such as bees. Bee colonies are frequently established by growers to enhance anthesis of their crop.

The insect problems sometimes confound an interpretation of planting date effects. Insects will generally seek out the most susceptible host plants, but with year to year variations of insect phenology, it is difficult to predict which planting dates will be associated with minimal insect infestations.

Archaeological evidence supports the belief that common sunflowers are native to both Central and North America, where wild species are adapt-

Table I.

MONITORING SCHEDULE - SUNFLOWER

Insect	May				June				July				August				Sept.		Follow-up Evaluation to Determine Effect of Pest (●) Notes
Cutworms	X	X	X	X	X	X	X							●	●				light trap
Defoliators																			
Sunflower beetle		X	X	X					X	X	X	X	X	X	X				yield
Thistle caterpillar										X	X	X	X						
Grasshoppers				X	X	X	X	X	X	X	X	X	X	X	X				
Stem and root weevils																			
1) Apion				X	X	X	X	X	X	X	X	X	●	●	●	X	X	X	
2) Cylindrocopturus				X	X	X	X	X					●	●	●	X	X		stem dissection & breakage
3) Baris				X	X	X	X	X					●	●					
Sunflower budworm							X	X	X	X	X	X	X	X	X	X			
Sunflower midge							X	X	X	X	X								
Sunflower moth								X	X	X	X	X	X	X					yield
Banded sunflower moth								X	X	X	X	X	X	X					
Sunflower "head clipper" weevil									X	X	X	X	X	X					
Sunflower maggots							X	X	X	X	X	X	X	X	X	X			
Sunflower seed weevil																			
1) *S. fulvus*										X	X	X	X	X	X	X	●		
2) *S. sordidus*										X	X	X	X	X	X	X	●		examination of seed

ed. They may be planted over a wide range of dates and,because of frost risk, in general, higher yields are associated with earlier plantings when insects or birds do not significantly affect the crop. Both Unger (31) and Beard and Geng (2) have researched the response of sunflower hybrids to late planting. Cultivars grown in a wide-range of environments respond similarly to late planting by accelerating development toward flowering. Yield losses can result when sunflowers are sown within 100 days of normal frost dates. A commonly used guideline for planting is when the average soil temperature first exceeds 45° F in the spring.

Cheng (4), Cobia and Zimmer (5), and Robinson (22), and others have shown that with adequate moisture sunflowers respond to nitrogen fertilizer. Phosphorus is frequently applied along with a starter fertilizer. Typical application rates of nitrogen, phosphorus and potassium are 50-100 lbs N, 15-30 lbs P, and 20-40 lbs K. Sunflowers remove as much nutrients from the soil as most other agronomic crops. Placement of fertilizer is usually in bands and not directly with the seed, since sunflower germination is quite sensitive to fertilizer salts. No micronutrients are recommended and little is known relative to their effects on the crop.

Plant populations under rainfed conditions generally range from 30,000 to 60,000 plants/hectare. With adequate moisture, Robinson et al (25) noted a significant increase in yield from 17,000 to 62,000 plants/hectare. However little effect on yield occurred between 25,000 and 49,000 plants/hectare. Beard (1) reports that plant populations for irrigation have exceeded 85,000 plants/hectare.

One of the most unique characteristics of sunflowers is the manner in which the crop orients its leaves and floral head toward the sun throughout the day. This characteristic is termed heliotropism or phototropism. Prior to flowering, the crop tracks the sun throughout the day, then returns to an eastward orientation during the night. Following anthesis (opening of the flower) the head faces only eastward. Robinson (23) researched this phenomena and found that it may be related to row direction of the crop. Most sunflower crops are grown with north-south rows rather than east-west.

Growth and Development Considerations

Siddiqui et al (28) were the first to develop a widely accepted growth and development scale for sunflowers. They devised a descriptive and numerical key for delineating the growth and development sequence of the crop. Morphological traits are used to identify both vegetative and reproductive stages, from emergence to physiological maturity. The maturity stage is defined as that time when the back of the head turns yellow and the phyllaries (small bracts on backside of the head) turn brown. Sometimes, plants are dried with a desiccant, which helps make the seed (or achene) moisture content more uniform at harvest.

The Siddiqui scale is used to assess yield reductions due to disease and insect problems since these pests have differential effects based on the crop stage of growth. A modified version of this scale is used by hail insurance adjustors to settle claims. Schneiter and Jones (26) reported that defoliation by hail at the bud or early flower stages (3.1 to 4.1 on the Siddiqui scale) can lead to a 20 to 30 percent reduction in seed yield if other environmental factors are not limiting. They found that hail damage in the vegetative stages did not significantly reduce yields.

Marc and Palmer (17) developed a similar scoring index for sunflower development to use in quantitative analysis of the relationship between environmental variables and sunflower ontogeny. Some cultivars have shown a photoperiod response in their development, while many others appear to be day-neutral.

Coultas (6) reported on a modified development index for sunflowers, with numerical, verbal, and sketched descriptions of each stage. These appear as Table 2 and Figure 5, respectively. This index is used frequently by field scouts in integrated pest management programs. Note that this index describes the ontogeny of a 115-day hybrid and infers a certain amount of stability by the relationship to growing degree units. This will be discussed in the next section.

Relationship to Growing Degree Days (GDD):

Robinson et al (20) were some of the first researchers to study the relationship between sunflower development and daily temperature accumulations. They found a strong relationship between the rate of sunflower development and the accumulation of temperature above a base of 7.2°C (45°F). The computation of daily Growing Degree Days using this base is shown as:

GDD = daily mean temperature-base

where the base equals 7.2°C. When this yields a negative quantity, then GDD are assumed to be zero for that day. They found that cumulative GDD related closely to the rate of development for similar sunflower cultivars. Furthermore, they tested this system for latitudes ranging from 31 to 49 degrees. Each degree of latitude increased the length of the planting to ray flowers period by 2 days. However, the GDD for this period varied in a narrow range from 829 to 948 from Lincoln, Nebraska to southern Manitoba. This indicates some degree of ontogenetic stability in individual cultivars when they are grown in wide ranging latitudes. The data suggest that the GDD relationship to development rate may be more stable for day-neutral

Table II.

Field Development of the Sunflower

Stage	Description
1. Emergence SN[1] = 1.1-1.4 DFP[2] = 0-14 GDU[3] = 0-190	From seeding until opposite leaves are fully expanded. Each leaf stage is distinguished from another when the leaf petiole is visible through the crown.
2. Vegetative SN = 2.1-2.4 DFP = 14-60 GDU = 191-1239	From the formation of the first alternate leaf until leaf formation ceases. Each successive alternate leaf after the formation of the 4th alternate leaf can be a substage of this stage. Total number of leaves can range from 28 to 38.
3. Bud SN = 3.1-3.4 DFP = 60-70 GDU = 1240-1510	Terminal bud forms a head rather than a cluster of leaves. Plant has reached maximum height and a flower bud is distinctly visible (½ to 1 inch button). Inflorescence separates from leaves and begins to open.
4. Anthesis SN = 4.1-4.5	
Early Bloom SN = 4.2 DFP = 70-80 GDU = 1511-1780	Petals of ray flowers become visible as inflorescence opens. First anthers appear at the outer edge of the inflorescence as anthesis begins in outer circumference of inflorescence and progresses to one-half bloom.
50% Bloom SN = 4.3 DFP = 80-90 GDU = 1781-2040	One-half of the disk flowers are in anthesis. Seed filling begins in outer florets and progresses inward.
Full Bloom SN = 4.5 DFP = 90-100 GDU = 2041-2280	Anthesis is complete. Seed filling continues. Seeds at outer edge of head become dark in color.
5. Seed Development SN = 5.1-5.2 DFP = 100-114 GDU = 2281-2545	Petals of ray flowers wilt and drop from head. Seed filling continues. Lower leaves begin to senesce. Head becomes inverted and is green in color.
Physiological Maturity SN = 5.3 DFP = 115 GDU = 2545-2581	Back of head is yellow and bracts are brown. Stems and seeds are hard and mature.

---

[1] Growth stages according to Siddiqui, Brown, and Allen ("Plant Disease Reporter," 1975, Vol. 59, pp. 7-11).

[2] Days from planting for a field to reach completion of particular growth stage.

[3] Approximate growing degree unit accumulation for a field of sunflower to reach a given stage of growth. GDU calculated from a base temperature of 45° F for a 115-day hybrid.

Picture	Description
Stage 1.1	Cotyledons emerged, petioles of first opposite leaves not visible
Stage 1.2	First pair of opposite leaves developed, petioles of second pair not visible
Stage 2-2.4 (vegetative)	First alternate leaf to last alternate leaf (drawing of all leaf stages)
Stage 3.1	Head visible, ¾ inch "button"
Stage 3.3	Bud elevated above crown leaves
Stage 3.3	Cross-section
Stage 4.0	First anthers visible on outer edge of inflorescence
Stage 4.1	Early bloom
Stage 4.1	Cross-section
Stage 4.3	50% bloom—seed filling in outer florets
Stage 4.4	75% bloom
Stage 4.5	Full bloom—anthesis complete, seeds in outer florets dark in color
Stage 5.1	Head inverts, petals of ray flowers drop from head
Stage 5.1	Cross-section
Stage 5.15	50% mature
Stage 5.3	Physiological maturity; back of head turns yellow, bracts brown

cultivars than those showing a photoperiod response. Indeed, Goyne et al (12) showed that a GDD system worked well in predicting sunflower develop rates in Australia, with the exception of the flowering period of cultivars with strong photoperiod response.

Robinson (21) in a separate study showed that the base 7.2°C GDD works reasonably well for different hybrids grown in the northern latitudes. For six common varieties, he found that the range in maturity as defined by total GDD from planting to complete senescence was more narrow than that reported for corn hybrids, ranging from about 1250 to 1350 GDD. Very late plantings had somewhat lower GDD requirements to reach maturity. GDD were shown to be better predictors of development than days from planting for all 6 cultivars.

Coultas (6) used Robinson's work as a basis for developing a Fahrenheit GDD system (base 45°F) for typical Minnesota sunflower hybrids. This system is used to estimate the develop of sunflowers such that schedules for insect scouting programs and irrigations can be better planned. Note in Table 2 that Minnesota sunflower hybrids typically need approximately 2550°F GDD to reach physiological maturity.

Hammer et al (14) used the GDD-phenology relationship to develop predictor variables for forecasting sunflower yields. They used a moisture stress index (based on evapotranspiration) during the GDD predicted flowering stage to forecast yields. The model validated very well for one cultivar grown in experimental plots. Moisture stress and yield modeling are discussed in the next section.

Response to Irrigation and Moisture Stress

Levitt (15) defines sunflower as a mesophytic plant with some drought tolerance and a water requirement (water used in transpiration/dry matter produced) ranging from 250 to 350. This water requirement is somewhat less than that of other mesophytes such as the small grains, but more than that of more xerophytic species such as sorghum. Ennen et al (9) studied the comparative water use of 8 common oilseed cultivars and other major crops grown in the Red River Valley along the Minnesota-North Dakota border. Total seasonal water use among cultivars and across locations only ranged from 30 to 34 cm (12 to 13.5 inches). Figure 6 shows a comparison of sunflower water use and that of other major crops in the Red River Valley based on data from 1973 to 1977. Note that sunflowers averaged 13 to 14 inches while alfalfa and corn required an average of 24 to 21 inches respectively.

Lindstrom et al (16) showed that under limited rainfall conditions, seasonal water use of sunflowers can be nearly comparable to that of corn, however sunflower production has been successful in areas where limited moisture has excluded corn production. They explain that the ability of the sunflower to produce a crop with limited moisture is not due to a lower water use, but to the crop's ability to escape or tolerate drought situations. Sunflower appears to be drought tolerant even for the three week interval from heading to flower completion, when it exhibits an ability to halt flower development during extreme moisture stress and resume when adequate moisture is restored. Other crops, such as corn, are susceptible to drought for longer periods and to a greater degree during their reproductive stages. Indeed, Sceiey and Spoden (27) showed that peak daily evapotranspiration rates of sunflower, though similar to corn, are not maintained for nearly as many days during the reproductive and filling periods.

The sensitivity to moisture during the flowering phase, though not as responsive as corn, is nevertheless a factor of importance in irrigation. Sionit (29) reported that prolonged moisture stress (two weeks or more) during flowering can reduce seed yields by 35 to 40 percent. For other growth stages, yield reductions ranged from negligible to 25 percent, with the least effects associated with the vegetative and senescence phases. Using this sensitivity in another way, Goyne et al (13) and Unger (30) reported that adequate moisture (via irrigation or rainfall) for maintaining near potential transpiration during the bud and flowering phases boosted yields significantly. Cobia and Zimmer (5) found that sunflowers respond as well to irrigation as alfalfa and soybeans, but not as well as corn. The yield response to irrigation varied little over plant populations ranging from 12,000 to 25,000 plants/acre.

Maximum leaf photosynthetic rates under irrigation at the flowering stage range from 38-40 mg $CO_2dm^{-2}hr^{-1}$ for sunflower, quite similar to other C_3 species, but considerably less than C_4 crops such as corn, which has shown maximum rates of 55-60 mg $CO_2dm^{-2}hr^{-1}$. Boyer (3) suggests that recovery of photosynthesis following moisture stress may be more rapid in sunflower than many other agronomic crops.

Water use efficiency (WUE) of sunflower has been researched to a limited extent. Unger (30) reports WUE as low as 25 kg $ha^{-1}cm^{-1}$ under moisture limiting conditions. However, Cox and Joliff (7) reported WUE as high as 105 kg $ha^{-1}cm^{-1}$ for cultivar 894 when grown in a favorable modified marine climate with very low vapor pressure deficits (1.5 KPa).

Ennen (10) reported WUE ranging from 37 to 53 kg $ha^{-1}cm^{-1}$ for sunflower yields of 1200 to 1500 kg/ha obtained under rainfed conditions in North Dakota. Irrigated yields of 3000 to 3700 kg/ha had WUE up to 76 kg $ha^{-1}cm^{-1}$. Cheng and Zubriski (4) found that irrigation and increasing nitrogen fertilizer applications up to 56 kg/ha raised yields from 2700 kg/ha to 4200 kg/ha and increased WUE by 25 percent.

No significant research or documentation was found on the effect of high temperature stress on sunflower seed yields. Hammer et al (14) and Fereres et al (11) reported on methods of relating evapotranspiration (ET) to yields and most ET computations consider temperature as a driving variable.

In summary, the literature showed that the following 7 major characteristics are important considerations for sunflower research and modeling efforts.

1) Sunflower is a native specie of Central and North America.
2) Sunflower is a C_3 plant and behaves similarly in many ways to other C_3 species.
3) Heliotropism, the characteristic of facing the sun until anthesis occurs is a unique trait with respect to most other agronomic crops.
4) Unlike field corn, sunflower hybrids exhibit a more narrow range of maturity types.
5) Sunflowers still benefit from an abundance of pollenator activity such as bees.
6) Because they are grown in latitudes with marginal growing seasons, sunflowers are sometimes sprayed with desiccants to enhance the uniformity in drying of the seed head.
7) Though progress has been made in both disease and weed control, sunflowers are still very susceptible to insect and bird damage.

2.2 DATA

The University of Minnesota Crop Pest Management (CPM) program conducted a detailed pest survey over thousands of acres of Minnesota cropland during the past 3 years. Sunflowers, being one of the major commodities produced in the state, were heavily surveyed in the west central and northwest districts of the state, shown in Figure 1. Weekly survey reports were filed by field scouts with the University of Minnesota, where they are stored as part of a pest management data base. Sample A shows an example of the weekly field survey form used for the 1980 and 1981 crop seasons.

A subset from the 1980 and 1981 sunflower data base contained a list of fields where end-of season yield samples were taken. Combining the data from 1980 and 1981 produced a total of 130 yield reports for fields ranging in size from 20 to 80 acres. These fields also had continuous weekly survey reports from CPM field scouts. This data set was the basis for developing environmental variables which could be used in regression analysis with yields.

Environmental variables were derived from daily weather observations by National Weather Service cooperative observers and by researchers at the University of Minnesota Agricultural Experiment Stations at Crookston and Morris. These observations contained records of daily maximum temperature, minimum temperature, and precipitation. Environmental data from sixteen different observers were used to describe the growing conditions for sunflowers in the 130 CPM fields. This represented a 13 county area located along the Minnesota border with North and South Dakota.

For the original 130 fields, a screening procedure eliminated 29 of them. These fields were deleted from the data set for various reasons

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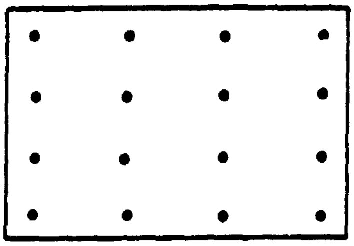
SAMPLE A

Agricultural Extension Service
University of Minnesota – U.S. Department of Agriculture
Institute of Agriculture, Forestry and Home Economics
St. Paul, Minnesota 55108

Field Survey Form – SUNFLOWERS



I. FIELD INFORMATION

Cooperator's name ____________________

Cooperator's field I.D. ____________________

Scout name & I.D. ____________ ____________

Date ____________________

II. CROP DESCRIPTION

	NW	SW	C	SE	NE
1. Plant height (average in inches)					
2. Plant population (1/100 A)					

3. Planting time ____________

4. Growth stage ____________

III. INSECT OBSERVATIONS (Total insects/20 plants at each location or % defoliation)

	NW	SW	C	SE	NE	Avg.	Total
1. Stem weevil							
2. Sunflower beetle (% defol.)							
3. Sunflower moth							
4. Painted lady (% defol.)							
5. Sunflower midge							
6. Seed weevil							
7. Banded sunflower moth							
8. Grasshopper							
9. Other ____________							

Comments ____

____

IV. SUNFLOWER DISEASES – Severity (0 - 9 scale) & % Incidence

	NW	SW	C	SE	NE	Distance Walked	No. of Diseased Plants	% Incidence
1. Downy mildew								
2. Sclerotinia								
3. Phoma								
4. Fusarium								
5. Rhizopus								
6. Verticillium								
7. Other ____________								

Comments ____

____

V. WEEDS

Common Name	Code	Stage	Severity

Comments ____

____

VI. CROP INJURY

☐ Yes ☐ No Location in Field: ☐ NW ☐ SW ☐ C ☐ SE ☐ NE

VII. COMMENTS

____

____

____

including irrigation, questionable yield estimates, incomplete weekly survey reports, disease or insect infestations not accounted for in the surveys, or lack of representative environmental data from a location in close proximity to the field site.

The data from the remaining 101 fields, along with computed environmental variables are shown in Appendix I. The data are separated by blank columns. There are a total of 16 records in each row of data. Table III shows the list of variables used in the original regression analysis on the CPM sunflower data base. All data were derived from the field survey reports and local weather observations. Growth stage data were collected using a modified Siddiqui type scoring system, where bud, anthesis (bloom), and seed development phases were denoted as stages 3.1, 4.1, and 5.1, respectively. Potential evapotranspiration (PET) estimates were calculated by the USDA-SCS Blaney-Criddle Method, which uses local daily temperature and daylength data along with empirically derived crop coefficients for sunflower growth stages. Field capacity coefficients (FCC) are based on soil texture data and represent relative water holding capacities of the soils. The insect codes pertain only to infestations of sunflower seed weevil and midge, which were found to be the primary causes of yield reductions in the 1980 and 1981 crop seasons. Insect counts and thresholds are based on number of larvae found on 20 plants in 5 different samples from each field (See Sample A).

The CPM data base provided the opportunity to study the variations in yields from individual fields which represented a range of soils and climate, but only spanned 2 crop seasons. In order to look at yield response from a different perspective, USDA-SRS county yield data from 4 Minnesota counties for the period 1971 to 1980 were used in a separate regression analysis. 1974 was excluded due to severe drought and crop failure. These data are from Marshall, Polk, Norman, and Traverse counties where the acreage planted to

Table III

Variables used in regression analysis on the CPM sunflower data base for 1980 and 1981.

YD = Yield in lbs/acre.

YR = Crop season.

FCC = Field capacity coefficient or relative water holding capacity of the soil.

PD = Planting date (julian day).

PP = Preseason precipitation (inches) from April 1 to May 31.

AD = Anthesis date (julian day).

FP = Precipitation (inches) from 10 days before to 10 days after flowering.

PET3 = Potential evapotranspiration (inches) from 5 days before to 5 days after the bud stage.

P3 = Precipitation (inches) from 5 days before to 5 days after the bud stage.

PET4 = Potential evapotranspiration (inches) from 5 days before to 5 days after anthesis.

P4 = Precipitation (inches) from 5 days before to 5 days after anthesis.

PET5 = Potential evapotranspiration (inches) from 5 days before to 5 days after seed development.

P5 = Precipitation (inches) from 5 days before to 5 days after seed development.

FPP = Final plant population (thousands/acre).

IC = Insect code for seed weevil and midge, indicates relative degree of infestation.

sunflowers is the highest in the state. Environmental data were collected from local National Weather Service cooperative observers and averaged for each county. These data appear in Appendix II, where they are defined. Since growth stage data were not available, with the exception of USDA-Crop Reporting Service estimates of planting dates, it was not possible to compute environmental variables similar to those used in the CPM data base. Several other detailed field data were not available, and therefore the predictor variable set was quite small. However, because of the longer time series of yields, both time trend and planting date effects could be studied. Table IV lists the variable names used in regression analysis of this data set. Note that the precipitation and temperature variables are oriented to an estimated date of anthesis, which was computed based on GDD of base 45°F (after Coultas). The temperature stress variable is used in this analysis as a substitute for the PET variable computed for the CPM data base. For the county data sets, it was not possible to accurately use the USDA Blaney-Criddle Method to estimate PET.

A discussion of the regression analyses on these two data sets follows.

Table IV

Variables used in regression analysis on the county sunflower yield data from 1971 to 1980, excluding 1974.

CAYD = County average yield in lbs/acre.

TTV = Time-trend variable, where.
1 = 1971 and 9 = 1980.

CAPD = County average planting date, when 50 percent of the acreage was planted (noted as julian day).

CAPF = Average county precipitation from 10 days before estimated date of flowering to 10 days after (inches).

CATSF = County average of number of days when the daily maximum temperature equaled or exceeded 90°F during the flowering period.

2.3 MODELS

Multiple regression analyses were done on both the CPM and county data sets. All variables and variable combinations were screened based on simple correlation coefficient, contribution to R^2, t-test, and F-test for each model. Only the best regression models are discussed in this section. Further analyses could be done by the reader using the data presented in Appendices I and II along with any of a number of available statistical analysis software packages.

Regression Analysis on the CPM Data Set

Tables V and VI summarize the statistics from the best fit model for yield using the CPM data base. The IC variable was by far the most significant predictor, accounting for 62 percent of the yield variation. Of the 101 cases, 36 showed some yield damage from seed weevil, midge or both. This represents 36 percent of the sunflower fields scouted and may or may not be indicative of the important role insects play in northern latitude sunflower production. Both 1980 and 1981 are described by entomologists as relatively high activity seasons for sunflower insects, and may not be most representative of average conditions based on more years of data. The PET5 variable was the second best predictor, indicating that the transpiration demand on the crop during the seed development stage, at least, partially determines yield. This would agree somewhat with findings reported in the literature. The only other variable significant at $P = .01$ level was PP, indicating the importance of early season stored soil moisture.

The other two variables, of lesser importance, were FP and FP^2 (FP squared), both significant at $P = .05$ level. This relationship agrees very well with

Table V

A summary of simple statistics from the best regression model for sunflower yield based on the CPM data base.

Variable (units)	Mean Value	Standard Deviation	Coefficient of Variation	Maximum Value	Minimum Value
YD (lbs/acre)	1434	311	.217	1800	600
PP (inches)	5.84	1.53	.262	8.98	3.89
FP (inches)	3.27	1.53	.468	7.19	1.47
PET5 (inches)	1.94	.20	.104	2.39	1.44
IC (coded)	0.42	.60	1.453	2.0	0
FP^2 (inches)	13.01	13.02	1.000	51.7	2.16

Table VI

A summary of regression statistics for the best sunflower yield model from the CPM data base.

Variable	Regression Coefficient	t-value	Contribution to R^2	Stepwise R^2
Intercept	1822.37	11.58	-	-
PP	20.07	2.78**	.07	.07
FP	80.39	2.00**	.07	.14
PET5	-232.71	-4.23**	.13	.27
IC	-440.62	-23.14**	.62	.89
FP^2	- 10.37	-2.19*	.01	.90

*Significant at P = .05 DF = 95

**Significant at P = .01

RMS = 105 lbs/acre RMS/standard deviation of YD = .34

that reported in the literature. A curvilinear relationship between moisture availability at flowering and seed yield worked slightly better than a simple linear one. It was, however, surprising that the relationship was not more significant. Certainly, the buffer from stress provided by stored soil moisture during the flowering period could have helped obscure the YD to FP relationship. A soil moisture budget modeling approach, utilizing the precipitation variables in conjunction with the FCC (field capacity coefficient) variable did not produce significant results, unfortunately.

The R^2 of the overall model was 0.90. If only environmental variables were used this value fell to 0.28. Thus for the years of 1980 and 1981, environmental variation over this geographic region apparently had little to do with sunflower yield variation. When insect effects were included, the root mean square was only 105. This represents a 66 percent improvement over the ability of the mean and standard deviation to characterize yields. Since yields ranged from 600 to 1800 lbs/acre, the overall regression model represents a reasonbaly good fit.

On a discouraging note, the importance of the IC variable signifies a critical need to monitor or model insect populations associated with sunflower production. In the case of the seed weevil and sunflower midge, field monitoring is tedious and difficult, while modeling their phenology and degree of infestation has not even been attempted to date. In remote sensing research, there is some hope that the damage caused by insects through defoliation or premature senescence (early death of leaf tissue) might be detectable by multipectral sensors. However, damage caused by seed weevils or midge occurs in the seed head and is not likely to be detectable by such sensors. In addition, bird damage occurs in a similar fashion and can be significant. Thus, it is important that some methods be developed to estimate the impacts of these biological variables in order to better model sunflower stress in certain environments.

Because of the limited number of years (2) used in the CPM data base, the nature and degree of impact from the environmental variables remains open to question. An analysis of yields from more diverse climates, either based on geographic distribution or long time series would be useful. The difficulty in this task is finding data of sufficient detail to compute meaningful predictor variables. Future research should include monitoring both growth stages and pests across a range of environments. Perhaps a cooperative effort between universities or counties interested in remote sensing applications to this crop would be more fruitful.

Regression Analysis on the County Data Set

Tables VII and VIII summarize the statistics from the best fit model for county sunflower yields. The most important predictor variable, and the only one significant at P = .01 was CAPF. This confirms once again the importance of available moisture during the critical flowering period. This variable alone accounted for nearly 28 percent of historical yield variation. Over the time period studied, the CAPF variable ranged from 3.32 inches to only 0.39 inches. In years with inadequate stored soil moisture, it would appear that a shortage of rainfall during the flowering period could significantly reduce yields. According to the regression coefficient, each inch of rainfall during this period accounted for a nearly 200 lbs/acre increase in seed yield.

The next important variable was TTV, as expected. Nearly all agronomic crops show a positive time trend due to improved genetics and cultural practices. The TTV variable accounted for 22 percent of the variation in yield, amounting to approximately a 29 lbs/acre increase each year. It is difficult

Table VII

A summary of simple statistics from the best regression model for sunflower yield based on the county data base.

Variable (units)	Mean Value	Standard Deviation	Coefficient of Variation	Maximum Value	Minimum Value
CAYD (lbs/acre)	1241	265	.214	1780	820
TTV (coded)	5.0	2.62	.524	9	1
CAPD (julian day)	142	7.41	.052	152	131
CAPF (inches)	1.73	.67	.388	3.32	0.39
CATSF (days)	4.83	3.32	.686	16	0

Table VIII

A summary of regression statistics for the best sunflower yield model from the county data base.

Variable	Regression Coefficient	t-value	Contribution to R^2	Stepwise R^2
Intercept	2223.85	2.96	-	-
TTV	29.45	2.44*	.22	.22
CAPD	-9.57	2.04*	.065	.285
CAPF	192.23	4.14**	.275	.56
CATSF	-21.86	2.14*	.06	.62

* Significant at P = .05 DF = 31

** Significant at P = .01

RMS = 173 RMS/standard deviation of CAYD = .65

to know how significant a time trend variable would be for other major sunflower producing areas. Based on this and other analyses, significant positive time trends in sunflower production have likely occurred in most major production areas.

The CAPD and CATSF variables were approximately equal as predictors of sunflower yield. Both were significant at $P = .05$. The planting date effects show an advantage to early planting, a concept discussed by other researchers in the literature. There was a 20 day range in county average planting dates for the 1971 to 1980 period. This compares with a 38 day range in planting dates from the CPM data base, where it was not a significant variable in the regression analysis. This fact may be due to the importance of the insect variable in the CPM analysis, which may have obscured any planting date effects.

The CATSF was really somewhat of a pseudo-PET variable in the county analysis. The number of days during flowering when the daily temperature was $90^{\circ}F$ or higher may be indicative of high potential evapotranspiration (PET). Little is mentioned in the sunflower research literature about high temperature stress. The CATSF variable indicated moderate reductions in seed yield with high temperatures during flowering. High temperatures were relatively absent in the CPM data set and were not used as a predictor.

The R^2 for the county yield model was only 0.62, with an RMS of 173. This represents only a 35 percent improvement over the mean and standard deviation in characterizing the sunflower yields of these counties. The relatively poor fit of this model may be due to the lack of more accurate growth stage estimates and to the absence of variables to account for pest damage. As sunflower culture has become more established in the Minnesota-North Dakota region, pests, likewise, have become more prevalent and had a greater impact on yields.

The GDD system, base 45 degree F, may be a suitable method to estimate the phenology of sunflowers. GDD estimates checked reasonably well with CPM surveys in cases where the hybrid maturity rating was known. Evaluating the GDD estimates of growth stage for the county data set was difficult due to the inadequacy of the USDA field surveys in the counties and to the range of maturity types represented in such data. As mentioned previously, the range of maturity in sunflower hybrids is rather narrow compared to field corn. However plant breeders have been working with this crop for a relatively short period of time. Therefore, the range in maturity types may increase in the future as breeders make greater use of the genetic diversity in this crop. In this context, it is important to relate GDD estimates of phenology to specific sunflower maturity types.

SUMMARY AND RECOMMENDATIONS

These initial, albeit relatively simple analyses of both detailed field data and historical county data have provided some important evidence and guidelines for future modeling research on sunflowers. Some of the more important characteristics of sunflower production related to modeling stress include the following:

1. There are significant time trends in sunflower yields since 1971.
2. Similar to other agronomic crops, sunflowers appear to be most sensitive to temperature and moisture stress during the critical flowering (anthesis) and seed development stages.
3. Using time trend, planting date, and environmental variables oriented to the flowering stage as predictors of yields, an R^2 of only 0.62 was obtained for Minnesota county data.
4. Using detailed field survey data, including growth stage and insect records,

along with phenology-oriented environmental variables, an R^2 of .90 was obtained on the CPM data base, where yields ranged from 600 to 1800 lbs/acre.

5. As sunflower culture becomes more established, pest variables, especially insects, will likely become important predictors of yield. For the CPM study, the sunflower seed weevil and midge were very important variables.

The morphological characteristics and nature of flowering in the sunflower crop would appear to invite remote sensing studies to determine the detectability of both growth stages and crop stress using multispectral scanners. Such a study was initiated in Minnesota during the 1982 crop season. Remote sensing may have the potential to provide stress-related information where environmental or biological variables affect the morphology, ontogeny, or color (necrosis or chlorosis) of the crop, as with drought, nutrient deficiencies or disease. However, some pests, such as the seed weevil and midge, may produce yield reducing effects not manifested by changes which are detectable by remote sensing techniques. For this reason, sunflower stress models should consider the use of meteorologically driven submodels for pest infestations.

FIGURES

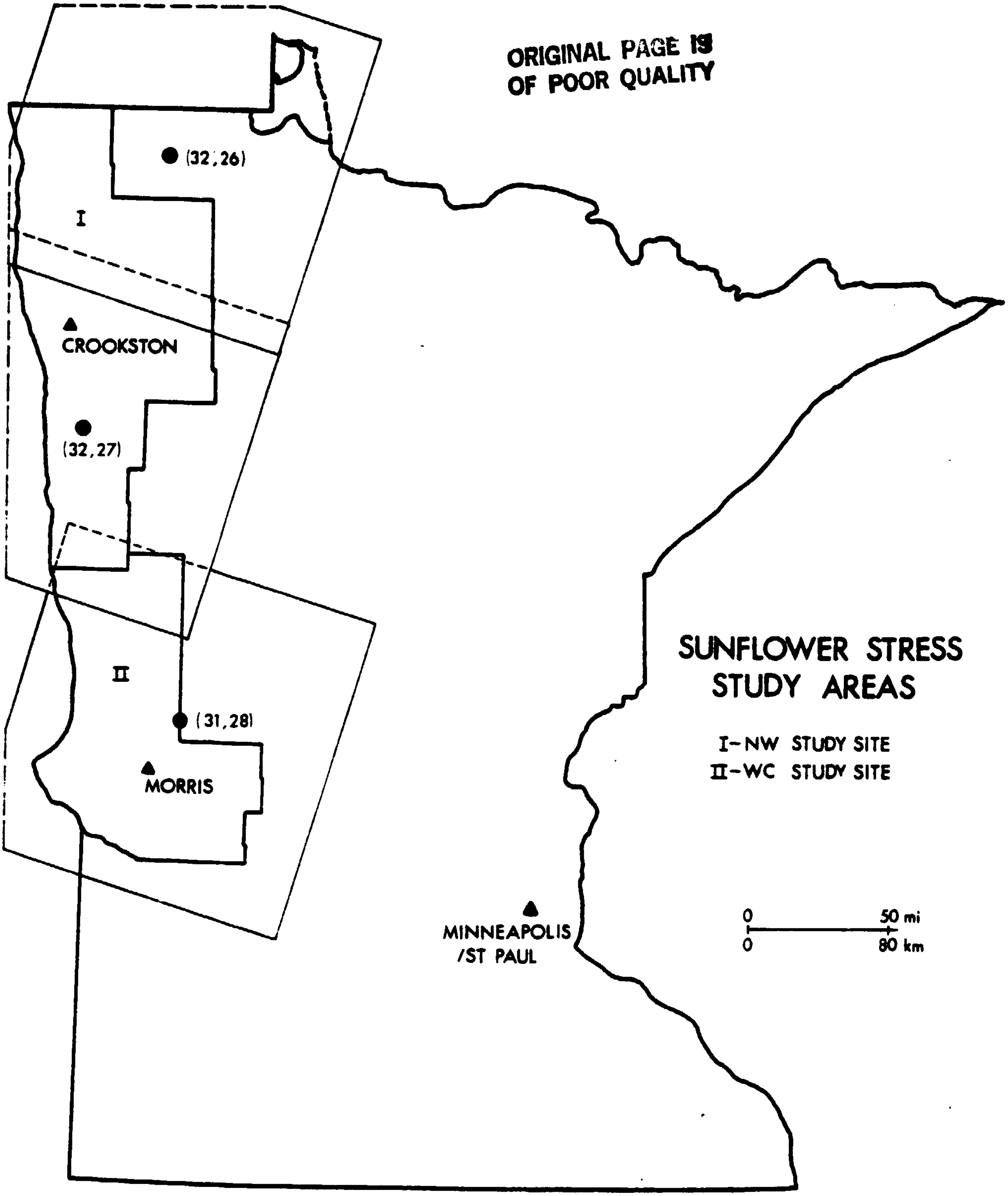


Figure 1. CPM Districts and Landsat Scenes Used in Study.

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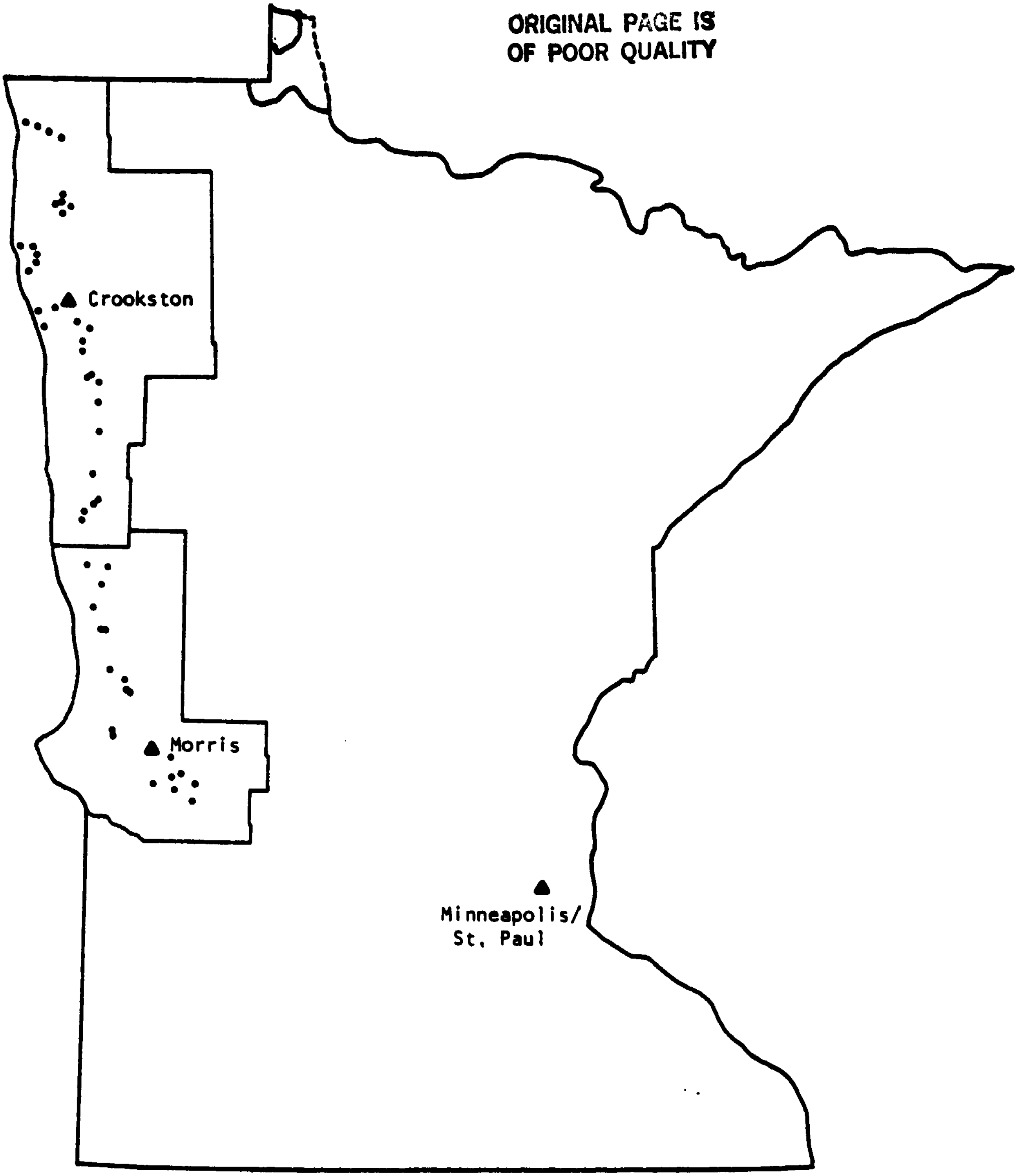
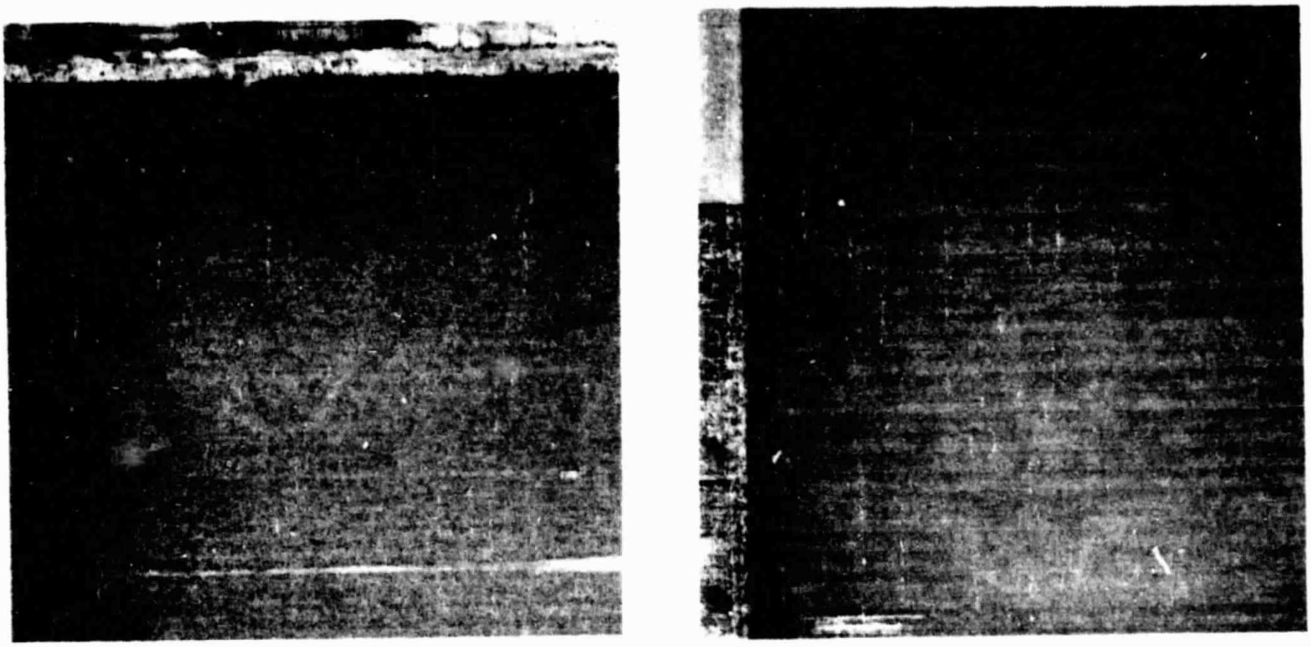
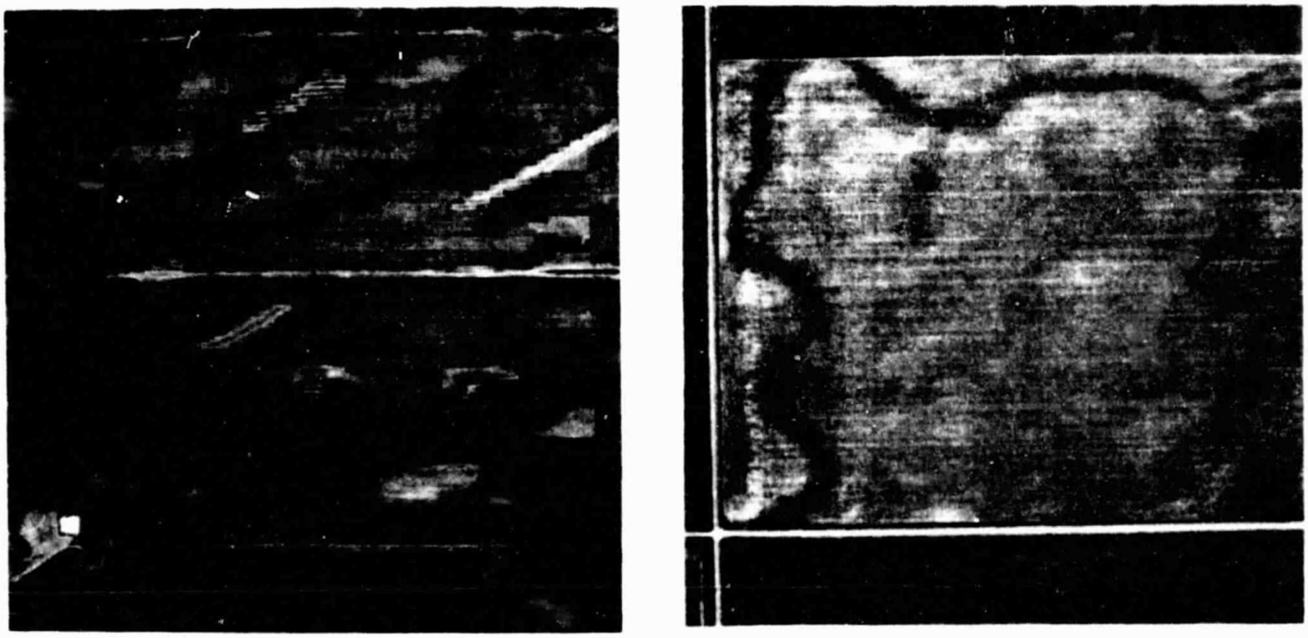


Figure 2. Geographical Distribution of Complementary Aerial Photography Acquired to Assist in Landsat Analysis.



a) Normal Field

b) Two Seed Varieties in Same Field

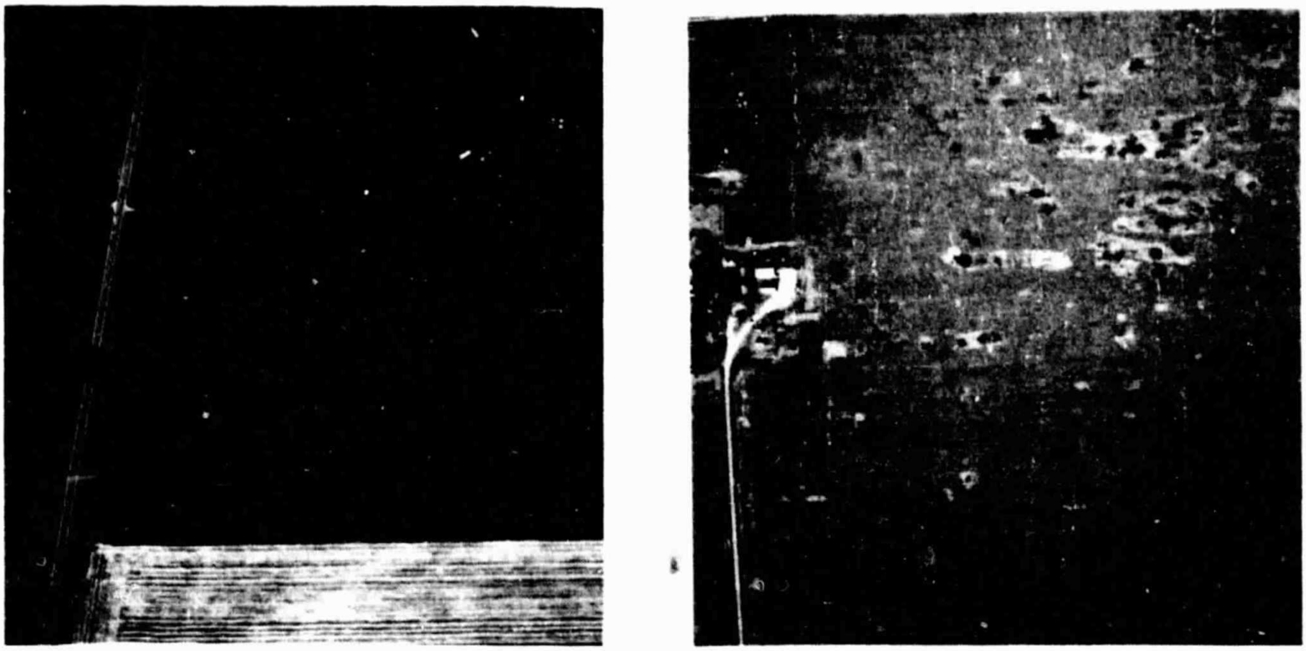


c) Drainage Problem

d) Soil Moisture Variability

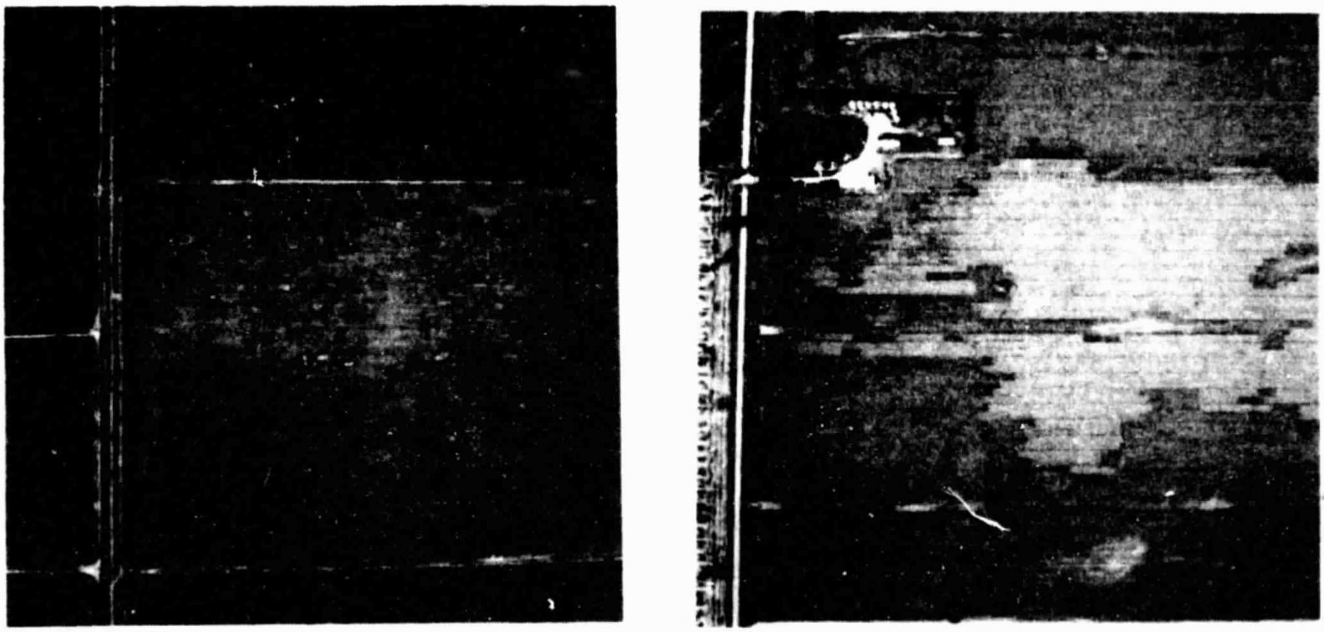
Figure 3. Sample Aerial Photographs Depicting "Normal" and Anomalous Field Conditions.

* Original photographs are contained in the Final Report sent to Agricultural Applications Branch-SH3, NASA LBJ Space Center.



a) Normal Field

b) Weed Problem



c) Moisture/Cultivator Damage

d) Replant Condition

Figure 4. Sample Aerial Photographs Depicting Normal and Anamolous Field Conditions.

* Original photographs are contained in the Final Report sent to Agricultural Applications Branch-SH3, NASA LBJ Space Center.

Figure 5.

GROWTH STAGES OF SUNFLOWERS

Adapted from M O Siddiqui, J F Brown, and S J Allen "Plant Disease Reporter" vol 59, pgs 7-11 (1975)

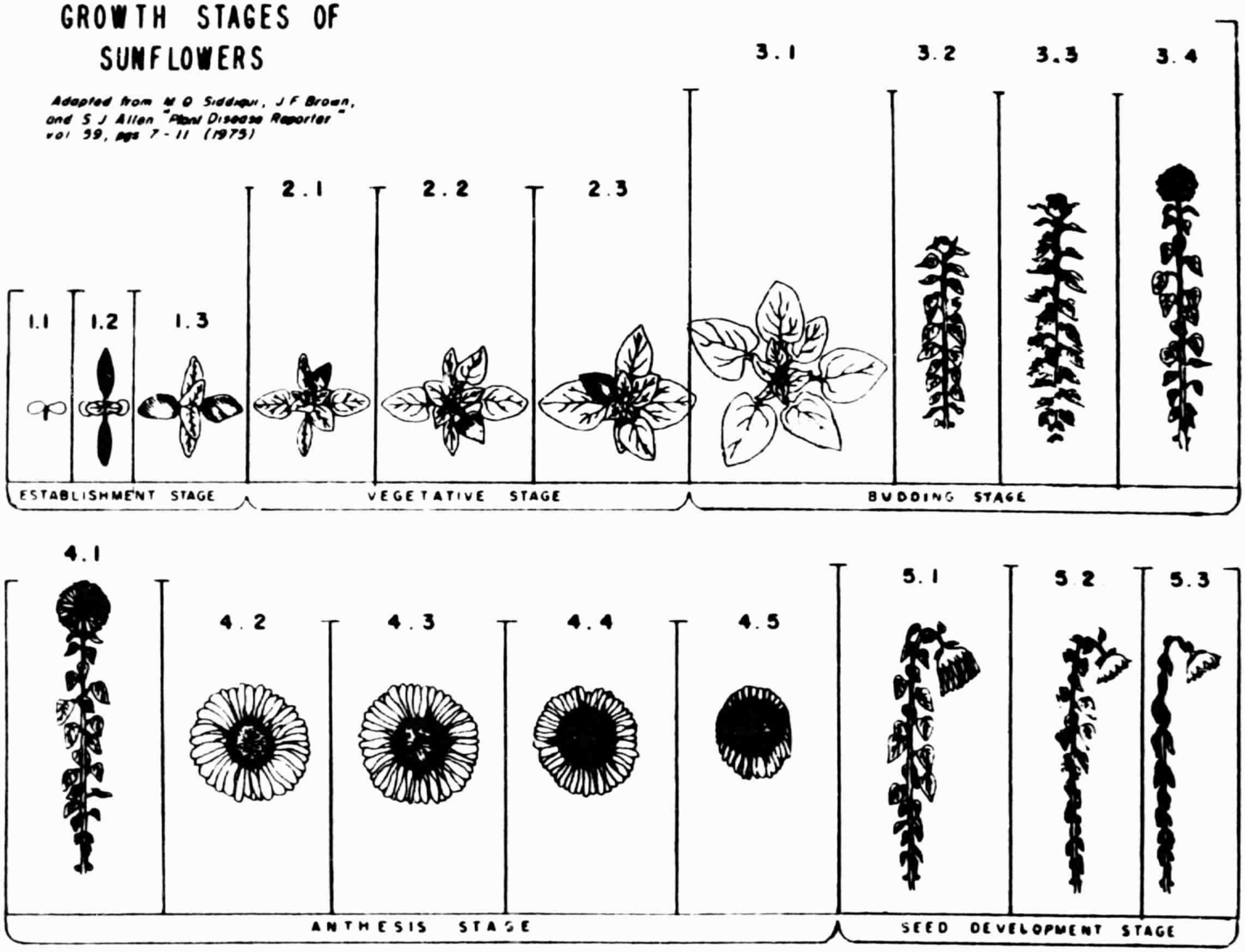
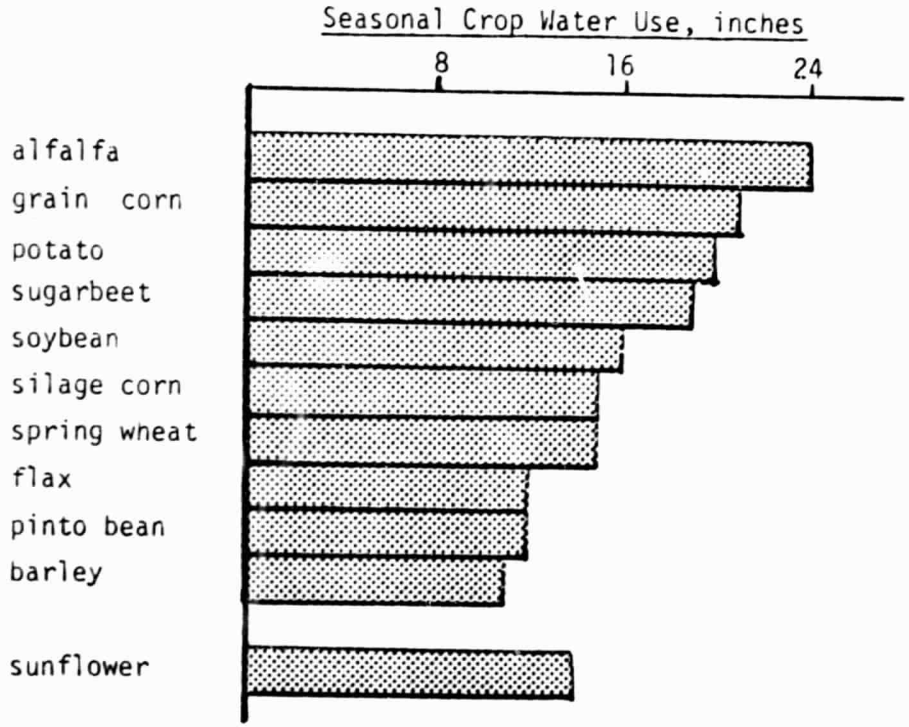


FIGURE 6



Crop water use of some crops commonly grown in the Northern Great Plains.

APPENDICES

APPENDIX I

THE DATA SET LISTED BELOW WAS DERIVED FROM THE UNIVERSITY OF MINNESOTA CROP PEST MANAGEMENT FIELD SURVEYS FOR 1980 AND 1981, ALONG WITH DAILY WEATHER RECORDS KEPT BY NATIONAL WEATHER SERVICE COOPERATIVE OBSERVERS. THERE ARE A TOTAL OF 101 ROWS OF DATA, EACH WITH 16 DATA FIELDS, SEPARATED BY BLANK COLUMNS. THE DATA FIELDS ARE DEFINED AS FOLLOWS:

DATA FIELD 1 = FIELD IDENTIFIER (MISC. CODE)
DATA FIELD 2 = SAMPLE YIELD (LBS/ACRE)
DATA FIELD 3 = YEAR COLLECTED
DATA FIELD 4 = FIELD CAPACITY COEFFICIENT (SOIL TEXTURE)
DATA FIELD 5 = PLANTING DATE (JULIAN DAY)
DATA FIELD 6 = PRESEASON PRECIPITATION (INCHES)
DATA FIELD 7 = DATE OF ANTHESIS (JULIAN DAY)
DATA FIELD 8 = RAINFALL 10 DAYS BEFORE TO 10 DAYS AFTER DATE OF ANTHESIS (STAGE 4.1) IN INCHES
DATA FIELD 9 = PET ESTIMATE FOR 5 DAYS BEFORE TO 5 DAYS AFTER BUD STAGE (STAGE 3.1) IN INCHES
DATA FIELD 10 = RAINFALL FOR 5 DAYS BEFORE TO 5 DAYS AFTER BUD STAGE (STAGE 3.1) IN INCHES
DATA FIELD 11 = PET ESTIMATE FOR 5 DAYS BEFORE TO 5 DAYS AFTER ANTHESIS (STAGE 4.1) IN INCHES
DATA FIELD 12 = RAINFALL FOR 5 DAYS BEFORE TO 5 DAYS AFTER ANTHESIS (STAGE 4.1) IN INCHES
DATA FIELD 13 = PET ESTIMATE FOR 5 DAYS BEFORE TO 5 DAYS AFTER SEED DEVELOPMENT (STAGE 5.1) IN INCHES
DATA FIELD 14 = RAINFALL FOR 5 DAYS BEFORE TO 5 DAYS AFTER SEED DEVELOPMENT (STAGE 5.1) IN INCHES
DATA FIELD 15 = FINAL PLANT POPULATION (IN THOUSANDS)
DATA FIELD 16 = INSECT CODE FOR SEED WEEVIL AND MIDGE
0 = NO SIGNIFICANT DAMAGE
1 = COUNTS APPROACHING ECONOMIC THRESHOLD
2 = COUNTS EXCEEDING ECONOMIC THRESHOLD

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NASA1 101 15 FORMAT
(6X,G4.0,G3.0,G5.2,G4.0,G5.2,G4.0,7G5.2,G3.0,G2.0)
10501 1800 80 0.80 154 5.42 218 5.53 2.74 0.34 2.18 2.42 1.77 0.20 14 0
12001 1700 80 0.80 129 7.06 207 2.55 2.23 0.77 2.27 0.37 1.80 1.61 15 0
13501 1650 80 0.80 129 5.42 210 4.39 2.13 0.19 2.30 1.16 1.90 0.28 18 0
14001 1200 80 0.60 136 4.58 206 3.84 2.22 0.30 2.27 0.65 1.79 0.98 17 1
14002 1200 80 0.60 136 4.58 206 3.84 2.22 0.30 2.27 0.65 1.95 1.35 17 1
13003 1300 80 0.60 134 4.58 204 3.94 2.22 0.30 2.26 1.49 1.99 0.82 21 1
15001 0750 80 0.75 125 8.98 200 2.55 2.37 1.03 2.62 1.34 2.39 0.23 19 2
16001 1450 80 0.60 148 4.73 216 2.47 2.61 1.70 2.62 0.26 2.15 0.39 18 0
17001 1800 80 0.60 128 8.98 206 2.18 2.60 0.79 2.27 0.06 1.80 0.99 15 0
18001 1750 80 0.75 135 8.98 206 2.18 2.60 0.79 2.27 0.06 1.80 0.99 18 0
18002 1600 80 0.75 135 8.98 209 1.82 2.60 0.79 2.39 0.23 1.95 1.24 20 0
19002 1700 80 0.75 135 4.58 209 2.57 2.29 0.09 2.37 0.65 2.01 2.50 18 0
21001 1650 80 0.80 133 4.10 202 2.20 2.21 0.53 2.30 0.35 1.89 1.32 14 0
25001 1650 80 0.75 135 7.06 209 2.53 2.60 0.19 2.39 0.66 1.89 0.96 17 0
28001 1200 80 0.65 136 5.76 208 2.68 2.83 0.55 2.59 0.33 2.15 1.17 14 1
30001 1200 80 0.75 160 4.58 204 3.94 2.28 0.30 2.26 0.63 1.92 1.35 17 1
31001 1200 80 0.75 159 4.58 202 3.27 2.18 0.30 2.30 0.96 1.95 1.35 15 1
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ORIGINAL PAGE IS
OF POOR QUALITY

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32001 1800 80 0.80 135 7.06 210 2.47 2.60 0.19 2.34 0.67 1.89 0.96 18 0
32501 1750 80 0.60 140 5.42 209 4.39 2.20 0.19 2.35 1.16 1.90 1.59 19 0
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38002 1700 80 0.75 142 5.42 211 4.39 2.69 0.43 2.32 1.20 1.52 0.27 16 0
39001 1750 80 0.80 127 4.73 203 2.19 2.51 0.51 2.47 0.91 1.84 2.11 15 0
40001 1800 80 0.60 125 8.98 203 2.17 2.26 0.73 2.26 0.74 1.82 1.24 17 0
40002 1800 80 0.60 123 7.15 201 1.64 2.08 2.02 2.33 1.01 1.73 2.42 20 0
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46001 1300 80 0.80 128 4.13 204 3.66 2.71 1.82 2.26 1.02 1.99 2.86 22 1
47001 1100 80 0.75 128 4.10 206 2.62 2.17 0.35 2.27 0.67 2.05 0.92 10 1
48002 1400 80 0.75 137 4.73 205 2.14 2.89 0.77 2.46 0.83 2.32 0.70 14 0
48003 1500 80 0.75 129 4.73 203 2.19 2.51 0.51 2.47 0.91 2.32 0.92 14 0
51001 0600 80 0.75 140 4.13 209 5.63 2.61 0.29 2.35 0.89 1.85 1.70 14 2
51002 0620 80 0.75 142 4.13 214 6.06 2.61 0.29 2.28 2.87 1.85 1.70 14 2
52001 0700 80 0.75 118 4.10 199 2.44 2.21 0.53 2.48 0.68 2.02 0.92 16 2
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56001 1500 80 0.75 134 4.13 207 5.62 2.28 0.25 2.29 0.84 2.11 0.99 18 0
58001 1700 80 0.60 126 4.73 208 2.40 2.19 0.40 2.32 0.16 1.88 1.87 15 0
59001 1500 80 0.60 131 4.58 204 3.94 2.28 0.30 2.26 0.63 1.95 1.35 20 0
59501 1500 80 0.60 121 8.98 202 2.17 2.40 0.80 2.41 0.70 1.89 1.19 17 0
60001 1600 80 0.60 135 4.00 204 4.11 2.24 0.37 2.29 0.67 1.97 3.64 20 0
60501 1650 80 0.60 137 4.58 204 3.94 2.24 0.39 2.29 1.49 2.01 0.82 18 0
62001 1550 80 0.75 135 4.10 202 2.20 2.17 0.35 2.30 0.35 2.05 0.92 18 0
63001 1600 80 0.75 127 4.73 204 2.11 2.94 0.77 2.49 0.91 2.15 1.87 18 0
63002 1300 80 0.75 122 4.73 201 1.88 2.51 0.51 2.59 0.91 1.84 2.11 12 1
66001 1400 80 0.80 128 5.76 201 2.05 2.41 0.73 2.59 0.02 2.39 0.51 18 0
67002 1650 80 0.60 140 5.76 217 2.69 3.01 1.61 2.62 0.51 2.16 1.12 15 0
67003 1700 80 0.60 132 4.73 211 3.03 2.89 0.77 2.62 0.16 2.15 2.09 20 0
68001 1725 80 0.65 139 4.73 218 2.46 2.36 0.91 2.60 0.70 1.77 0.09 16 0
69001 1550 80 0.60 133 5.76 202 2.05 2.59 0.43 2.48 0.02 2.15 1.17 14 0
70001 1700 80 0.80 134 4.73 206 2.40 2.22 0.40 2.27 0.30 1.80 1.87 21 0
71001 1725 80 0.80 164 7.06 213 2.46 2.60 0.19 2.30 0.65 1.89 0.96 15 0
72001 1650 80 0.60 140 4.69 204 4.67 2.28 0.21 2.26 1.10 1.85 0.59 13 0
74001 1000 80 0.75 126 4.10 200 2.42 2.20 0.11 2.44 0.23 2.02 0.92 17 1
74002 1000 80 0.75 136 5.76 208 2.66 2.83 0.35 2.59 0.33 2.10 0.26 22 1
74003 0950 80 0.75 127 5.76 200 2.43 2.43 0.63 2.62 1.29 2.39 0.51 15 1
74004 1050 80 0.75 133 5.76 203 2.01 2.71 0.55 2.47 0.30 2.39 0.60 19 1
74005 1100 80 0.75 129 6.50 201 2.45 2.37 0.73 2.59 0.45 2.39 0.45 23 1
77001 1475 80 0.75 133 4.73 210 2.33 2.89 0.77 2.64 0.16 2.32 0.68 13 0
77002 1050 80 0.80 133 5.76 207 2.08 2.89 0.75 2.54 0.08 2.37 0.84 12 1
78001 1100 80 0.75 133 4.10 204 2.55 2.21 0.53 2.26 0.50 2.05 0.92 17 1
79001 1550 80 0.60 127 4.00 197 2.39 2.21 0.50 2.64 1.43 2.33 0.93 20 0
80001 1700 80 0.75 139 4.10 207 2.35 2.17 0.35 2.29 0.67 1.89 1.41 19 0
80002 1700 80 0.75 140 4.10 207 2.35 2.17 0.35 2.29 0.67 1.89 1.41 18 0
10B01 1550 81 0.75 134 7.40 216 1.57 2.51 2.83 2.54 1.30 1.80 0.53 21 0
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11B03 1650 81 0.75 134 7.40 223 2.17 2.51 2.83 2.22 0.27 1.73 1.22 28 0
12B03 1600 81 0.75 149 7.88 217 1.47 2.52 2.03 2.40 0.71 1.78 2.62 23 0
13B01 0900 81 0.75 138 7.15 215 5.18 2.48 1.94 2.46 3.16 1.83 3.95 14 2
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15B01 1600 81 0.60 140 6.03 210 4.48 2.97 0.85 2.44 2.28 2.10 1.50 20 0
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20B02 1200 81 0.60 125 7.15 201 6.98 2.71 0.21 2.38 2.73 1.99 0.15 21 1
20B03 1100 81 0.60 125 7.15 201 6.98 2.29 0.50 2.38 2.73 1.99 0.15 20 1
23B01 1400 81 0.60 132 4.25 204 5.32 2.51 0.68 2.15 1.37 1.79 0.24 20 0
24B02 1500 81 0.60 138 5.94 210 1.56 2.51 3.26 2.24 0.29 1.75 0.91 20 0
26B01 1050 81 0.60 135 4.25 211 2.89 2.77 0.79 2.24 0.41 1.74 0.64 17 1
28B02 1475 81 0.60 140 7.15 215 5.18 2.70 0.21 2.10 3.46 1.82 3.95 20 0
29B01 1650 81 0.80 135 7.40 216 2.40 2.51 2.83 2.54 1.30 1.73 1.22 16 0
35B01 1000 81 0.75 136 4.78 210 1.83 2.97 1.28 2.44 0.56 2.10 0.91 14 1
36B01 1700 81 0.75 125 7.40 209 2.89 2.43 0.52 2.22 0.68 1.75 0.69 16 0
36B02 1700 81 0.75 125 7.40 209 2.89 2.43 0.52 2.22 0.68 1.75 0.69 16 0
36B03 1700 81 0.75 125 7.40 209 2.89 2.43 0.52 2.22 0.68 1.75 0.69 16 0
36B04 1500 81 0.75 125 7.40 203 4.91 2.43 0.02 2.26 0.93 1.91 0.15 19 0
36B05 1500 81 0.75 125 7.40 203 4.91 1.74 0.09 2.26 0.93 1.91 0.15 21 0
45B05 1600 81 0.75 163 7.40 217 2.40 2.44 2.62 2.45 1.30 1.44 0.52 23 0
48B01 1400 81 0.75 146 3.89 215 1.68 2.52 0.98 2.51 1.20 1.91 1.27 16 0
52B01 1150 81 0.60 139 7.15 222 7.11 2.48 1.94 2.21 1.85 1.82 3.95 20 1
58B01 0900 81 0.75 134 4.78 210 1.83 2.97 1.28 2.44 0.56 2.10 0.91 16 1
60B01 1500 81 0.60 132 6.40 207 3.42 2.48 1.36 2.26 1.16 1.94 0.10 14 0
63B01 1500 81 0.65 139 5.11 220 3.77 2.19 2.05 2.20 0.53 1.82 1.02 17 0
68B01 1100 81 0.75 133 5.11 209 6.32 2.75 0.73 2.17 2.67 1.82 1.02 20 1
69B01 1100 81 0.65 130 5.55 204 7.19 2.77 1.88 2.15 1.05 1.79 1.03 15 1
69B03 1300 81 0.65 130 5.55 204 7.19 2.30 0.36 2.15 1.05 1.86 0.22 16 1
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APPENDIX II

THE YIELD DATA SET LISTED BELOW WAS DERIVED FROM USDA - SRS YIELD DATA FOR MARSHALL, POLK, NORMAN, AND TRAVERSE COUNTIES OF MINNESOTA, COVERING THE PERIOD FROM 1971 THROUGH 1980. THE YEAR 1974 WAS ELIMINATED DUE TO SEVERE DROUGHT AND INACCURATE YIELD ESTIMATES FROM ABANDONED OR UNHARVESTED ACREAGE. THE PREDICTOR VARIABLES WERE DERIVED FROM USDA - CROP REPORTING SERVICE SURVEYS AND FROM LOCAL NATIONAL WEATHER SERVICE COOPERATIVE OBSERVER RECORDS OF DAILY TEMPERATURE AND PRECIPITATION. THERE ARE A TOTAL OF 36 ROWS OF DATA, EACH WITH 6 DATA FIELDS, SEPARATED BY BLANK COLUMNS. THE DATA FIELDS ARE DEFINED AS FOLLOWS:

DATA FIELD 1 = COUNTY CODE, WHERE 1=MARSHALL, 2=POLK, 3=NORMAN, AND 4=TRAVERSE
DATA FIELD 2 = YIELD IN LBS/ACRE (COUNTY AVERAGE)
DATA FIELD 3 = TIME TREND, WHERE 1=1971 AND 9=1980
DATA FIELD 4 = PLANTING DATE WHEN 50 PERCENT OF THE SUNFLOWER ACREAGE WAS SOWN ACCORDING TO USDA SURVEYS (JULIAN DAY)
DATA FIELD 5 = PRECIPITATION FROM 10 DAYS BEFORE TO 10 DAYS AFTER THE ESTIMATED DATE OF ANTHESIS (USING A GDD METHOD) IN INCHES
DATA FIELD 6 = NUMBER OF DAYS WHEN THE DAILY MAXIMUM TEMPERATURES EXCEEDED 90 DEGREES F DURING THE PERIOD FROM 10 DAYS BEFORE TO 10 DAYS AFTER THE ESTIMATED DATE OF ANTHESIS

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COUNTY 36 6 FORMAT

1 1090 1 140 1.49  2
1  980 2 148 1.63  7
1  950 3 148 1.76  4
1  820 4 152 0.39  3
1 1580 5 137 3.20  5
1 1486 6 133 1.77  3
1 1516 7 140 3.32  1
1 1339 8 152 1.03  0
1  914 9 131 1.59  7
2 1200 1 140 1.87  2
2 1000 2 148 1.85  6
2  950 3 148 1.90  6
2 1193 4 152 1.40  2
2 1310 5 137 1.66  5
2 1522 6 133 1.90  5
2 1658 7 140 2.86  3
2 1389 8 152 2.66  0
2 1155 9 131 1.60  7
3 1020 1 140 1.21  2
3  880 2 148 1.70  3
3 1000 3 148 1.38  6
3  890 4 152 0.55  5
3 1780 5 137 2.29  8
3 1540 6 133 1.70  4
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3 1696 7 140 2.32  3
3 1439 8 152 1.22  0
3 1268 9 131 1.13  7
4 1280 1 135 1.60  3
4  950 2 145 0.87  9
4 1200 3 145 2.63  6
4 1223 4 146 1.53  9
4  940 5 131 1.01 16
4 1581 6 131 2.75 10
4 1297 7 143 1.30  6
4 1330 8 149 1.64  1
4 1325 9 137 1.71  3
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