Global Crop Condition Assessment

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A glossary of acronyms is provided at the end of this article.

Accepted for publication 24 May 1983.

Operational satellite remote sensing programs covering foreign areas are administered by the Foreign Agricultural Service (FAS) and carried out by the Foreign Crop Condition Assessment Division (FCCAD, hereafter called the Division) located near the Johnson Space Center in Houston, Texas.

This paper will address meteorologically driven models used by the Division to estimate yield reduction and condition assessment. The models were developed by the Division and the research community. The major model contributor from the research community has been the Early Warning/Crop Condition Assessment Project (EW/CCA) of the Agriculture and Resource Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS). This is a joint program of the U.S. Department of Agriculture, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, the U.S. Department of Interior, and the Agency for International Development. This program was initiated in Fiscal Year 1978 and was originally composed of eight projects: Foreign Commodity Production Forecasting, Domestic Crops and Land Cover, Early Warning of Conditions Affecting Crops, Renewable Resources Inventory, Conservation and Pollution, Yield Model Development, Soil Moisture Studies, and Supporting Research. The AgRISTARS is currently being reorganized into three projects which have been directed to be more responsive to user requirements. These three projects are: Foreign Crop Assessment Research, Domestic Crop Assessment Research, and Land Resources Monitoring Research.

The Division was established officially in January 1978 to support the FAS with foreign crop production estimates. Since then the Division has provided routine and ad hoc reports on such diverse commodities and agriculturally related subjects as food and coarse grains, oil seeds and other industrial crops, winterkill, deforestation, monitoring water impoundments, plant disease, and moisture stress in plants. These analyses presently emphasize the USSR, Eastern Europe, Brazil, Argentina, Mexico, China, and India. The Division utilizes three major data sets—remotely sensed satellite data (both LANDSAT and NOAA satellite series), meteorological data, and ancillary data such as soils and historical agricultural statistical data (area, yield, and production).

One of the Division's four computers is dedicated to storage and retrieval of all ancillary data (soils, meteorological, historical statistical data, model results, etc.). The parameters used as input to the model as well as the output of the model are stored in the Crop Assessment Data Retrieval and Evaluation (CADRE) data base (Fig. 1). The Division has adopted the U.S. Air Force I,J geographic grid network (25 × 25 nautical mile grid cell) to construct its global data base. The grid is a rectangular mesh on a polar stereographic plane and is projected onto the earth's surface from the opposite pole. All data are entered at the cell or subcell level. For example, soil data are encoded at the quadrant level and meteorological data from the World Meteorological Organization (WMO) are entered at the cell associated with the geographic location of the station. Whereas the gridded meteorological data are entered for a selected sample of cells, historical agricultural statistical data are entered only in cells that have traditionally been cropped. Vegetative greenness and/or biomass values are calculated for each cell (between 60 degrees north and south) from satellite imagery data and stored, as are other model output or results, at the cell level.

Personnel of the Division's Commodity Analysis Branch have multidisciplinary backgrounds consisting of formal education in economics, soil science, and geography. They all were brought up on farms or, at least, in a rural setting. Once selected, the analyst enters an intensive study of remote sensing and of his assigned country (or countries) with periodic familiarization trips to the assigned areas. He also becomes an expert in remote sensing and all aspects of agriculture of the country (or countries), including cultural practices, cropping areas, agricultural trends, government agricultural policy, transportation networks, export/import facilities and capabilities, and the interrelationships of the agricultural economy with the overall economy.

I have selected wheat as the crop to emphasize in this paper, because all available parameters and models available to the Division (except stress models for corn and sorghum) are directly applicable to wheat. These models will be discussed in the chronological order of their use by the Division for crop analysis as the crop season progresses.

The Division analysts use the Robertson Phenological Growth Stage Model (8) for wheat as modified by the Large Area Crop Inventory Experiment (LACIE) (2) and further refined by AgRISTARS (10). Since the degree of yield reduction caused by any event is highly correlated to the growth stage, this model is an essential tool for the analysis of satellite data and crop condition. Furthermore, the modified Growth Stage Model is an essential feature of other models such as the stress models. The Growth Stage Model as well as others used by the Division is run on a daily basis and summarized periodically for historical basis.

The two-layer soil moisture model used by Division analysts is similar to the Palmer Two-layer Model (5). In their model of sorghum stress (9), T. W. Taylor of the EW/CCA and F. W. Ravet of NASA (subsequently employed by the Division in the FAS) questioned certain assumptions used in the Palmer model. Their investigation led to changes in the basic model (9), the principal change being the way moisture could be removed from the lower level.

In both the Palmer Two-layer Model and in the modified model, the amount of water withdrawn by both direct evaporation from the soil surface and transpiration by plants is determined by atmospheric demand and soil water availability. Both models also assume that the first 2.54 cm (1 inch) of available water is held in the top layer. The actual thickness of each layer is variable depending on soil type, rooting depth, and layers permeability.

The original Palmer model assumed that moisture was removed from the surface layer at a rate equal to potential evapotranspiration calculated by the Thornthwaite method (11) and that moisture was removed from the lower layer at a fraction of the potential rate. It was assumed that moisture could not be removed from the lower layer until the surface layer was completely dry. These assumptions do not adequately represent the true condition.

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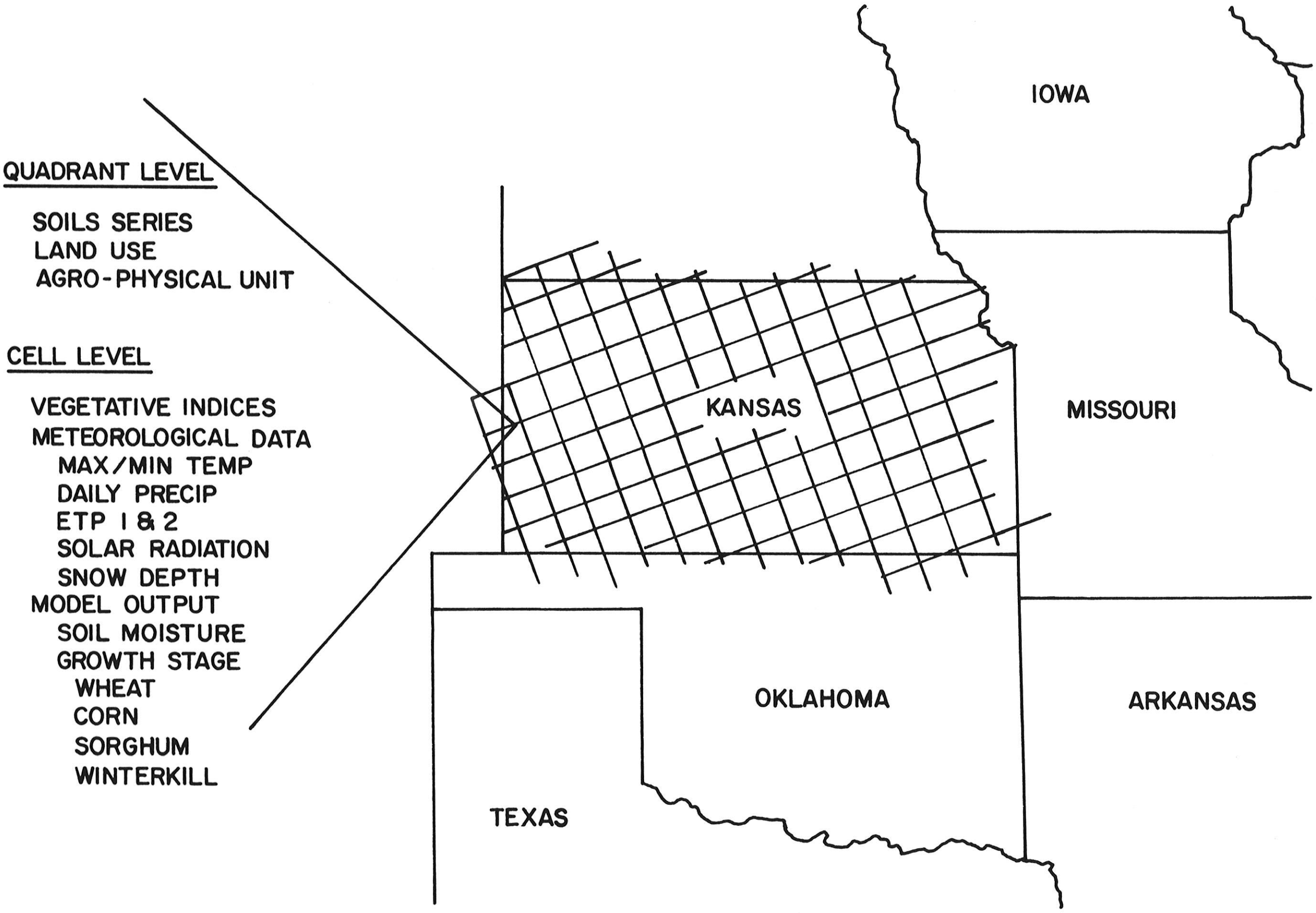

Fig. 1. Ancillary data and graphical example of the geographic grid (25 × 25 nautical mile grid cell) network used for the on-line storage, retrieval, and evaluation of crop assessment data by the Foreign Crop Condition Assessment Division.

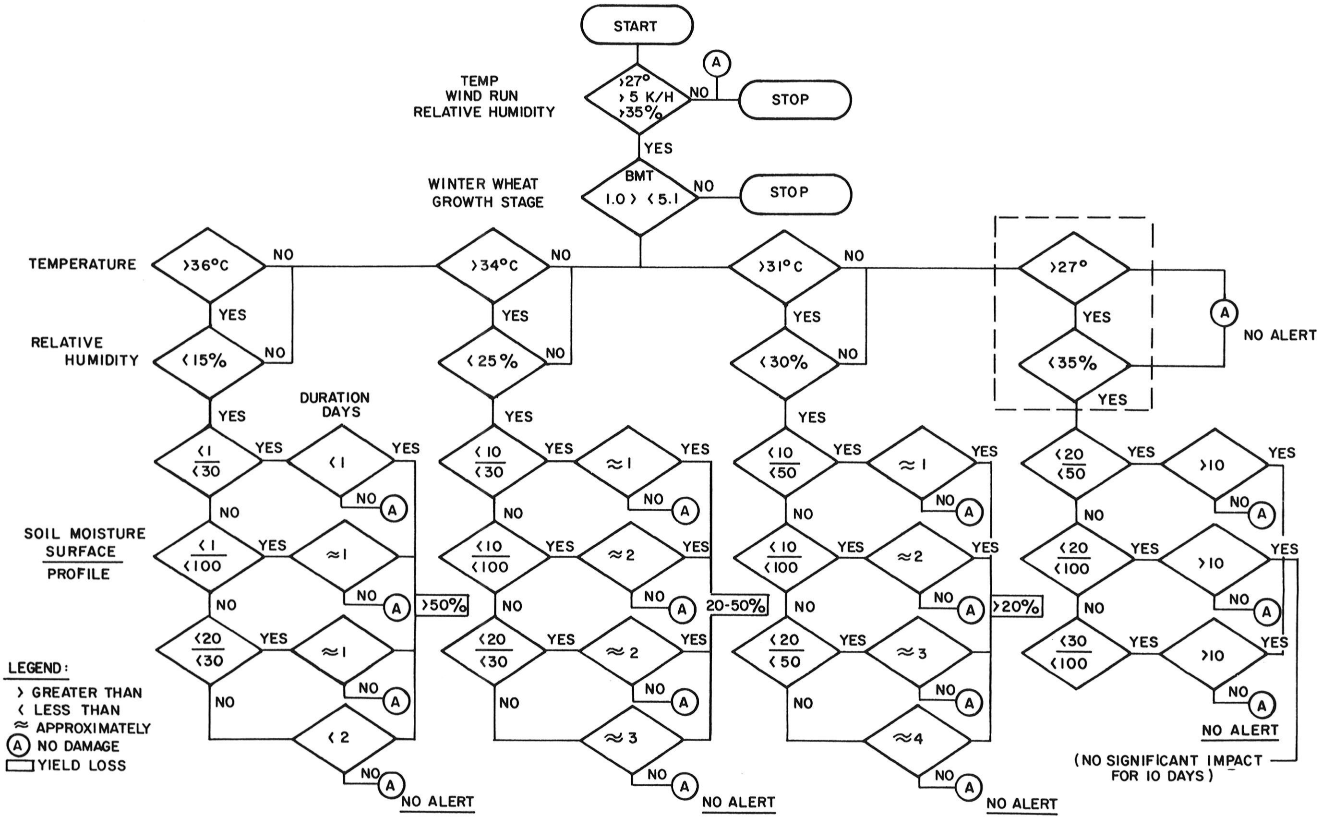

Fig. 2. Probable percent yield reduction that may occur because of desiccation from hot, dry winds and low soil moisture.

The various stress indicator models being developed required more accurate representation of the soil moisture condition, particularly in the surface layer. The two-layer model was modified to allow a more gradual and realistic depletion of the surface layer. A moisture extraction function was developed to allow depletion from the surface at the full potential rate down to 75% depletion of surface capacity. After 75% depletion, moisture is extracted from the surface at a reduced rate with extraction from the lower layer supplying the remaining requirement. Moisture is extracted from the lower layer at a fraction of potential. This fraction is calculated as a ratio of actual water held at field capacity.

Precipitation enters the model by first completely filling the surface layer and then the lower layer. When the capacity of both layers is reached, excess precipitation is treated as runoff and is lost from the model. The output of this model is used as "stand alone" data for crop condition analysis as well as input for other models. This is the only meteorologically driven model that is run continuously year after year.

The wheat stress model (7) is initiated at the same time as the crop calendar. Actually, the crop calendar model and soil moisture model provide inputs to this model. The stress model monitors both stress and optimum conditions with regard to temperatures and soil moisture during the entire growing season until an estimated 50% of the crop is "dead ripe."

The Division does not have an objective way to determine yield loss from varying causes (ie, adverse temperature or soil moisture). We must rely on the analytical skills of the responsible analysts and their knowledge of plant pathology, their assigned country (or countries), similar historical occurrences, and the significance of the variation in the vegetative indices (greenness/biomass value calculated from the digital remotely sensed satellite data) to determine yield reduction for the crop in question. EW/CCA and other projects are reportedly investigating procedures for objectively calculating these yield reductions.

The winterkill model (6) is initialized in the northern hemisphere before dormancy each year in order to calculate the wheat plant's winter hardiness. The first phase of hardening is development of frost resistance. This occurs during sunny days with maximum mean daily air temperatures of about 2 C and minimum night temperatures of about 0 C. The second phase of hardening, which is independent of sunlight, occurs during frost periods when temperatures range from 5 to −2 C. This is followed by four more hardening stages. The degree of hardening can vary the ability of the wheat plant to withstand low temperatures by 3 C or less. Snow cover is another critical factor in this model. The insulating effect of snow is nonlinear and is approximately ten times that of mineral soil (4).

Since high winds, uneven terrain, wind breaks, and other factors cause variations in snow depths, another component of the winterkill model uses information from the WMO station report to calculate snow depth over a large area. This calculation is based on data gathered by Russian scientists to allow them to predict the percentage of actual depths of snow from WMO station reported snow depth (4). The model then calculates the percent of potential winterkill of the plant population for the area. Nominally, this is based on soil temperature falling below −17 C at the tillering node. Again, the actual killing temperature at the node is uncertain, because it depends on the hardiness of the plant. The question of hardiness deserves additional attention from the research community. Because of these uncertainties, the analysts prefer to wait until two or three days of potential killing conditions have been determined by the model before they predict substantial winterkill. However, two or three days reporting severe kill by the model will alert the analyst to monitor high-density wheat areas using the remotely sensed satellite image data after dormancy in an attempt to estimate any winter losses.

As the spring "green-up" begins, the stress model and the vegetative indices again become important in the crop condition assessment analysis. These two tools, among others, and the visual analysis of the LANDSAT permit the analyst to make a reasonable comparison with the previously designated base year. This gives a percentage increase or decrease from the base year which must be classed as subjective even though the analysis is based on objective methodology and techniques.

As the season proceeds into the warmer, dry months, yield reduction due to desiccation from the hot, dry winds may occur. These winds in combination with low relative humidity and soil moisture can be devastating in a very short time—as little as one day (3). Figure 2 illustrates the details of weather conditions leading to specific yield reductions. Two of the model parameters (wind speed and relative humidity) are not available to the Division on real time and the EW/CCA has attempted to develop substitute parameters and/or input evapotranspiration data. A model using evapotranspiration is currently running on one of the Division computers, but the data are preliminary and will require more study and comparison with ground observations. The Division's analysts are determining the correlations of these data with vegetative indices and output from the stress model and other operational models and techniques.

Another important tool of the analyst is the use of the vegetative

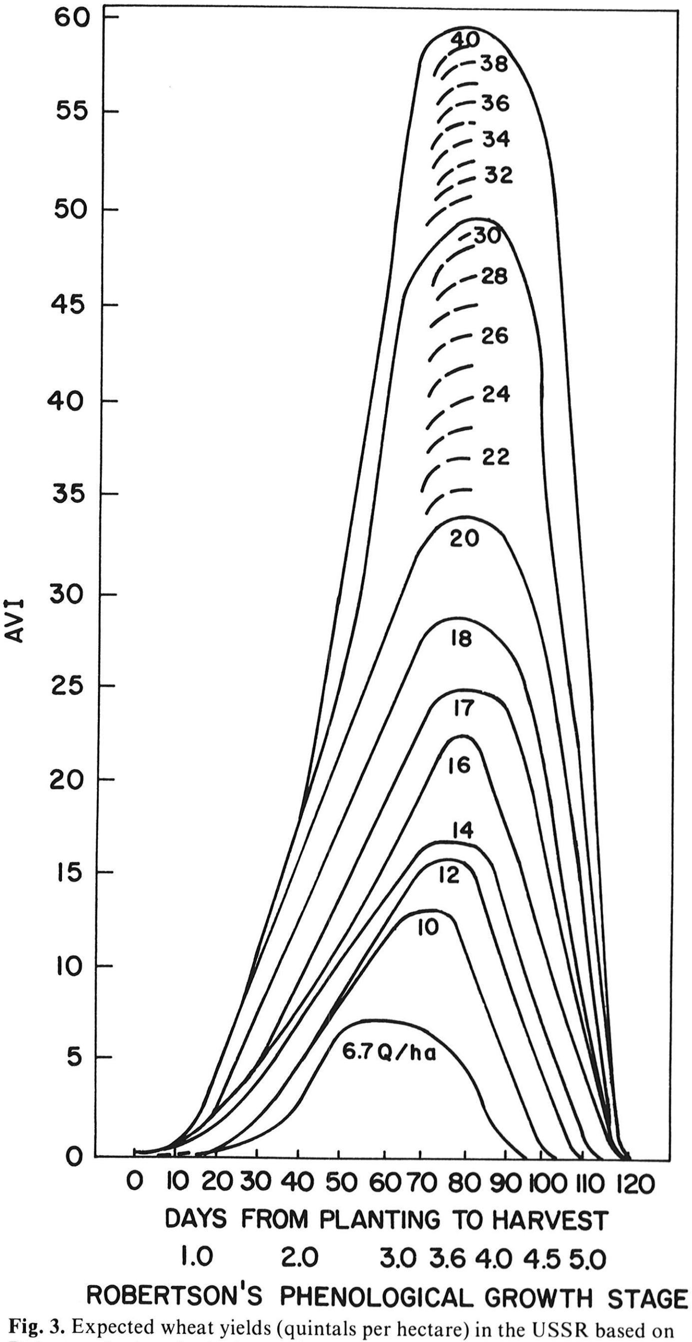

Fig. 3. Expected wheat yields (quintals per hectare) in the USSR based on Robertson's phenological growth stage and the Ashburn Vegetative Index (AVI) number. (Reproduced from Ashburn [1].)

indices as a yield indicator (1). The change in vegetative indices plotted over the growing cycle of the crop usually follows a normal curve. A deviation from the expected slope of the curve indicates that the crop is not progressing normally and that the yield potential may be affected. The peak (peak greenness normally occurs at the flowering stage) is an indicator of yield potential. The greater the greenness value, the greater the yield. As the crop matures and chlorophyll content decreases, the color changes from green to a golden or straw color and the vegetative index values decline rapidly. Figure 3 is an example of the varying levels of green values and the corresponding expected yield (1).

The vegetative index alone is not sufficient for predicting yield. There have been instances in which temperatures fell to 0 C for a few hours during the flowering stage sterilizing or "blasting" a significant part of the crop with no discernible difference in vegetative index values. Therefore, the analysts working with the stress model must use vegetative indices in combination with other inputs to assure an accurate analysis.

In conclusion, all of the models discussed in this paper have certain weaknesses or shortcomings. For example, we are still uncertain about the "hardening" calculation for winter wheat and the percentage yield reductions for various durations of the different types of stress considered by the wheat stress model. This paper has not addressed plant disease per se. Although the Division has long been aware of the need to model the effects of weather on pathogens and insects that cause yield reduction, the resources have not been available for this undertaking. While it is relatively simple to identify a stressed crop and to identify the probable cause as disease through deduction (ie, soil moisture is good, temperatures normal, etc.), it is not possible at this time to assess impact. As the Division continues to refine and enhance its crop condition assessment capabilities, it will have to address yield reduction from disease and insects.

Because of the uncertainties in modeling yield reductions, the Division's analysts do not define their analysis of a crop/situation until several indicators point to the same conclusion or until they understand the reason for any discrepancies. Over the past four years the Division has achieved an accuracy of ±4% in estimating production in those areas of the world that the analysts have worked with for three or more years. This accuracy is documented by comparing the Division results with releases of official production figures by the various foreign governments.

GLOSSARY

AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
EW/CCA	Early Warning/Crop Condition Assessment Project in AgRISTARS
FAS	Foreign Agricultural Service
FCCAD	Foreign Crop Condition Assessment Division
NASA	National Aeronautics and Space Administration
WMO	World Meteorological Organization

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