



# **A Center for Commercial Development of Space: Real-Time Satellite Mapping**

## **Remote Sensing-Based Agricultural Information Expert System**

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## ABSTRACT

The research project results in a powerful yet user friendly CROPCAST OSU expert system for use by a client to determine the crop yield production of a certain crop field. The study is based on the facts that heuristic assessment and decision making in agriculture are significant and dominate much of agribusiness. Transfer of the expert knowledge concerning remote sensing based crop yield production into a specific expert system is the key program in this study. A knowledge base consisting of a root frame, CROP-YIELD-FORECAST, and four subframes, namely, SATELLITE, PLANT-PHYSIOLOGY, GROUND, and MODEL were developed to accomodate the production rules obtained from the domain expert. The expert system shell Personal Consultant Plus version 4.0. was used for this purpose. An external geographic program was integrated to the system.

This project is the first part of a completely built expert system. The study reveals that much effort was given to the development of the rules. Such effort is inevitable if workable, efficient, and accurate rules are desired. Furthermore, abundant help statements and graphics were included. Internal and external display routines add to the visual capability of the system. The work results in a useful tool for the client for making decisions on crop yield production. The knowledge base has been tested with successful results. A step-by-step illustration of consultation is presented. A revenue of over US \$13 million for a workable and completely built system is estimated by EarthSat on a six year market projection.



## ACKNOWLEDGMENT

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## 1. INTRODUCTION

Agriculture, while having a strong scientific base, is operated as a heuristic enterprise. Farmers base their operations on a combination of "what worked well last year" and "what my father did worked well for him and I'm not going to change." While these statements exaggerate the actual situation they provide a basis to try and review the role of expert systems in agricultural enterprises.

First let us examine the problem faced by the farmer or the agricultural extension agent in trying to assess production. The farmers know what came off each of their fields last year and the years before that with high confidence. They can walk into the fields and sample; they can examine their neighbors' success on similar soils with similar varieties; they arrive at their seasonal production estimate by weighing these factors together with the amount of rain that has fallen and their knowledge of other factors that influence crop production. The actual process they use in arriving at their estimate is heuristic in that it is a discovery process but is generally incapable of proof.

The production discovery process outlined is characteristic of many operational problems faced in agriculture. Clearly, if the process can be captured then it is possible to combine the process with the available knowledge in an expert system shell to allow a computerized system to make the estimate.

The real problem is the process, since if we do not understand how the farmer or extension agent seeks to discover the answer, we have no way of teaching a computer to duplicate the process. Let us now examine the range of problems that are addressed with heuristic processes in the agricultural sector. The range extends from price discovery, where the farmer or the speculator is seeking to discover the price at which it is economically beneficial to buy or sell an agricultural commodity or even the asking price for a piece of equipment the individual may wish to sell, to decisions regarding the amount of fertilizer to use or the appropriate time to apply herbicides. Each of these decision activities makes use of the heuristic process in one way or another.

Expert systems can be applied to the full range of agricultural problems alluded to in the foregoing. Expert systems have evolved from the field of Artificial Intelligence; they attempt to provide a cost-effective means to simulate human reasoning processes in order to find the one or several solutions that may be contained in a given knowledge base. Success with expert systems has been achieved in many fields including medical diagnosis,

equipment repair, financial advice, etc. Some expert systems developed at The Ohio State University are among others related to construction (Hadipriono, 1989), structural damage (Hadipriono, 1988), and drainage pattern analysis (Hadipriono et. al., 1989). The strength of expert systems technology is that it offers a way effectively to use human process reasoning even if that specific expert is unavailable. Thus if Farmer Jones's father had process knowledge on the best way to solve a problem and that knowledge had been captured in an expert system before he could no longer operate the farm, his reasoning processes would still be available to the farm business.

In this project, we explore the problem faced by the crop analyst who wishes to estimate crop yield and production at the farm, county, state, or multistate level. This project is the first of a multi-phase project, encompassing the development of an expert system for crop production and price demand analyses. Therefore, the objective of this first phase work is to transfer the expert knowledge into the knowledge base in the specific expert system for crop yields based on information from satellite, ground, model, and plant physiological resources. The package will be designed so that it can be acquired by a variety of clients, ranging from small farming businesses to large corporations in the United States as well as in foreign countries.

## 2. COMMERCIAL POTENTIAL OF THE EXPERT SYSTEM

In the mid-1970's, our corporate partner, Earth Satellite Corporation (EarthSat), developed a commodity forecasting system (CROPCAST) which today provides daily worldwide production estimates for some 20 commodities to more than 90 organizations. EarthSat's current client base represents about 5% of the food processor and exporter/importer market with sales of over \$100 million. The CROPCAST system ingests and integrates data and information from many sources, such as the agrometeorological data, ground investigative reports, and Landsat and Metsat. For the past ten years, CROPCAST has been providing accurate production forecasts to a growing community of clients. The CROPCAST model has shown excellent skill on relatively large area estimates, but it was not designed to provide absolutely accurate information at county or farm levels, even though the processes used in CROPCAST are appropriate to small area processes.

The clients' requirements are evolving; i.e., both public and private sector clients seek the capability to combine the current CROPCAST technology with other supply- and demand-side techniques so that they may better focus their resources in a continually changing marketplace. The development of a remote-sensing based agricultural-information-knowledge-base expert system is expected to significantly expand the marketability of the crop forecasting services. It will allow such services to reach various segments of users ranging from farmers and individuals to large corporations worldwide. It is believed that the entire agribusiness community will expand and benefit.

EarthSat has identified three major segments in the market. Segment 1, which will employ the integrated knowledge bases, includes large corporations, such as financial institutions, commodity brokerage companies, food manufacturers, and foreign trading firms. There are at least 1,500 potential clients classified in this segment. Several of these organizations, including La Arrocera, Toepfer International, Hershey Foods Corporation and General Foods Corporation have shown a strong interest in the program. EarthSat predicts a market penetration of 10 - 15% over a six-year period.

Segment 2 consists of foreign and regional governments, which need to use the knowledge base as a tool for managing their agricultural demands or for participating in the international commodity market. EarthSat estimates about 120 potential clients in this segment who are interested in the system, and expects about 20 - 25% of market penetration over a six-year period.

Segment 3 is comprised of small businesses, individual speculators, and farmers, who are interested in the subsystem of the knowledge base. EarthSat approximates 20,000 elements of this segment and assumes a 10% marketability over a six-year period.

Table 2.1 shows a market forecast for the expert system we anticipate selling to the three market sectors. Revenues do not include the sale of hardware. Marketing of the knowledge base expert system could start as early as the end of this year (end of 1989). We will encourage early buyers to participate and contribute their expertise for the development of the production rules. An early buyer discount package will be offered for the rights to use their programs. It is expected that we could perform the first real-time tests at the end of the first year. Based on the test results, we could improve the marketing strategy, for instance, by modularizing the package into several different packages to achieve maximum utility of each purchase.

Next, we discuss the expert knowledge available to the analyst and the development of an expert system, incorporating such knowledge.

Table 2.1. Average Product Price (\$000 omitted)

YEAR	1	2	3	4	5	6
-----	-----	-----	-----	-----	-----	-----
\$SALE/SEGMENT 1	25	35	50	125	125	125
\$SALE/SEGMENT 2	NA	NA	250	250	250	250
\$SALE/SEGMENT 3	NA	NA	25	35	35	35
YEAR	1	2	3	4	5	6
-----	-----	-----	-----	-----	-----	-----
SEGMENT 1 CUSTOMERS	25	35	50	125	125	75
SEGMENT 2 CUSTOMERS	NA	NA	250	250	250	9
SEGMENT 3 CUSTOMERS	NA	NA	25	35	35	50
YEAR	1	2	3	4	5	6
-----	-----	-----	-----	-----	-----	-----
TOTAL SALES	125	280	2,150	6,100	10,100	13,375
=====	=====	=====	=====	=====	=====	=====

### 3. EXPERT KNOWLEDGE

The expert knowledge available to the analyst can provide a variety of simulations of crop processes. Knowledge of production is essential to the entire agricultural decision-making process. The kinds of knowledge that the analysts may use are generally listed in Table 3.1. This knowledge is classified based on the source of information. Eight sources are considered for a completed crop production expert system: Satellite-, Ground-, Model-, Plant-Physiological-, Statistical-, Geographical-, Hydrological-, and Topographical-based information (Column 1 of Table 3.1). The parameters of each source of information are listed in Column 2. These parameters, affecting the crop yield production, were used by the expert to establish the knowledge. In this report, we focus our work on the first four sources.

The knowledge in Table 3.1 is obtained from experts who are actively involved in solving crop production problems. Examples of such knowledge for Satellite-, Ground-, Model-, and Plant-Physiological-based information are provided in Appendix B. They are furnished by our corporate partner, Earth Satellite Corp. (EarthSat). This knowledge is expressed in the form of IF-THEN statements. Examples of such statements in each of the four sources of information are presented here:

#### SATELLITE-based statement:

IF the appearance of an area of crops as measured by greenness counts is equal to the greenness count of a city,  
THEN the loss on crop yield will be significant and may reach total loss.

#### GROUND-based statement:

IF the plant appears yellow early in the season and there has been flooding,  
THEN the plant has been oxygen starved and yields may be reduced.

#### MODEL-based statement:

IF the subsoil moisture during the reproductive period is below 30 percent of capacity or is fluctuating around 30 percent,  
THEN the chance of above trend yields is significantly reduced.

#### PLANT-PHYSIOLOGICAL-based statement:

IF the plant is in the tassel and ear initiation (8-10 leaf stage to tasseling),  
THEN stress from heat and/or low soil moisture will cause serious loss in ear size, kernel size and count, etc.



In this project, we compiled these statements into workable rules, commonly called the production rules, or rules expressed by the experts in the form of experience-based rules of thumb, educated guesses, and heuristic assessments. We also modified and redefined the parameters in Table 3.1 so that we can use them for the production rules. These rules, presented in the next section, are essential in the development of the expert system.

TABLE 3.1 KNOWLEDGE BASE OUTLINE

TYPES OF INFORMATION (1)	PARAMETERS (2)
A. SATELLITE	Greenness Area of Greenness Variability of Greenness Flooding Area of Flooding Length of time flooding exists Field preparation (L/S and Spot) Irrigation Application (L/S and Spot) Irrigation type (center pivot, flood, etc.) Soil Erosion (Wind, Water, etc.) Growth stage (inferred from greenup timing)
B. GROUND	Growth stage Plant height Plant condition Damage assessment Soil moisture assessments Field preparation Varieties planted Flooding locations Reproductive progress, i.e., tasseling, bloom, etc.
C. MODEL	Areal soil moisture estimated for three layers Estimate of yield valid to +/-10 percent at state levels and 15-20 percent at county level. Areal estimates of crop yield variability Areal estimates of growth stage, accuracy near 5 days near 40 degrees north and south Areal estimates of crop condition with accuracy estimated at 65 percent Areal estimates of the occurrence and timing of stress events from drought or flood Disease potentials due to humidity and/or clouds Planting and Field preparation delay potentials Freeze locations and area of potential
D. PHYSIOLOGICAL	Estimates of plant processes given growth stage Estimates of damage potential given growth stage and conditions of the plant

TABLE 3.1 KNOWLEDGE BASE OUTLINE (continued)

TYPES OF INFORMATION (1)	PARAMETERS (2)
E. STATISTICAL	Total planted area to county level (year old) Variety information (usually more than a year old) Yield estimates at the county level with an accuracy valid to +/-15-20 percent Agrichemical useage at county level (one to two years old) Tillage practices (usually more than a year old) Planting dates (historical) Stocks to use ratios On farm storeage estimates
F. GEOGRAPHICAL/CLIMATOLOGY	Maps of locations of drainage Maps of soils Location of transportation and Elevators Political boundaries (township, county, stated, etc.) Broad area land cover Location of water bodies (lakes, ponds, rivers, etc.) Maps of topography and climate Maps of normal high and low temperatures Maps of rainfall Maps of normal freeze dates Maps of degree days
G. HYDROLOGICAL	Maps of ground water tables Ground water flow potential Water quality information
H. TOPOGRAPHIC	Detailed topographic information

#### 4. THE EXPERT SYSTEM

An expert system may be defined as a computer software that captures, accommodates, and manipulates human knowledge and expertise to solve a particular problem. An expert system deals primarily with knowledge rather than data. The architecture of the first phase of CROPCAST OSU (the name of our program) is shown in Figure 4.1a.

In general, an expert system consists of two important parts: the inference engine and the knowledge base. The inference engine performs the inference process. It is a mechanism that processes information provided by a user or client and the knowledge within the system to obtain the solution of a particular problem. The knowledge base contains frames, parameters, and production rules. A frame is a structure that provides for the collection of information concerning the knowledge base (PC Plus: Getting Started, 1988). A frame groups the parameters and production rules. A parameter represents an individual piece of knowledge. In this project, the production rules were compiled from the knowledge acquired from an expert in the form of IF-THEN statements and through interviews as presented in Appendix B.

Besides the inference engine and knowledge base, the expert system should be able to interface with the client and external programs. Client interface involves the input of evidences, leading to a decision-making process. The client may wish to obtain the reason for the decision through the explanation facility. In the first phase of this project, the external programs employed to interface with the knowledge base are limited to graphic software only (Figure 4.1a). However, as the project evolves, we will include other data bases and computational models as shown in Figure 4.1b.

A general purpose expert system software developed with an inference mechanism and a body of knowledge for use to accommodate production rules is called an expert system shell. There are currently numerous expert system shells with various capabilities in the market that can be used for our project. After a selection process, we decided that Personal Consultant Plus version 4.0 (PC Plus), produced by Texas Instruments Inc., was the most suitable and within the range of our project budget. PC Plus runs on IBM AT compatible personal computers with DOS version 2.10 or higher. Memory requirement for developing the knowledge base are at least 640 KB, plus 0.5 MB of extended or expanded memory. A floppy disk drive and a hard drive are required. PC Plus is a highly functional tool for expert system environment and has been given a high rating by many (Palmer and Mar, 1988; Maloney and Miller, 1988). Other significant

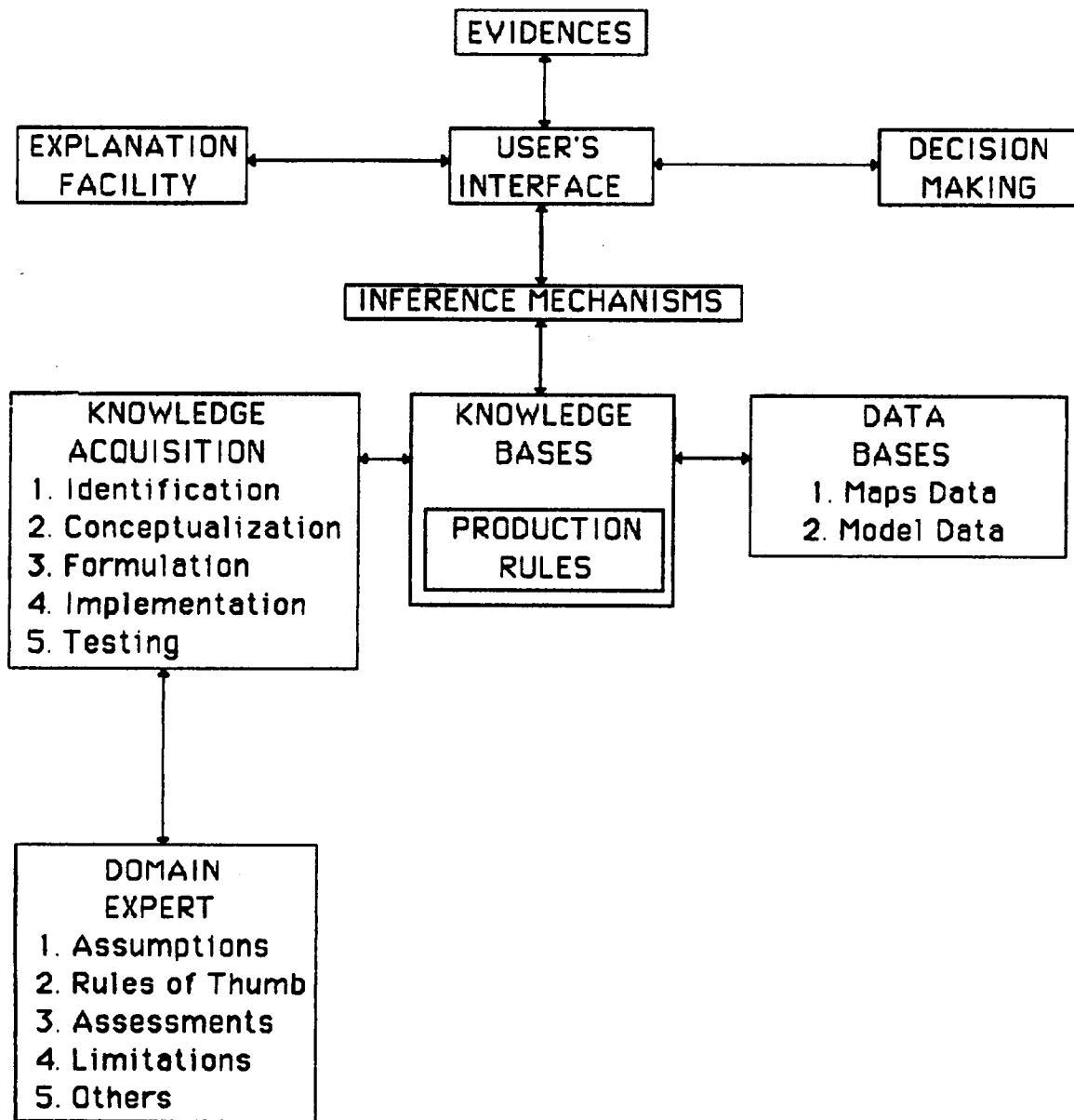


Figure 4.1a. The Architecture of CROPCAST OSU (Phase 1)

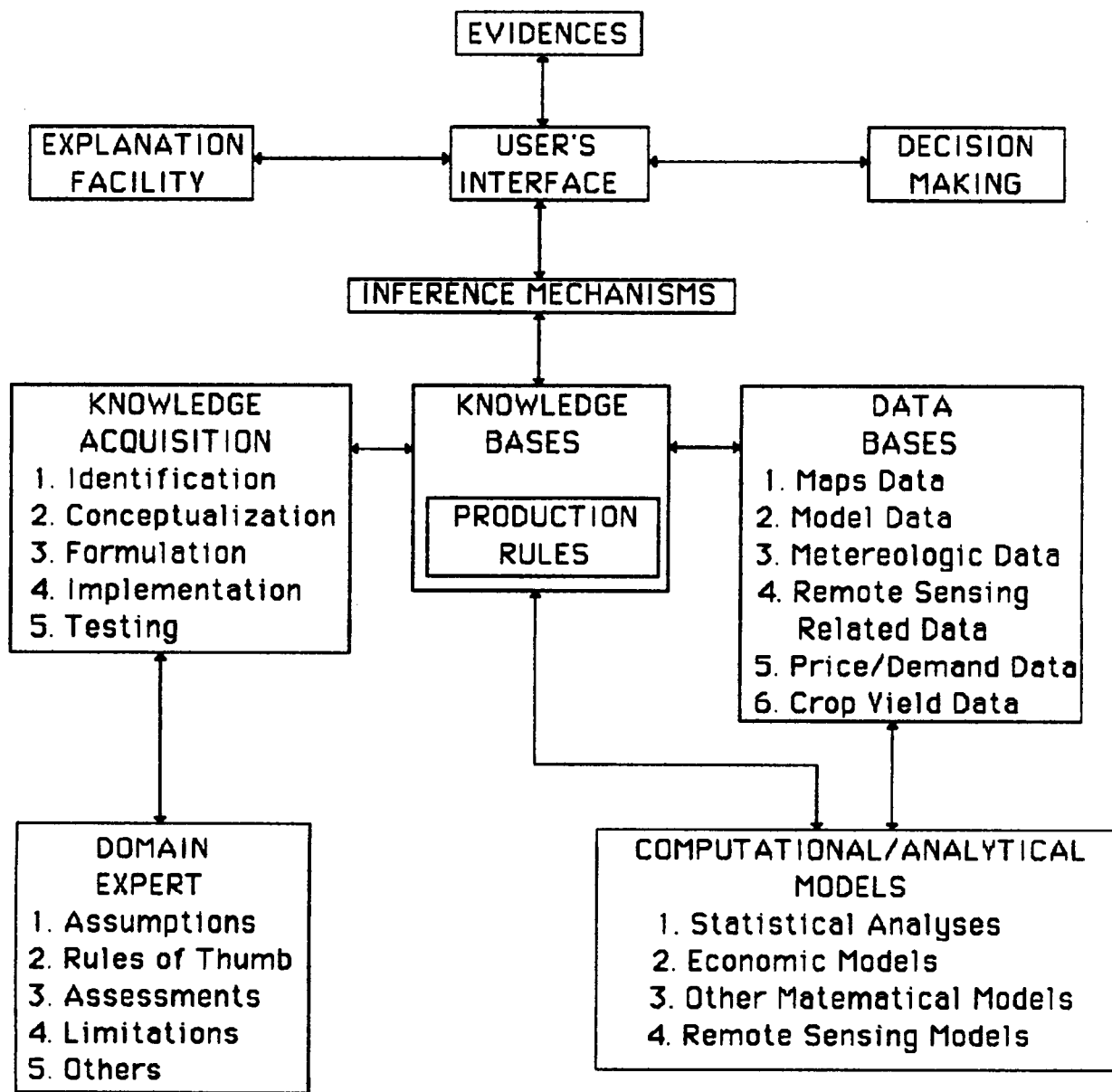


Figure 4.1b. The Architecture of CROPCAST OSU

features of this expert system shell are its highly interactive environment for development and testing, access to external packages, graphic display capability, and window-oriented interactive mode with extensive online help. In addition, PC Plus is able to translate the rules that are written in the Abbreviated Rule Language into the English language. Moreover, PC Plus offers a utility that helps to translate the knowledge base into other languages such as French and Portuguese.

PC Plus involves three activities: DEVELOP, BUILD, and CONSULT. The Activity DEVELOP is used by the knowledge engineer (an engineer involved in developing an expert system) to construct the knowledge base. BUILD is used to construct a workable copy of the expert system without accommodating the PC Plus shell. This copy of the program is for use by the client to consult the expert system. CONSULT is the activity for the knowledge engineer to test the expert system. These activities are presented in the next chapters.

## 5. DEVELOPING THE KNOWLEDGE BASE

As mentioned before, a frame groups its parameters and rules. The development of a knowledge base constitutes the construction of the frames, parameters, and production rules.

### 5.1. The Construction of Frames

First, we develop the knowledge base by constructing the frames. A knowledge base may have two types of frames, a root frame and subframes. Each knowledge base should have at least the root frame, but it can have only one root frame. However, a knowledge base can have as many subframes as the problem requires. In this project, a root frame CROP-YIELD-FORECAST and its four subframes SATELLITE, PLANT-PHYSIOLOGY, GROUND, and MODEL were established. They represent the sources of information used to determine the crop yield that are acquired from the domain experts (EarthSat). The root frame and subframes can be networked together by using a special instruction that is constructed in a rule. The root frame CROP-YIELD-FORECAST integrates the four subframes through the use of rules, and hence, combines the conclusions obtained from the four subframes. Appendices C, D, E, F, and G contain the lists of the frames, parameters, and rules that we use for CROP-YIELD-FORECAST, SATELLITE, PLANT-PHYSIOLOGY, GROUND, and MODEL, respectively.

#### 5.1.1. Properties of the Root Frame

In order to allow a frame to function as desired, we have to provide certain basic information to the frame during the development phase. First, at the Knowledge Bases Screen, select "create a new knowledge base." Then enter the value of DOMAIN, which will prompt a heading that is shown in the screen during consultation. Next, assign the name of the frame, CROP-YIELD-FORECAST. Following this, enter the current objective, which describes of the objective of the frame. Figure 5.1 shows the properties of the frame CROP-YIELD-FORECAST.

Now, the root frame CROP-YIELD-FORECAST has a general property VARIABLES. This property contains \$\$TITLE and DOMAIN variables. As mentioned before, the DOMAIN variable prompts a heading that is shown in the screen during consultation. The value of DOMAIN is "CROPCAST OSU, Copyright 1989, The Ohio State University." The \$\$TITLE variable contains the name of the graphic that is presented when the client starts a consultation. In our case, the value of this variable is (PICTURE CROPCAST).



```

=====
VARIABLES
=====

$$TITLE
  VALUE :: (PICTURE CROPCAST)
  DOMAIN :: "CROPCAST OSU, Copyright 1989, The Ohio State
            University"

=====
  Frame :: CROP-YIELD-FORECAST
=====

IDENTIFIER :: CROP-YIELD-FORECAST-
TRANSLATION :: (Crop Yield Forecast)
GOALS :: (LOCATION SATELLITE-PRODUCTION SATELLITE-
          COMMENTS GROUND-PRODUCTION GROUND-COMMENTS
          PHYS-PRODUCTION PHYS-COMMENTS MODEL-
          PRODUCTION MODEL-COMMENTS PRODUCTION INITIAL
          CROP )
INITIALDATA :: (INITIAL GROWTH-STAGE WEEKS FLOOD HIGH-
                TEMP SOIL-MOISTURE )
PROMPTEVER :: (:LINE 5 :ATTR (CYAN HIGH) "Crop Yield
               Forecast" :LINE :ATTR (WHITE HIGH) :ATTR
               (YELLOW HIGH) "*****" )
DISPLAYRESULTS :: YES
PARMGROUP :: CROP-YIELD-FORECAST-PARMS
RULEGROUPS :: (CROP-YIELD-FORECAST-RULES)
OFFSPRING :: (SATELLITE PLANT-PHYSIOLOGY GROUND MODEL)
CROP-YIELD-FORECAST-PARMS :: (CROP FLOOD GROUND-
                              COMMENTS GROUND-
                              PRODUCTION GROWTH-STAGE
                              HIGH-TEMP INITIAL
                              LOCATION MODEL-COMMENTS
                              MODEL-PRODUCTION PHYS-
                              COMMENTS PHYS-PRODUCTION
                              PRODUCTION SATELLITE-
                              COMMENTS SATELLITE-
                              PRODUCTION SOIL-MOISTURE
                              WEEKS )
CROP-YIELD-FORECAST-RULES :: (RULE021 RULE022 RULE074
                              RULE075 RULE076 RULE077
                              RULE078 RULE096 )

```

Figure 5.1. Properties of the Frame CROP-YIELD-FORECAST

Besides the above-mentioned property, the root frame has other, more specific properties (see Figure 5.1) The property IDENTIFIER specifies the group name for the parameters and rules defined in this frame. TRANSLATION describes the frame, while GOALS lists the goal parameters whose values PC Plus attempts to establish during consultation. The property INITIALDATA shows the parameters whose values are requested by PC Plus from the client each time a frame is instantiated. This property also determines the desired order of the parameters in which the questions are requested. Note that since these parameters are question-related, they do not appear in the property GOALS and vice versa. An exception to this rule is the parameter INITIAL. To get the preliminary information, INITIAL should be contained in INITIALDATA, while for updating purposes, INITIAL should be contained in GOALS. The property PROMPTEVER of the root frame CROP-YIELD-FORECAST prompts "Crop Yield Forecast" in magenta underlined by yellow stars. Note that this prompt can be displayed in any color by changing the PROMPTEVER property.

The property DISPLAYRESULTS indicates whether or not the goals of the consultation are displayed when the frame finishes the consultation process. The property PARMGROUP groups the parameters of the root frame, while RULEGROUPS groups the production rules of the root frame. The property OFFSPRING identifies the subframes of the frame CROP-YIELD-FORECAST. The properties CROP-YIELD-FORECAST-PARMS and CROP-YIELD-FORECAST-RULES lists all parameters and rules in the root frame, respectively.

Note that on the screen one can only see the properties that can be edited. Figure 5.1 shows all properties including the User Defined properties (those that cannot be edited) such as RUEGROUPS and SATELLITE-PARMS.

#### 5.1.2. Properties of Subframes

The properties of the subframes are almost the same as those in the root frame. Figures 5.2, 5.3, 5.4, and 5.5 show the properties of subframes SATELLITE, PLANT-PHYSIOLOGY, GROUND, and MODEL. In these subframes we add other properties. The property PARENTS identifies the root frame of a subframe. For all subframes, the root frame is CROP-YIELD-FORECAST. The property ANTECEDENT requires a more detailed description. First, a frame can reach its objectives by using either the precedent or antecedent mode. The property ANTECEDENT is added if the frame is to perform in an antecedent mode, otherwise; the frame performs in a precedent mode.

```

=====
Frame :: SATELLITE
=====

IDENTIFIER :: "SATELLITE-"
TRANSLATION :: (crop yield forecast from satellite
                information)
PARENTS :: (CROP-YIELD-FORECAST)
GOALS :: (SATELLITE-PRODUCTION SATELLITE-COMMENTS)
INITIALDATA :: (AVHRR L-S GREEN-RED GREEN-RED-PREVIOUS
                NIR FOREST CENTERED MAXIMUM POND-NIR
                POND-VIR )
PROMPTEVER :: (:LINE 6 :ATTR (CYAN HIGH) "SATELLITE
                INFORMATION" :LINE :ATTR (YELLOW HIGH)
                "*****" )
PARMGROUP :: SATELLITE-PARMS
RULEGROUPS :: (SATELLITE-RULES)
ANTECEDENT :: YES
SATELLITE-PARMS :: (AVHRR CENTERED FOREST GREEN-RED
                    GREEN-RED-PREVIOUS L-S MAXIMUM NIR
                    POND-NIR POND-VIR )
SATELLITE-RULES :: (RULE023 RULE024 RULE025 RULE026
                    RULE027 RULE028 RULE029 RULE030
                    RULE031 RULE080 RULE081 RULE091
                    RULE092 RULE093 RULE094 RULE095 )

```

Figure 5.2. Properties of Subframe SATELLITE

```

=====
Frame :: PLANT-PHYSIOLOGY
=====

IDENTIFIER :: "PLANT-PHYSIOLOGY-"
TRANSLATION :: (crop yield forecast from plant
                physiology information)
PARENTS :: (CROP-YIELD-FORECAST)
GOALS :: (PHYS-PRODUCTION PHYS-COMMENTS)
INITIALDATA :: (PLANTING-DATE LOW-TEMP NIGHT-TEMP SOIL-
                TEMP WATER-STORAGE SUN LEAVES FUNGI )
PROMPTEVER :: (:LINE 7 :ATTR (CYAN HIGH) "PLANT
                PHYSIOLOGY INFORMATION" :LINE :ATTR
                (YELLOW HIGH)
                "*****" )
PARMGROUP :: PLANT-PHYSIOLOGY-PARMS
RULEGROUPS :: (PLANT-PHYSIOLOGY-RULES)
ANTECEDENT :: YES
PLANT-PHYSIOLOGY-PARMS :: (FUNGI LEAVES LOW-TEMP NIGHT-
                          TEMP PLANTING-DATE SOIL-TEMP
                          SUN WATER-STORAGE )
PLANT-PHYSIOLOGY-RULES :: (RULE001 RULE002 RULE003
                          RULE004 RULE005 RULE006
                          RULE007 RULE009 RULE010
                          RULE011 RULE012 RULE013
                          RULE014 RULE015 RULE016
                          RULE017 RULE018 RULE019
                          RULE020 RULE087 RULE090 )

```

Figure 5.3. Properties of Subframe PLANT-PHYSIOLOGY

```

=====
Frame :: GROUND
=====

IDENTIFIER :: "GROUND-"
TRANSLATION :: (crop yield forecast from ground
                information)
PARENTS :: (CROP-YIELD-FORECAST)
GOALS :: (GROUND-PRODUCTION GROUND-COMMENTS)
INITIALDATA :: (COLOR FIRED HEIGHT LEAN RECOVER-
                OVERNIGHT SILK-DRY SOIL-STICK WILT )
PROMPTEVER :: (:LINE 7 :ATTR (CYAN HIGH) "
                GROUND INFORMATION" :LINE :ATTR (YELLOW
                HIGH) "*****" )
PARMGROUP :: GROUND-PARMS
RULEGROUPS :: (GROUND-RULES)
ANTECEDENT :: YES
GROUND-PARMS :: (COLOR FIRED HEIGHT LEAN RECOVER-
                OVERNIGHT SILK-DRY SOIL-STICK WILT )
GROUND-RULES :: (RULE057 RULE058 RULE059 RULE060
                RULE061 RULE064 RULE065 RULE067 RULE068
                RULE069 RULE070 RULE071 RULE072
                RULE089)

```

Figure 5.4. Properties of Subframe GROUND

```

=====
      Frame :: MODEL
=====

IDENTIFIER :: "MODEL-"
TRANSLATION :: (crop yield forecast from model
                information)
PARENTS :: (CROP-YIELD-FORECAST)
GOALS :: (MODEL-PRODUCTION MODEL-COMMENTS)
INITIALDATA :: (DEW-POINT ETP EARLY-STRESS MODERATE-
                STRESS-EXTEND RAIN-FREQ SOIL-MOISTURE-
                TOP SOIL-MOISTURE-PLOW SOIL-MOISTURE-
                LOWER SUBSOIL-MOISTURE TEMPERATURE )
PROMPTEVER :: (:LINE 7 :ATTR (CYAN HIGH) "
                MODEL INFORMATION" :LINE :ATTR (YELLOW
                HIGH) "*****" )
PARMGROUP :: MODEL-PARMS
RULEGROUPS :: (MODEL-RULES)
ANTECEDENT :: YES
MODEL-PARMS  :: (DEW-POINT EARLY-STRESS ETP MODERATE-
                STRESS-EXTEND RAIN-FREQ SOIL-MOISTURE-
                LOWER SOIL-MOISTURE-PLOW SOIL-MOISTURE-
                TOP SUBSOIL-MOISTURE TEMPERATURE )
MODEL-RULES  :: (RULE033 RULE034 RULE035 RULE036 RULE037
                RULE038 RULE039 RULE040 RULE041 RULE042
                RULE043 RULE045 RULE046 RULE047 RULE088)

```

Figure 5.5. Properties of Subframe GROUND

There is a significant difference between the precedent and antecedent mode. In the precedent mode, a frame reaches the objective by using the lowest possible number of parameters. For example, if information concerning two parameters is sufficient to reach the objective, the program requires the input of only those two parameters. Therefore, the precedent mode has the advantage of reaching the objective with the minimum information. However, by using this mode, the frame does not take full advantage of all the information available. In the antecedent mode, a frame reaches the objective by using all available information. The use of an antecedent mode is more advantageous, particularly when the objective depends on several independent parameters. However, the property INITIALDATA must include all the parameters whose values should be provided by the client, even when they are not needed.

The four subframes have the property ANTECEDENT for two reasons. First, the large number of independent parameters, and second, the updating process of certain parameters. An example of such a parameter is SATELLITE-PRODUCTION in subframe SATELLITE. This parameter may have to be updated several times during a consultation because it may be affected by one or more combinations of parameters, such as AVHRR and GREEN-RED. If the ANTECEDENT property is not assigned to the frame SATELLITE, the parameter is updated only once. For more detailed information about antecedent and precedent modes, the reader may refer to the PC Plus Reference Guide.

## 5.2. Parameters

A parameter must be defined in the frame in which the parameter is used. If a parameter is used in more than one subframe, say in subframes SATELLITE and MODEL, then it has to be defined in the root frame. This is the case of the parameter WEEKS. Therefore, a parameter that is defined in a root frame also functions in the subframes. However, the opposite is not true. A specific procedure must be followed when defining a parameter.

### 5.2.1. Parameters of Root Frame and Their Properties

The parameters of the root frame CROP-YIELD-FORECAST are shown in Table 5.1. These parameters and their properties are also listed in Appendix C. The definitions of these parameters are presented in the glossary in Appendix H.

Each parameter has its properties that are important for use in the activity CONSULT. An example is the properties of the parameter HIGH-TEMP. We must first select HIGH-TEMP in the Parmgroup:CROP-YIELD-FORECAST-PARMS Screen

Table 5.1. Parameters Defined in the Root Frame  
CROP-YIELD-FORECAST

Parameter	Rules
CROP	74, 75, 76, 77, 78
FLOOD	3, 57, 69, 89
GROUND-COMMENTS	37, 57, 58, 59, 60, 61, 64, 65, 67, 68, 69, 70, 71, 72, 89
GROUND-PRODUCTION	21, 22, 57, 58, 60, 61, 64, 65, 67, 68, 69, 70, 71, 72, 89, 96
GROWTH-STAGE	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 33, 35, 36, 37, 38, 39, 40, 42, 45, 57, 58, 61, 64, 67, 68, 71, 72, 80, 87, 89, 90, 94
HIGH-TEMP	6, 7, 14, 41, 45, 46, 87
INITIAL	21, 22, 74, 75, 76, 77, 78, 96
LOCATION	5, 15, 16, 17, 18, 19, 20
MODEL-COMMENTS	33, 34, 35, 36, 38, 39, 40, 41, 42, 43, 45, 46, 47, 88
MODEL-PRODUCTION	21, 22, 33, 34, 35, 36, 37, 38, 39, 40, 41, 43, 45, 46, 47, 88
PHYS-COMMENTS	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 87, 90
PHYS-PRODUCTION	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 87, 90
PRODUCTION	21, 96
SATELLITE-COMMENTS	23, 24, 25, 26, 27, 28, 29, 30, 31, 80, 91, 92, 93, 94
SATELLITE-PRODUCTION	21, 22, 23, 24, 25, 26, 27, 29, 30, 80, 81, 91, 95, 96
SOIL-MOISTURE	6, 7, 14, 39, 41, 45, 46
WEEKS	23, 24, 25, 26, 27, 28, 30, 37, 64, 70, 71, 72, 81, 90, 92, 93, 94, 95



(a screen showing a group of parameters). Figure 5.6 shows the parameter HIGH-TEMP and its properties. The property TRANSLATION describes a parameter. In the CONSULT mode, the TRANSLATION of HIGH-TEMP is shown as "the highest temperature before pollination." PROMPT displays a text or a question for the client. TYPE indicates the type of the value, while EXPECT selects the value category of the parameter. In this case, the TYPE is SINGLEVALUED, while EXPECT has a value category NUMBER. ANTECEDENT-IN lists all the rules having an antecedent mode whose IF statement contains this parameter. The property HELP provides help in a text mode. This property is very useful for the client when consulting the system. By pressing the F1 key, the client could obtain further detail of instruction or information. The property CERTAINTY-FACTOR-RANGE is useful to allow the introduction of degree of certainty into the consultation process. If this property is set to UNKNOWN, the program assumes that the parameter is unknown whenever the client does not give a value to the parameter when he/she is prompted to do so. The property RANGE shows the range of the value of HIGH-TEMP.

Another example is the properties of the parameter SATELLITE-PRODUCTION (Appendix C). We must first select SATELLITE-PRODUCTION in the Parmgroup:CROP-YIELD-FORECAST-PARMS Screen. The parameter SATELLITE-PRODUCTION is defined in the root frame because it functions in both the root frame, CROP-YIELD-FORECAST, and the subframe SATELLITE. Some of the properties are similar to those in HIGH-TEMP but others have not been described. The property UPDATED-BY lists the rules that update the parameter. UPDATED-IN lists the antecedent rules that update the parameter. Note also that the value of property TYPE of the parameter SATELLITE-COMMENTS is MULTIVALUED (Appendix C). This simply means that the parameter contains several values.

The Parameter LOCATION has the property METHOD (see Appendix C). This property contains a DOS-CALL command that calls the Geographic Interface (GI), an external program showing maps of all counties in the USA. When the parameter LOCATION is required during a consultation, DOS-CALL loads the GI and the client can select the desired county. When the client exits the GI, the program continues with the consultation in PC Plus.

### 5.2.2. Parameters of Subframes and Their Properties

The procedure of defining the parameters for the subframes is the same as that for the root frame. For brevity, we focus the discussion on the parameters and properties of the subframe SATELLITE. First, we choose the DEVELOP mode in the Activity Screen. Next, in the Frame Screen, we select SATELLITE. Then, we choose SATELLITE-

# HIGH-TEMP

=====

TRANSLATION :: (the highest temperature before  
pollination)  
PROMPT :: (:ATTR (CYAN REVERSE) "Enter the highest  
temperature observed before pollination in  
Fahrenheit." )  
TYPE :: SINGLEVALUED  
EXPECT :: NUMBER  
ANTECEDENT-IN :: (RULE041 RULE045 RULE046 RULE007  
RULE014 RULE006 RULE087 )  
HELP :: ("This value comes from the observations"  
:LINE "of the current year." :LINE "Punch  
ENTER if this temperature is unknown." :LINE  
"This parameter is of low importance during  
the" :LINE "early stages of the plant, but it  
is very" :LINE :ATTR ( MAGENTA HIGH )  
"important" :ATTR (WHITE HIGH) "during the  
late stages of the plant." )  
CERTAINTY-FACTOR-RANGE :: UNKNOWN  
RANGE :: (60 140)

Figure 5.6. Properties of Parameter HIGH-TEMP

PARMS in the Parmgroup:SATELLITE-PARMS Screen (a screen showing a group of parameters). Now it is possible to define a parameter or modify an existing one. These parameters and their use in the production rules can be found in Table 5.2. Similar procedures were repeated for constructing other subframes. Tables 5.3, 5.4, and 5.5 list the parameters used in subframes PLANT-PHYSIOLOGY, GROUND, and MODEL, respectively. A complete list of the parameters and their properties of these subframes are listed in Appendices D, E, F, and G. These parameters are defined in the glossary in Appendix H.

An example is the parameter GREEN-RED as shown in Figure 5.7. This parameter is defined in the subframe SATELLITE. The property TRANSLATION, describing the parameter, reads: "the green-red reflectance." PROMPT instructs the client to provide the information or evidence concerning the parameter. The property TYPE is SINGLEVALUED and EXPECT has a POSITIVE-NUMBER. ANTECEDENT-IN lists all the rules having an antecedent mode whose IF statement contains the parameter GREEN-RED. USED-BY lists the rules whose IF statement contains this parameter, but does not have the property ANTECEDENT. HELP is a useful property for helping the client to obtain further information or instruction during consultation. The value of CERTAINTY-FACTOR-RANGE here is UNKNOWN, hence, this value allows the knowledge base not to activate the rules associated with GREEN-RED if the value of this parameter is unknown (a client has to press ENTER for "unknown"). The value of RANGE is between 0 and 300. Note that if the client inputs an unacceptable or unspecified value for these properties, then the value is rejected and the client is prompted to enter a new value. GPROMPT is the same as PROMPT except that this property provides a graphic to the client in addition to the text provided by PROMPT. Note that GPROMPT has a filename CITYCOUN.

It is important to note that the parameter MAXIMUM, from subframe SATELLITE, has a different value for TYPE. This value is either YES or NO. This can be seen in Figure 5.8. Also observe that the value for CERTAINTY-FACTOR-RANGE property is UNKNOWN. Without this latter property, the TYPE value will be either YES or NO; however, by adding the CERTAINTY-FACTOR-RANGE property, a client will have three options, i.e., YES, NO or UNKNOWN. During consultation, these choices are displayed in the screen as a menu.

Examples of the properties HELP and GHELP can be found in Figure 5.8 which shows the parameter MAXIMUM. Here, the value of GHELP is COUNT. The property GHELP prompts a graphic that is displayed simultaneously with the text provided by HELP. In general, properties GHELP and GPROMPT must have a graphic filename since both are in graphic mode.

Table 5.2. Parameters Defined in the Subframe SATELLITE

Parameter	Rules
AVHRR	23, 24, 25, 26, 30, 81, 91, 95
CENTERED	31
FOREST	81, 95
GREEN-RED	23, 24, 25, 26, 27, 28, 30, 81 91, 92, 93, 94, 95
GREEN-RED-PREVIOUS	27, 28, 92, 93, 94
L-S	23, 24, 25, 26, 30, 81, 95
MAXIMUM	80
NIR	23, 24, 25, 26, 30, 81, 95
POND-NIR	29, 93
POND-VIR	29, 93

Table 5.3. Parameters in the Subframe PLANT-PHYSIOLOGY

Parameter	Rules
FUNGI	12
LEAVES	13
LOW-TEMP	2, 4, 6, 7, 14
NIGHT-TEMP	7, 9, 10, 14
PLANTING-DATE	15, 16, 17, 18, 19
SOIL-TEMP	1
SUN	11, 90
WATER-STORAGE	5, 20

Table 5.4. Parameters Defined in the Subframe GROUND

Parameter	Rules
COLOR	61, 68, 69
FIRED	65
HEIGHT	64, 70
LEAN	58
RECOVER-OVERNIGHT	65
SILK-DRY	67
SOIL-STICK	59, 60
WILT	65

Table 5.5. Parameters Defined in the Subframe MODEL

Parameter	Rules
DEW-POINT	36
EARLY-STRESS	88
ETP	36, 38
MODERATE-STRESS-EXTEND	43
RAIN-FREQ	46, 47, 88
SOIL-MOISTURE-LOWER	34
SOIL-MOISTURE-PLOW	34, 35
SOIL-MOISTURE-TOP	33
SUBSOIL-MOISTURE	40, 47
TEMPERATURE	41, 42, 45, 46

GREEN-RED

=====

```
TRANSLATION :: (the green-red reflectance)
PROMPT :: (:ATTR (CYAN HIGH) "Enter the green-red
           reflectance for the crop field" )
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: (RULE025 RULE091 RULE027 RULE092
                  RULE093 RULE094 RULE081 RULE023
                  RULE024 RULE095 RULE026 RULE030 )
USED-BY :: (RULE028)
HELP :: ("The value of green-red reflectance is a
         visual" :LINE "estimate of the AVHRR counts
         using photographic" :LINE "images.":LINE "High
         values of green-red reflectance indicate"
         :LINE "abundant green vegetation." :LINE "A
         value of 250 for AVHRR is considered" :LINE
         "high, while 100 is considered low" :LINE
         "Punch ENTER if this value is not available."
         )
CERTAINTY-FACTOR-RANGE :: UNKNOWN
RANGE :: (0 300)
GPROMPT :: "CITYCOUN"
```

Figure 5.7. Properties of Parameter GREEN-RED

MAXIMUM

=====

```
TRANSLATION :: (the maximum greenness observation
                occurred during this period )
PROMPT :: (:ATTR (CYAN HIGH) "Is this the maximum
           greenness observation for this season ?" )
TYPE :: YES/NO
ANTECEDENT-IN :: (RULE080)
HELP :: ("The greenness can be observed from AVHRR
         digital" :LINE "tapes as greenness counts or
         from AVHRR" :LINE "photographic images as
         green-red reflectance." :LINE "Answer YES if
         the greenness started to decline" :LINE
         "during this period." :LINE "If a decline in
         the greenness has not been" :LINE "observed,
         the maximum green-area probably has" :LINE
         "not been reached yet." )
CERTAINTY-FACTOR-RANGE :: UNKNOWN
GHELP :: (COUNT)
```

Figure 5.8. Properties of Parameter MAXIMUM

The graphic files are constructed using the SNAPSHOT utility provided with PC Plus and graphic packages available in the market. In this project the Dr. Halo graphic program was used. For more details about graphic construction, see the PC Plus Reference Guide. The property PROMPT in a certain frame has a characteristic color. This will make it easy for a client to distinguish what frame he/she is in during the consultation process. The root frame CROP-YIELD-FORECAST uses cyan reverse. The subframes SATELLITE, PLANT-PHYSIOLOGY, GROUND, and MODEL use cyan, cyan reverse, yellow, yellow reverse, respectively.

### 5.3. Production Rules

After determining the parameters and their properties, a knowledge engineer may begin to develop the rules. The rules provided by the experts are usually presented in the form of statements expressed in a natural language (see Appendix B). We wrote the rules in a language called Abbreviated Rule Language (ARL) which can be translated into the English language. The conversion of an expert knowledge into workable rules should be performed in such a way that the expert knowledge is not altered. Each rule must be defined in the frame that contains the rule. The rules for frames CROP-YIELD-FORECAST, SATELLITE, PLANT-PHYSIOLOGY, GROUND, and MODEL are listed in Appendices C, D, E, F, and G. In the following sections we discuss the development of production rules.

#### 5.3.1. The Properties of Production Rules

Here, the subframe SATELLITE is used as an example for defining the rules. First, we chose the activity DEVELOP in the Activity Screen. Then, we entered SATELLITE in the Frame Screen. Next, we selected SATELLITE-RULES in the Frame:SATELLITE Screen. Now, it is possible to define a new rule or modify an existing one. Then, we provided the rules with certain properties. The properties are assigned so that a rule could perform in the desired way. Some of these properties are described here. As an example, in order to find the properties of Rule 29 we must select RULE029 in the Rulegroup-SATELLITE (Figure 5.9). This rule has an ANTECEDENT property. A rule may be in an antecedent or precedent mode. If the rule is in a precedent mode, it is tested only once during the consultation. On the other hand, if the rule has the property ANTECEDENT, it will be tested repeatedly during a consultation. Note also, that a rule is fired only once during the consultation regardless of the number of times the rule is tested.

The IF property contains the conditions that must be satisfied in order to fire a rule. In Rule 29, the IF property indicates: POND-NIR > 200 AND POND-VIR > 200. This



Rulegroup: SATELLITE-RULES

RULE023  
RULE024  
RULE025  
RULE026  
RULE027  
RULE028  
RULE029  
RULE030  
RULE031  
RULE080  
RULE081  
RULE091  
RULE092  
RULE093  
RULE094  
RULE095

13

Figure 5.9. Rule group-SATELLITE.

is an example of a statement in the ARL. The same IF property in English shows "If the Near Infrared Reflectance around ponds is greater than 200, and the Visible Infrared Reflectance around ponds is greater than 200." The THEN property contains the procedure that is executed when the rule is fired. In ARL language, the THEN property is stated as: "SATELLITE-PRODUCTION = 0.9 \* SATELLITE-PRODUCTION AND. . . ." In the English language the THEN property states "it is definite that the production obtained from satellite information is [0.9 times the previous production obtained from satellite information], and. . . ." Rules can also be used to display a particular message or graph. The PC Plus Reference Guide gives a detailed description of these features.

### 5.3.2. Transforming Rules Draft to ARL

A rule draft provided by an expert should be transformed into the ARL. Here, we describe such a transformation using Rule 93 as an example (see Figure 5.10). In Appendix B, the rule draft Number 7 (in Satellite Rules Draft) states the following:

"If the loss in greenness as seen in either AVHRR or L/S-Spot is accompanied by a decrease in the size of small farm ponds then the loss in greenness can be related to drought in the area."

Although this statement contains both an "if" and a "then" clause, it is not yet a readily workable rule. The first step to create a rule out of this statement is to determine the parameters involved. The "loss in greenness" occurs when GREEN-RED (the green-red reflectance) is lower than GREEN-RED-PREVIOUS (the green-red reflectance value of the previous observation). We obtained additional information from the expert for the IF statement in the rule. This new information is about the "decrease in the size of small farm ponds." The expert explained that this reduction can be observed in the readings of near- and visible-infrared-reflectance around small ponds. The parameters POND-NIR and POND-VIR were defined as the near- and visible-infrared-reflectance respectively. The expert also suggested that readings of visible- and near-infrared-reflectance higher than 200 indicated a decrease in the size of small ponds. Furthermore, the expert indicated that this statement holds true if the plants are in vegetative state (one to eleven weeks after planting). To keep this information, the parameter WEEKS was then defined as the number of weeks after planting. After incorporating additional information, the IF property in Rule 93 becomes: GREEN-RED < GREEN-RED-PREVIOUS AND WEEKS BT 1 11 AND (POND-NIR > 200 OR POND-VIR > 200).

RULE093

=====

SUBJECT :: SATELLITE-RULES

ANTECEDENT :: YES

DESCRIPTION :: (7)

- If
- 1) the green-red reflectance is less than the previous green-red reflectance, and
  - 2) the number of weeks after emergence from the soil is less than 11 but greater than or equal to 1, and
  - 3)
    - 1) the Near Infrared Reflectance around ponds is greater than 200, or
    - 2) the Visible Infrared Reflectance around ponds is greater than 200,

Then it is definite (100%) that the additional information obtained from satellite data is The reduction in greenness is due to drought in the area..

IF :: ( GREEN-RED < GREEN-RED-PREVIOUS AND WEEKS BT  
1 11 AND ( POND-NIR > 200 OR POND-VIR > 200 )  
)

THEN :: (SATELLITE-COMMENTS = "The reduction in  
greenness is due to drought in the area." )

Figure 5.10. Rule 93

The "then" statement provided by the expert is treated in a different way. The "then" statement indicates that "the loss in greenness can be related to drought in the area." For this type of observations, we defined the parameter SATELLITE-COMMENTS. This parameter has the property TYPE set to MULTIVALUED so it can contain the comments concluded by the rules that are fired in the subframe SATELLITE. In ARL language, the THEN property is stated as: "SATELLITE-COMMENTS = "The reduction in greenness is due to drought in the area." The complete production rule in ARL language is shown as the following:

```
IF    (GREEN-RED < GREEN-RED-PREVIOUS AND WEEKS BT 1 11 AND
      (POND-NIR > 200 OR POND-VIR > 200) )
THEN(SATELLITE-COMMENTS = "The reduction in greenness is
due to drought in the area.")
```

The complete rule is shown in Figure 5.10 in both English and ARL. Note that when the ARL is translated into English, the term "previous production" was simply written as "production."

Another example is Rule 81 (see Figure 5.11). This rule combines the rule drafts numbers 8, 9 and 10 (see Satellite Rules Draft in Appendix B.) This rule finds the value of the parameter SATELLITE-PRODUCTION as a function of parameters WEEKS and FOREST. WEEKS was explained before, while FOREST indicates how close the AVHRR counts of the crop field to that of a nearby forest. As an example, if the AVHRR count of the crop field is the same as that of a nearby forest, then the value of FOREST should be 100 %. Also, rule draft number 9 states that if FOREST is 100 %, then the expected crop yield production (the value of SATELLITE-PRODUCTION) is 100 %.

The value of parameter SATELLITE-PRODUCTION can be found by other rules. The property DOBEFORE of Rule 81 tells the program to find the value of SATELLITE-PRODUCTION by using rules 25, 26, 30, and 91 before testing Rule 81. After the properties DOBEFORE and IF are satisfied, the property THEN is executed. The property THEN combines the values of SATELLITE-PRODUCTION found by rules 25, 26, 30, 91, and the value of FOREST, to obtain the updated value of SATELLITE-PRODUCTION. Note that in the property THEN, the value of CERTAINTY FOREST is used instead of FOREST. This is due to the special way the parameter FOREST was defined.

The parameter FOREST has the property CERTAINTY-FACTOR-RANGE set to POSITIVE (see Appendix D). The format that PC Plus uses to prompt the client for the certainty factor of a parameter is very user-friendly. In order to take advantage of this, when the client enters the value of FOREST, the property EXPECT was set to LIKE\_FOREST.

```

RULE081
=====
SUBJECT :: SATELLITE-RULES
ANTECEDENT :: YES
DOBEFORE :: (RULE025 RULE026 RULE030 RULE091)
DESCRIPTION :: (8 and 10)
If 1) the number of weeks after emergence from the soil is
    less than 11 but greater than or equal to 7, and
    2) there is no evidence that the percentage of area
        that looks like forest is not LIKE_FOREST, and
    3) 1) the AVHRR greenness counts is known, or
        2) the L-S count is known, or
        3) 1) the green-red reflectance is known, and
            2) the Near Infrared Reflectance is known,
Then it is definite (100%) that the production obtained from
satellite information is [[the production obtained from
satellite information plus the measure of certainty
associated with the percentage of area that looks like
forest] divided by 2].

IF    :: (WEEKS BT 7 11 AND FOREST IS MIGHTBE
        LIKE_FOREST AND (AVHRR IS KNOWN OR L-S IS
        KNOWN OR (GREEN-RED IS KNOWN AND NIR IS KNOWN)
        ) )
THEN :: (SATELLITE-PRODUCTION = ((SATELLITE-PRODUCTION
        + CERTAINTY FOREST ) / 2 ) )

```

Figure 5.11. Rule 81

When the client enters the value of FOREST, the program considers this value as the certainty factor of FOREST. Therefore, in Rule 81, the CERTAINTY FOREST represents the value of FOREST.

Another method to determine the crop yield production (the value of SATELLITE-PRODUCTION) can be seen in Rule 30 (see the complete rule in Appendix D). Rule 30 was developed base on four rules (draft), 1, 2, 3, 14 (see Satellite Rules Draft in Appendix B). We reinterpreted these rules (draft) as the following: "if the AVHRR count or the L-S count is between 210 and 223 or the difference between the green-red reflectance and the near infrared reflectance is between 55 and 60, then the crop yield production can be reduced by 15%." However, the expert added that rule draft number 14 "assumes observations are made at or just prior to silking of corn." Since silking occurs between eight and eleven weeks after planting, then we could consider that rule draft number 14 holds true if observations were made between eight and eleven weeks after planting.

Parameters AVHRR, L-S, GREEN-RED, NIR are defined as the four observations of the "if" part in the first expert's statement. Parameter WEEKS contains the number of weeks after planting. This parameter is also part of the "if" statement. As the expert's "then" statement implies a reduction of 15% in the crop yield (see satellite rule draft number 14), the property THEN of Rule 30 indicates: (SATELLITE-PRODUCTION = 0.85 \* SATELLITE-PRODUCTION) AND. . . .

### 5.3.3. Certainty Factors in Rules

In some cases, the expert may provide a statement with a degree of certainty. A certainty factor of, say, 70 % could mean the expert may consider that there is a seventy percent chance that the statement is true. From the frame CROP-YIELD-FORECAST, an example of these factors is presented in Rule 21 . Figure 5.12 shows the rule. Note that the property THEN in Rule 21 contains parameter PRODUCTION whose TYPE is MULTIVALUED (see Appendix C). Then a certainty factor is assigned in ARL to each value of that parameter. Note that the THEN property of Rule 21 states: "PRODUCTION = (1 \* SATELLITE-PRODUCTION) CF 40 AND PRODUCTION = (1 \* GROUND-PRODUCTION) CF 50 ...." The number that follows the CF is the certainty factor. If a certainty factor is not assigned, the default is 100.

### 5.3.4. Rules that Connect Frames

Rules are also useful to connect the root frame and subframes. An example of this feature is shown in Rule 22 (see Figure 5.13). Here, the THEN property contains the

RULE021

=====

SUBJECT :: CROP-YIELD-FORECAST-RULES

DOBEFORE :: (RULE022)

DESCRIPTION :: (PROD=SAT-PROD,GROUND-PROD,MODEL-  
PROD,PLANT-PHYS)

If the percentage of the optimum crop yield to be used as  
the preliminary production is greater than 0,

Then 1) there is weakly suggestive evidence (40%) that the  
updated expected percentage of the optimum crop  
yield is [1 times the production obtained from  
satellite information], and

2) there is suggestive evidence (50%) that the updated  
expected percentage of the optimum crop yield is [1  
times the production obtained from ground  
information], and

3) there is suggestive evidence (60%) that the updated  
expected percentage of the optimum crop yield is [1  
times the production obtained from plant physiology  
information], and

4) there is suggestive evidence (50%) that the updated  
expected percentage of the optimum crop yield is [1  
times the production obtained from model  
information].

IF :: (INITIAL > 0)

THEN :: (PRODUCTION = (1 \* SATELLITE-PRODUCTION) CF  
40 AND PRODUCTION = (1 \* GROUND-PRODUCTION )  
CF 50 AND PRODUCTION = (1 \* PHYS-PRODUCTION )  
CF 60 AND PRODUCTION = (1 \* MODEL-PRODUCTION )  
CF 50 )

Figure 5.12. Rule 21

RULE022

=====

SUBJECT :: CROP-YIELD-FORECAST-RULES

DESCRIPTION :: (CONSIDERFRAME SATELLITE, GROUND,  
PLANT-PHYSIOLOGY, MODEL )

If the percentage of the optimum crop yield to be used as  
the preliminary production is greater than or equal to 0,

Then 1) it is definite (100%) that the production obtained  
from satellite information is [1 times the  
percentage of the optimum crop yield to be used as  
the preliminary production], and

2) it is definite (100%) that the production obtained  
from ground information is [1 times the percentage  
of the optimum crop yield to be used as the  
preliminary production], and

3) it is definite (100%) that the production obtained  
from plant physiology information is [1 times the  
percentage of the optimum crop yield to be used as  
the preliminary production], and

4) it is definite (100%) that the production obtained  
from model information is [1 times the percentage of  
the optimum crop yield to be used as the preliminary  
production], and

5) instantiate the frame crop yield forecast from  
satellite information if appropriate, and

6) instantiate the frame crop yield forecast from  
ground information if appropriate, and

7) instantiate the frame crop yield forecast from  
plant physiology information if appropriate, and

8) instantiate the frame crop yield forecast from  
model information if appropriate.

IF :: (INITIAL >= 0)

THEN :: (SATELLITE-PRODUCTION = (1 \* INITIAL) AND  
GROUND-PRODUCTION = ( 1 \* INITIAL ) AND PHYS-  
PRODUCTION = (1 \* INITIAL) AND MODEL-  
PRODUCTION = (1 \* INITIAL) AND CONSIDERFRAME  
SATELLITE AND CONSIDERFRAME GROUND AND  
CONSIDERFRAME PLANT-PHYSIOLOGY AND  
CONSIDERFRAME MODEL )

Figure 5.13. Rule 22



instruction CONSIDERFRAME SATELLITE. This causes the root frame to access the subframe SATELLITE when the IF property is satisfied.

#### 5.3.5. Rules that Call External Files

Section 5.2.1. explains how PC Plus can call an external program by using the property METHOD in the parameter LOCATION. Rules can also be used to integrate external files into PC Plus. An example of this is Rule 22 (see Appendix C).

The property THEN of Rule 22 contains the commands DOS-CALL and DOS-FILE-IN. DOS-CALL is used to call the external program NSEW.EXE. This program reads the file ZONE.PCD which contains the global coordinates of the crop field selected in a consultation, and transfers the coordinates to a new file that can be easily accessed by PC Plus. The new file is ZONE.RD. DOS-FILE-IN is used to read the file ZONE.RD and assigns the first value from this file that shows the zone of the desired crop field to the parameter LOCATION.

#### 5.4. Geographic Interface

The purpose of the Geographic Interface (GI) is to create a graphic display of every county in the USA. GI allows the client to select any region of the USA from a set of maps (this set includes regions and states) that the program displays on screen during consultation. It also offers a zooming capability that expands any area selected by the client. For the states of Ohio, Iowa, Indiana and Illinois, GI offers a display of the typical soil moisture and corn loss. In future studies this feature will be expanded to every state. This interface will also be expanded to include other type of data such as meteorological and topographical.

During consultation, GI creates a file that contains the X and Y global coordinates of the area selected by the client. The global coordinates are those commonly used to identify any place in the world. Rule draft number 2.d (see Rule Draft Plant Physiology in Appendix B) uses the location of the crop field to determine the effect of the planting date on the crop production. The location of the crop field is also important for other sources of information, such as meteorological and topographical, that will be a part of CROPCAST OSU in the near future.

## 6. BUILDING A RUNTIME VERSION FOR THE PROGRAM

Once the knowledge base is developed, we can transfer it to a runtime version using the BUILD activity. This runtime mode allows the client to consult the program without PC Plus. Hence, the program is compiled and protected from being read or written. To construct the runtime version, the following steps have to be followed:

Step 1: Make a copy of the PC PLUS RUNTIME disk to the BUILD disk. The PC PLUS RUNTIME disk contain files necessary to make the runtime version of our program.

Step 2: Load the PC Plus and select CROPCAST OSU (the name of our program) in the Knowledge Bases Screen. Select the disk drive where the BUILD disk is inserted, then activate the BUILD activity.

Step 3: Copy the external programs (in this case graphic programs) onto the BUILD disk.

Now the disk is ready for consulting purposes. The CONSULT activity is presented in the next chapter.

## 7. CONSULTING THE EXPERT SYSTEM

Consultation could be performed by the client through the BUILD disk or by the knowledge engineer through the use of the program in PC Plus by selecting the CONSULT activity. In this chapter, we discuss the hardware requirement, installation procedure, important commands for the client, and the use of the mouse. This discussion is followed by an illustration of a consultation through a self-explanatory screen-by-screen sequence.

### 7.1. Hardware requirement

The minimum hardware requirements are:

- IBM PC, IBM XT, IBM AT, IBM PS/2, or compatibles.
- 640 Kb RAM.
- One double side double density floppy drive and a hard drive with at least 3 Mb available.
- IBM VGA Color graphics card and monitor.
- Optional equipment is a Microsoft or Logitech mouse and a printer.

### 7.2. Installation

In order to install this program, one is expected to have some basic knowledge of MS DOS. The program must be installed in the hard drive. The first step of the installation is to create four directories in the hard drive. They are CROPCAST, TURBO4, CIS and MAPS. In the directory TURBO4, create two subdirectories: TP and PIC. In the directory CIS create the subdirectory DATA.

Next, copy the System Disk (the disk produced in Activity BUILD) into the directory CROPCAST, the Maps disk (external graphics program) into the directory MAPS, the Picture Disk (external graphic program) into the subdirectory PIC. Then, copy the Utility Disk (external graphics program) into the subdirectory TP, and copy the Data Disk into the subdirectory DATA. Now the program is ready for consultation.

### 7.3. Important Commands

CROPCAST OSU provides several commands that allow the client/user to save, retrieve, print, or modify the consultation data. To make use of a command before, during, or after a consultation, simply press F2. A menu with available commands is displayed. To select a command, just move the cursor using the arrow keys in the computer keyboard.

The command CONTINUE lets the user continue the

consultation in normal routine. If this command is called at the end of a consultation, the program begins a new consultation. The command EXIT allows the user to quit CROPCAST OSU. The command GET PLAYBACK FILE allows the user to load the data used in a previous consultation. This data must have been saved previously by using the command SAVE PLAYBACK FILE. The command HOW tells the user how the program has reached the conclusions of the consultation. The command NEW START lets the user quit the current consultation and start a new one. PRINT CONCLUSIONS prints a list of the parameters and the values entered by the users. This command also prints the conclusions. The command REVIEW allows the user to modify the data that were previously entered during the consultation or after using the command GET PLAYBACK FILE.

If the command REVIEW is used during a consultation, the program displays the list of the parameters and their respective values that the user has entered. In this list, the user can choose the parameters that need to be modified. To select the parameter, use the up and down arrow keys in the computer keyboard. When the desired parameter is highlighted, use the right arrow key. The user can select as many parameters as needed. After the parameters that need modification have been selected, press ENTER. The program will prompt the user with new values for the selected parameters and the consultation may continue. If the command REVIEW is called at the end of a consultation or after a file has been retrieved by using the command GET PLAYBACK FILE, the user can test the influence of different parameters on the result of the crop. This is particularly useful if the user does not have accurate information about certain parameters and wants to run some "what if" tests and find the possible results. The command WHY explains why a parameter that is prompted is required during the consultation.

#### 7.4. The Use of Mouse

The use of mouse is optional, but due to the increasing popularity of this device, its support was considered. To install the mouse, simply copy the file MOUSE.COM that comes with the Utility disk of the mouse into the CROPCAST directory. If that utility comes with a different name such as GMOUSE.COM or LMOUSE.COM there are two alternatives. The first is to rename the file to MOUSE.COM. The second is to modify the file CC.BAT in the CROPCAST directory. Check the MS DOS manual for instructions on how to modify the CC.BAT file. If the mouse uses three buttons, usually the left, middle, and right buttons are equivalent to the ENTER, ESC, and F2 keys, respectively. In the case of this type of mouse, pressing the left and right buttons simultaneously is equivalent to the F1 key (used to obtain HELP window). If

the mouse uses four buttons, the right and left buttons are equivalent to the ENTER and F2 key, respectively. Pressing the two buttons simultaneously is equivalent to the key ESC. The mouse can also be used to make selections in the menus. To move the cursor in a menu, just move the mouse in the up/down direction. To select items in a multiple choice menu, move the mouse in the left/right direction.

#### 7.5. Consultation: An Illustration

A client starts the consultation after installing the five disks into the hard drive (see Section 7.2.). Then insert the Utility Disk into drive A. Next, change to CROPCAST directory in the hard drive, and type CC before pressing ENTER.

A list of knowledge bases appears on the screen. Select CROPCAST from the list, then press ENTER. A welcome screen with a copyright sign is displayed; then press ENTER. Next are screens showing sequence of queries for the client to answer. For help during any stage of the consultation, simply press F1. After consultation is completed, press F2, and from the menu that is displayed choose EXIT. The following figures show the screens in sequential order during a consultation process. They are self-explanatory and on-screen help is available by pressing F1. Note that in the following figures, the underlined value is the choice made by the client.

Note that at a certain stage during the consultation a list of states or groups of states is displayed. Select one option by pressing the number that corresponds to the desired zone, and followed by ENTER. The map of the selected zone is now displayed. Note that a list of function keys and available commands is displayed at the bottom of the screen. The next step is to select the particular county or counties. To do this, press the function key that corresponds to the ZOOM command (press F2). A red frame appears on the screen. This frame encloses the desired zone to be zoomed. To move the lines of the frame, use the keyboard as indicated in the instructions at the bottom of the screen. Press F2 or F3 before using the arrows, Home, End, Page Up, and Page Down keys. After reaching the desired zone, press F6 key to zoom. Use F3 key to save it. Then, the program asks for a file name twice. At this stage, enter a file name ZONE at both times. Answer Yes to overwrite the filename. The FILLDATA command (F8 key) allows the client to color the selected zone. The on-screen help is available by pressing F1. Press F10 key to exit from the geographic display to continue the consultation. CROPCAST OSU will lead the client through the rest of the consultation.

Texas Instruments Personal Consultant (tm) Series

Knowledge bases: CROPCAST



Current objective: \_\_\_\_\_

Crop Yield Forecast  
\*\*\*\*\*

\*\* End - press ENTER to continue.

Enter the preliminary assessment of the crop yield

100

Help: \_\_\_\_\_

Enter the result of the previous consultation  
in percentage of the optimum crop yield.  
If this is the first consultation enter 100.  
This percentage will be updated during the  
consultation.

\*\* End - press ENTER to continue.

1. Enter a positive number.
2. press ENTER to continue.

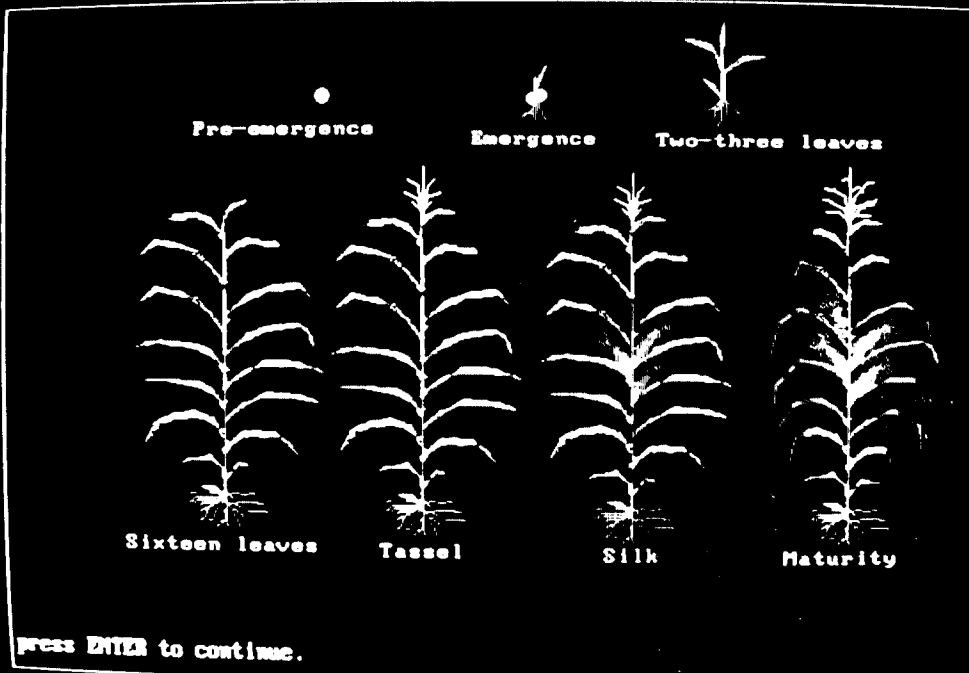
CROPCAST OSU, Copyright 1989, The Ohio State University

1. Select the growth stage of corn plant

- Yes
- PRE\_EMERGENCE
  - EMERGENCE
  - TWO\_LEAVES
  - FOUR\_TO\_SIX\_LEAVES
  - **SIXTEEN\_TO\_FOURTEEN\_LEAVES**
  - Tassel
  - SILK
  - POLLINATION
  - FILL\_STAGE
  - MATURITY
  - HARVEST\_STORAGE

1. Use arrow key or first letter of item to position the cursor.
2. Select all applicable responses.
3. After making selections, press ENTER to continue.

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Enter the number of weeks after emergence from the soil

6

Help:

Punch ENTER if this value is unknown.

\*\* End - press ENTER to continue.

1. Enter a positive number.
2. press ENTER to continue.

Enter YES if the crop was flooded before the plants had at least two leaves.

YES

NO

UNKNOWN

Help:

Select UNKNOWN only if there is uncertainty about the occurrence of flooding. This parameter is important only during the early stages of the plant.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

Enter the highest temperature observed before pollination in Fahrenheit.

80

Help:

This value comes from the observations of the current year.  
Punch ENTER if this temperature is unknown.  
This parameter is of low importance during the early stages of the plant, but it is very important during the late stages of the plant.

\*\* End - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

Enter the soil moisture as a percentage of its capacity.

60

Help:

The soil moisture can be measured in various ways. Gravimetric, where the moisture is determined by weighting a sample before and after drying. Newton Detection, where a source of nuclear radiation is used. This method is less accurate than the Gravimetric near the surface.

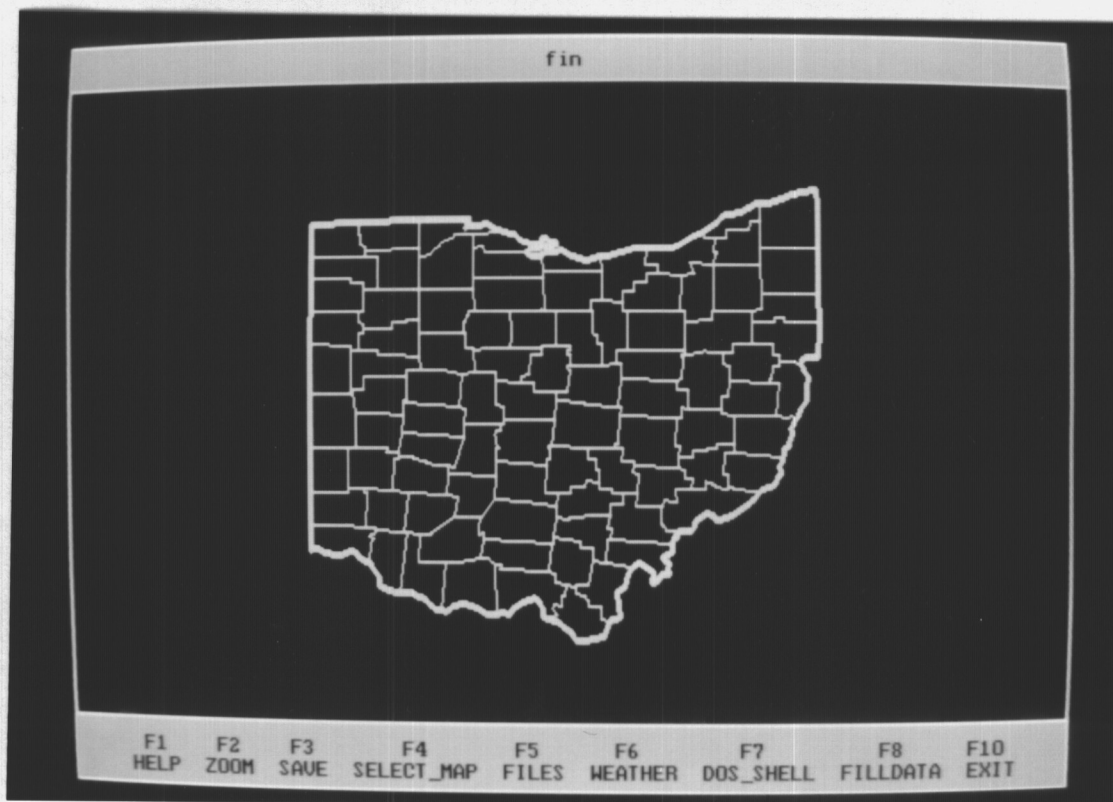
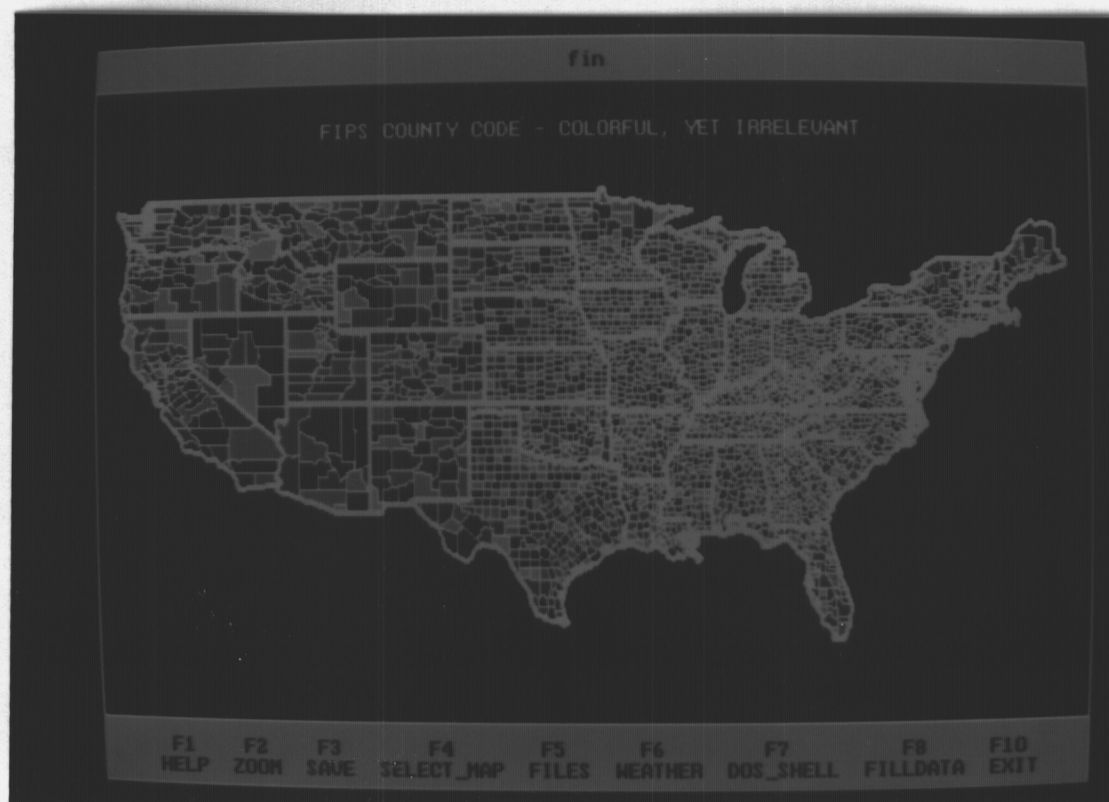
This parameter is very important during the late stages of the plant.

Enter the soil moisture in percentage of the

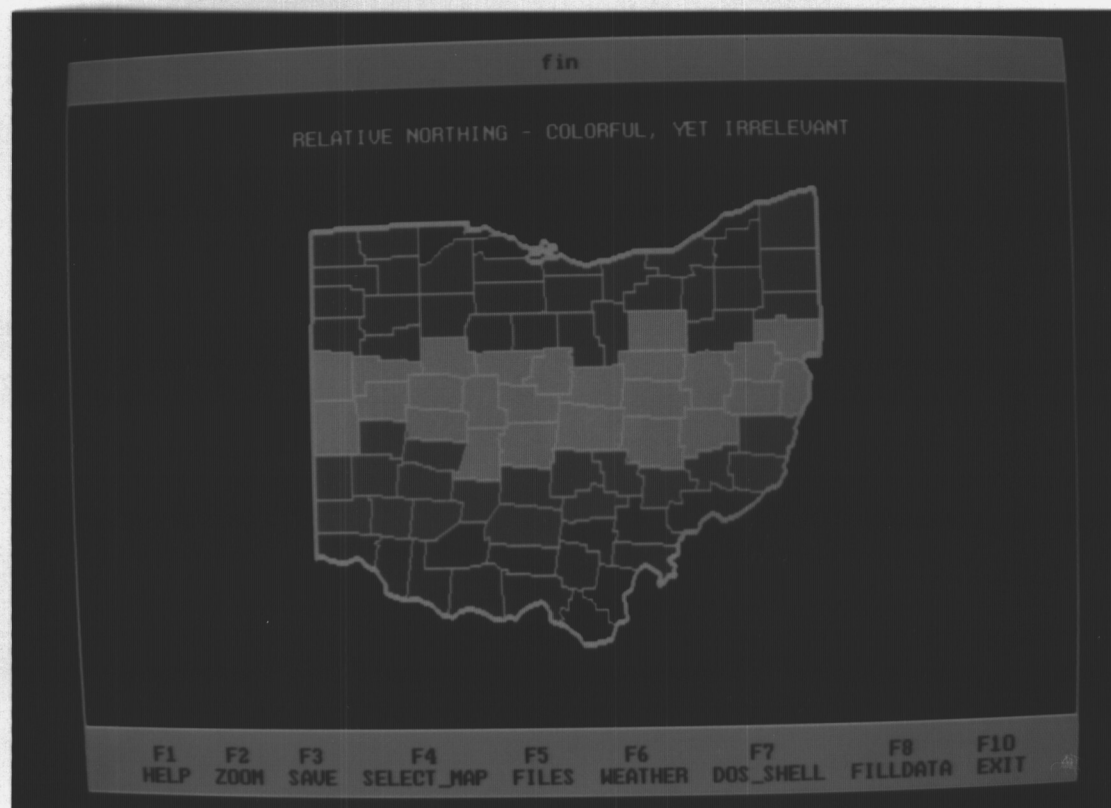
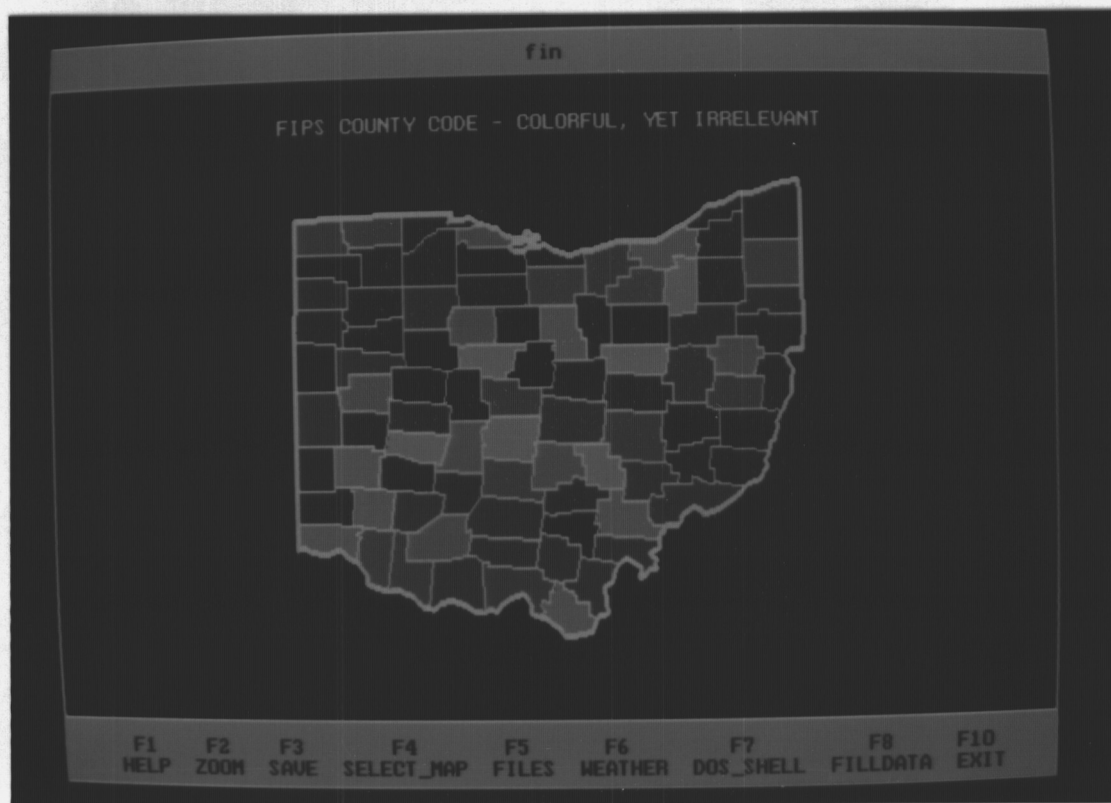
\*\* More - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

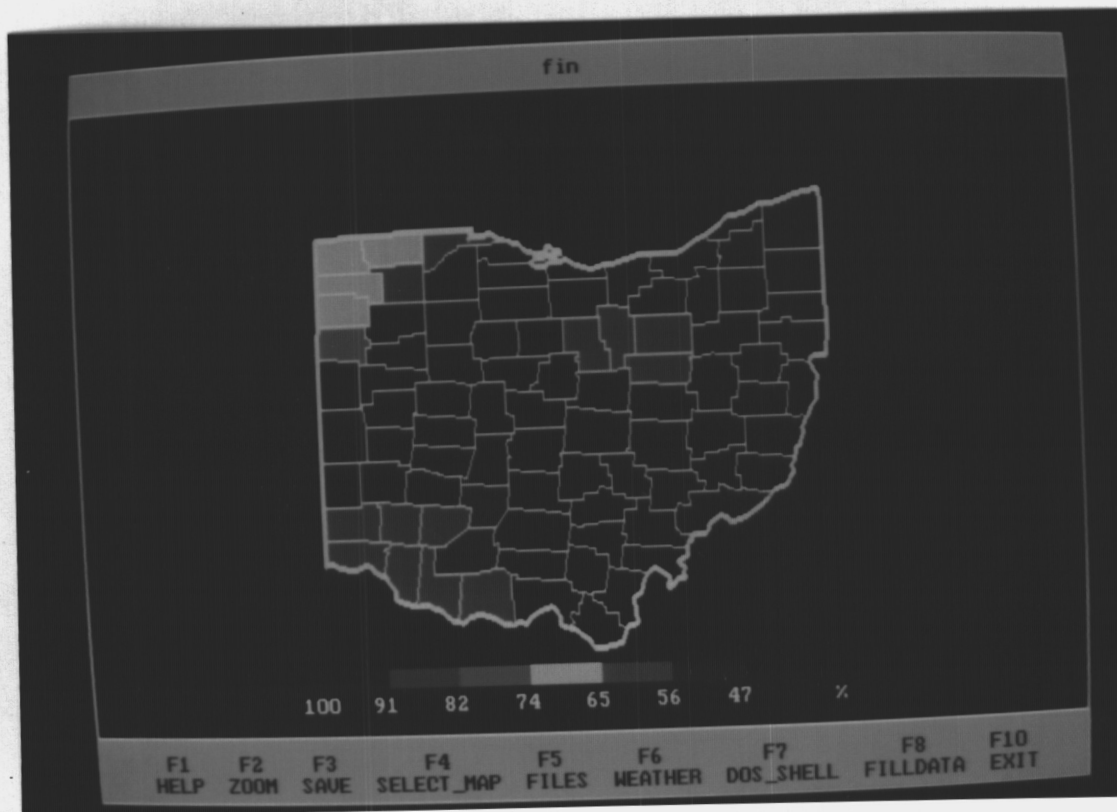
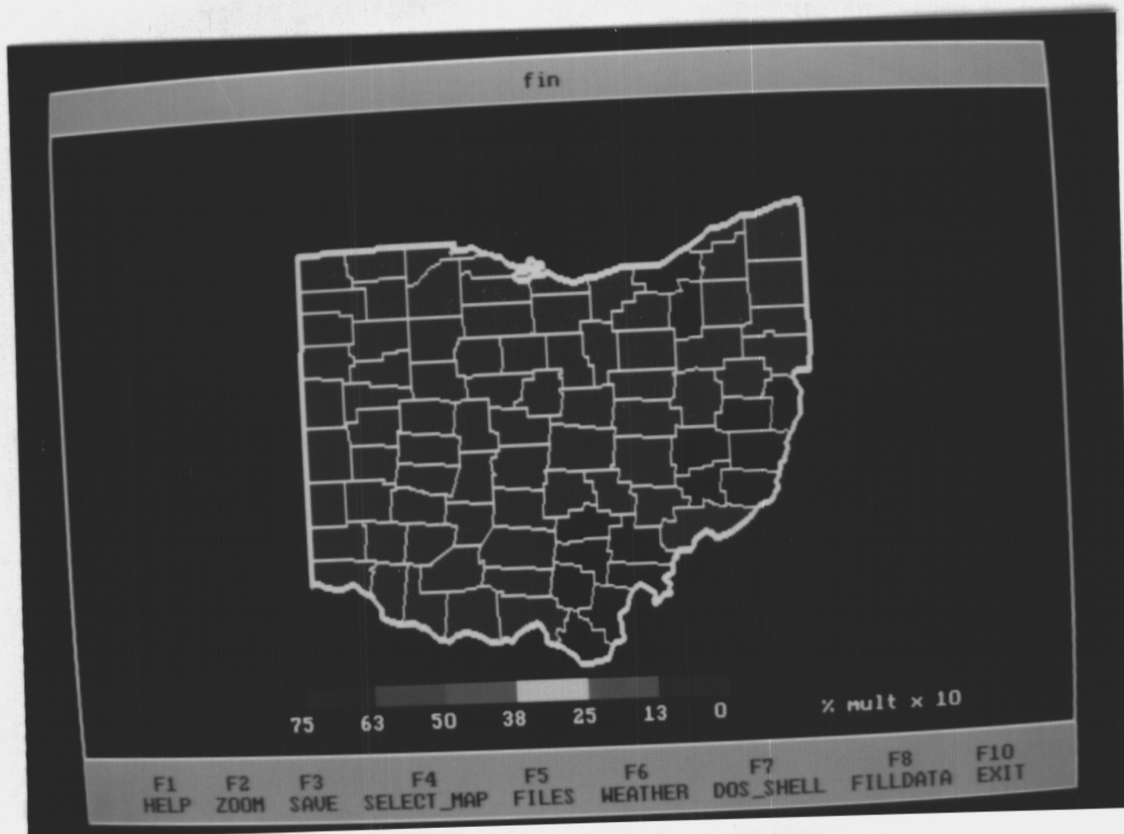
ORIGINAL PAGE  
COLOR PHOTOGRAPH



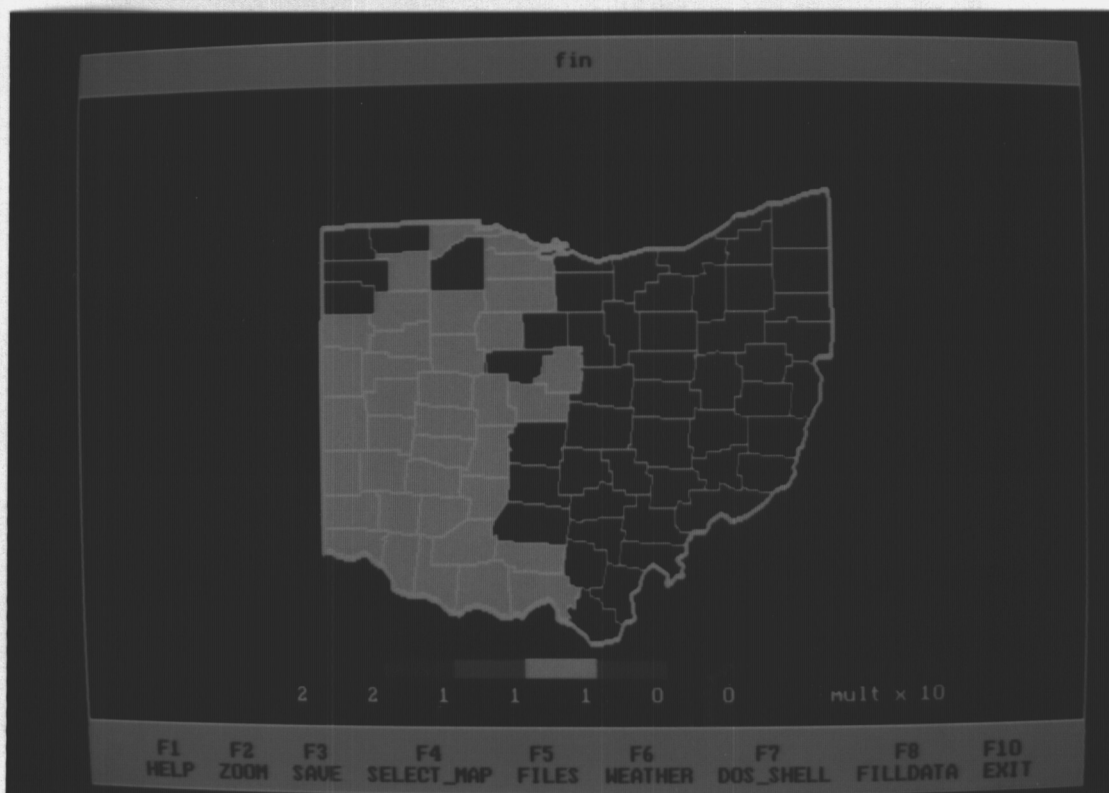
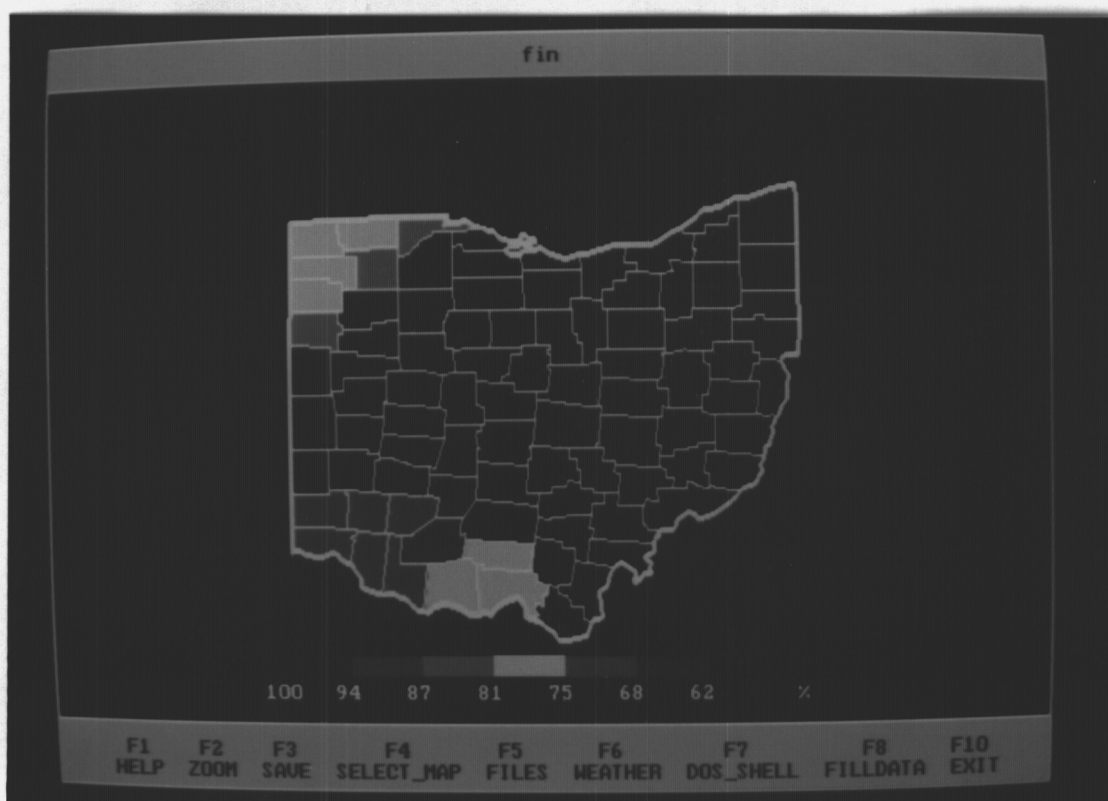
ORIGINAL PAGE  
COLOR PHOTOGRAPH



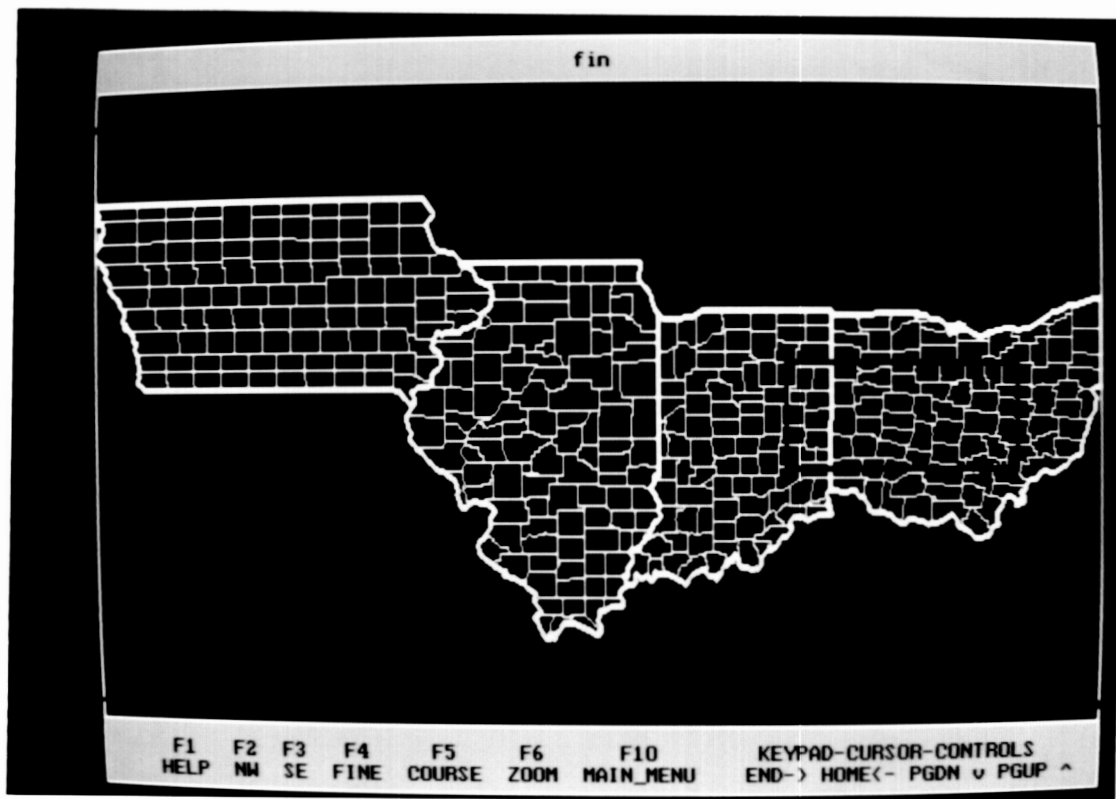
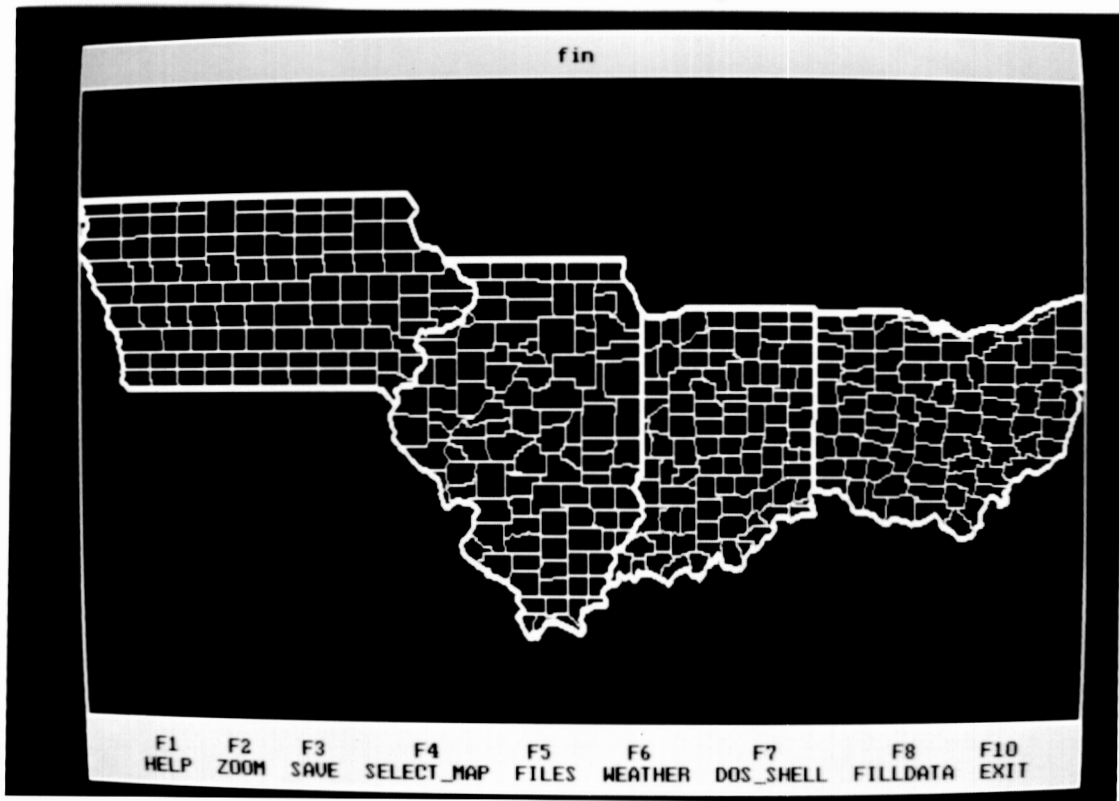
ORIGINAL PAGE  
COLOR PHOTOGRAPH



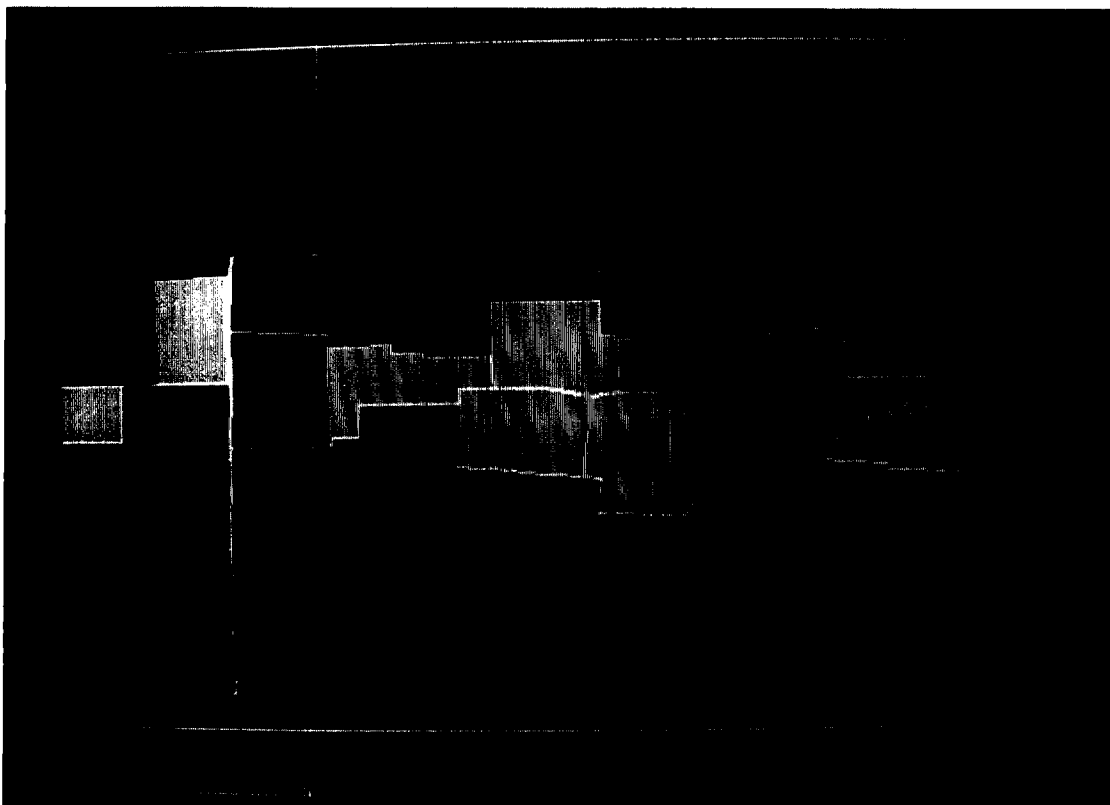
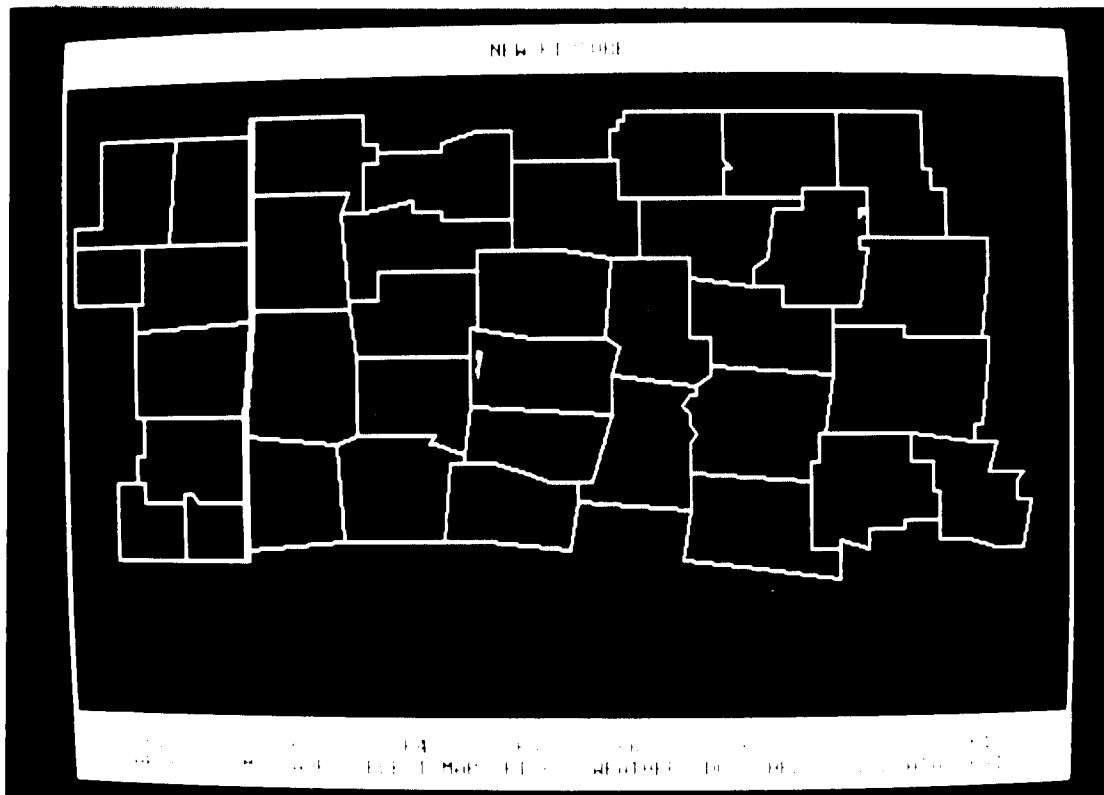
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COLOR PHOTOGRAPH



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COLOR PHOTOGRAPH



ORIGINAL PAGE  
COLOR PHOTOGRAPH





Current objective: \_\_\_\_\_

SATELLITE INFORMATION  
\*\*\*\*\*

\*\* End - press ENTER to continue.

Enter the AVHRR greenness counts

150

Help: \_\_\_\_\_

AVHRR (Advanced Very High Resolution Radiometer) greenness counts are digital values derived from the AVHRR sensor digital tapes. High values of AVHRR greenness counts indicate that a high percentage of the crop field is covered by green vegetation. A value of 250 for AVHRR is considered high, while 100 is considered low. Punch ENTER if the AVHRR greenness count is not available.

\*\* End - press ENTER to continue.

1. Enter a positive number.
2. press ENTER to continue.

ORIGINAL PAGE  
COLOR PHOTOGRAPH

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Enter the value of the L-S count

160

Help:

This observation can be obtained from digital tapes provided by the Landsat information. High values of L-S count indicate that a high percentage of the crop field is covered by green vegetation. Punch ENTER if this value is not available.

\*\* End - press ENTER to continue.

1. Enter a positive number.
2. press ENTER to continue.

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Enter the green-red reflectance for the crop field

150

- ☐ EXCELLENT
- ☐ GOOD
- ☐ FAIR
- ☐ POOR
- ☐ UNCLASSIFIED



CITY

1. Enter a positive number.
2. press ENTER to continue.

ORIGINAL PAGE  
COLOR PHOTOGRAPH

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Enter the green-red reflectance for the crop field

150

Help:

The value of green-red reflectance is a visual estimate of the AVHRR counts using photographic images.

High values of green-red reflectance indicate abundant green vegetation.

A value of 250 for green-red reflectance is considered high, while 100 is considered low.

Punch ENTER if this value is not available.

\*\* End - press ENTER to continue.

FOREST

CITY

1. Enter a positive number.
2. press ENTER to continue.

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Enter the previous green-red reflectance for the crop field

140

Help:

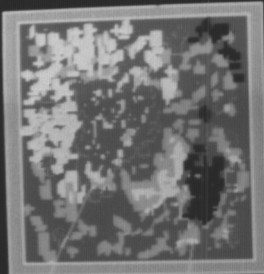
The previous green-red reflectance observation is obtained from the previous AVHRR information. The value of green-red reflectance is a visual estimate of the AVHRR counts using photographic images.

High values of green-red reflectance indicate abundant green vegetation.

A value of 250 for green-red reflectance is considered high, while 100 is considered low.

Punch ENTER if this value is not available.

\*\* End - press ENTER to continue.



FOREST

CITY

1. Enter a positive number.
2. press ENTER to continue.

ORIGINAL PAGE  
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Enter the observation for Near Infrared Reflectance

100

Help:

The Near Infrared Reflectance (NIR) is the reflected energy received at the satellite in the NIR spectrum.  
The NIR spectrum is the part of the micrometer spectrum that cannot be observed by human vision.  
High values of NIR indicate poor vegetation on the crop field.  
A value of 200 for NIR is considered high.  
Punch ENTER if the NIR value is not available.  
  
\*\* End - press ENTER to continue.

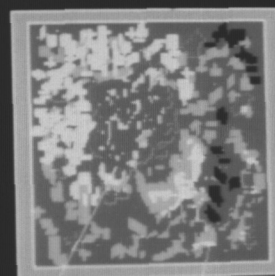
1. Enter a positive number.
2. press ENTER to continue.

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Indicate how close is the greenness of the crop field to that of a forest

Yes  
■■■■■■... LIKE FOREST

■ EXCELLENT  
■ GOOD  
■ FAIR  
■ POOR  
■ UNCLASIFIED



FOREST

CITY

1. Use arrow key to indicate your degree of certainty.
2. To select one item, with 100% certainty, press CTRL-right arrow.
3. After making selections, press ENTER to continue.

ORIGINAL PAGE  
COLOR PHOTOGRAPH

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Indicate how close is the greenness of the crop field to that of a forest

Yes  
#####...

LIKE\_

Help:

To compare the greenness count of the crop field and the greenness count of a city, observe the AUMER photographic images. You can use greenness counts from digital tapes or green-red reflectance from photographic images. Punch ENTER if this value is not available.

== End - press ENTER to continue.

1. Use arrow key to indicate your degree of certainty.
2. To select one item, with 100% certainty, press CTRL-right arrow.
3. After making selections, press ENTER to continue.

YES  
NO  
UNKNOWN



Enter the observation of Near Infrared Reflectance (NIR) around ponds

150

Help: \_\_\_\_\_

The Near Infrared Reflectance (NIR) is the reflected energy received at the satellite in the NIR spectrum.

The NIR spectrum is the part of the micrometer spectrum that cannot be observed by human vision.

High values of NIR around ponds indicate severe evaporation of water.

A value of 200 for NIR is considered high.

Punch ENTER if this value is not available.

\*\* End - press ENTER to continue.

1. Enter a positive number.
2. press ENTER to continue.

Enter the observation of Visible Infrared Reflectance around ponds

150

Help: \_\_\_\_\_

The Visible Infrared Reflectance (VIR) is the reflected energy received at the satellite in the VIR spectrum.

The VIR spectrum is that part of the micrometer spectrum that can be observed by the human vision.

High values of VIR around ponds indicate severe evaporation of water.

A value of 200 for VIR is considered high.

Punch ENTER if this value is not available.

\*\* End - press ENTER to continue.

1. Enter a positive number.
2. press ENTER to continue.

Current objective: \_\_\_\_\_

GROUND INFORMATION  
\*\*\*\*\*

\*\* End - press ENTER to continue.

Select the color of the corn plants

BRIGHT-GREEN  
DARK-GREEN  
YELLOW  
BROWN  
UNKNOWN

Help: \_\_\_\_\_

The color of the corn plants is the main color of the plant. It can be bright green, dark green, yellow, or brown.  
Select UNKNOWN if there is no information about this variable.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

Are the lower leaves of the plants fired ?

YES  
NO  
UNKNOWN

Help: \_\_\_\_\_

When the leaves of plants are fired, the surface of the leaves is extremely dry and is not green.  
Select UNKNOWN if there is no information about it.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

Enter the height of the plant by July 4 (in feet)

4

Help: \_\_\_\_\_

Punch ENTER if the height of corn plants was not measured.

\*\* End - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

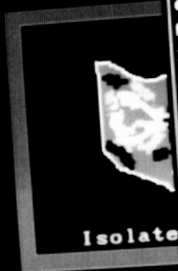


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Is the green area an isolated spot

YES  
NO  
UNKNOWN



Help:

The green area can be observed in the AVHRR digital tapes as greenness counts or in the AVHRR photographic images as green-red reflectance. Select UNKNOWN if undecided.

== End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

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Is this the maximum greenness observation for this season?

YES  
NO  
UNKNOWN



Help:

The greenness can be observed from AVHRR digital tapes as greenness counts or from AVHRR photographic images as green-red reflectance. Answer YES if the greenness started to decline during this period. If a decline in the greenness has not been observed, the maximum green-area probably has not been reached yet.

== End - press ENTER to continue

1. Use arrow key or first letter of item to position the cursor
2. press ENTER to continue

ORIGINAL PAGE  
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Is the outside row of corn plants leaning or falling down ?

YES  
NO  
UNKNOWN

Help: \_\_\_\_\_

Select UNKNOWN if there is no information about it.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

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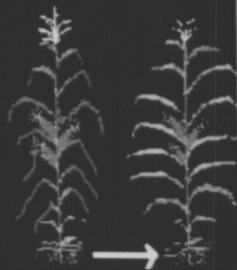
Do the corn plants recover overnight from wilt ?

YES  
NO  
UNKNOWN

Help: \_\_\_\_\_

When the plant wilts, it becomes less fresh, bends, and starts to die.  
Select UNKNOWN if there is no information about it.

\*\* End - press ENTER to continue.



1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

Are the silks dry ?

YES  
NO  
UNKNOWN

Help:

Select UNKNOWN if there is no information about it.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

The soil is wet or so dry that it...

sticks to your shoes  
is picked up by the wind  
UNKNOWN

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

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Is wilt observed in the upper leaves ?

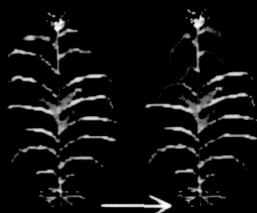
YES  
NO  
UNKNOWN

Help:

When the plant wilts, it becomes less fresh,  
bends, and start to die.

Select UNKNOWN if there is no information about  
it.

\*\* End - press ENTER to continue.



wilt on upper leaves

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

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Current objective: \_\_\_\_\_

PLANT PHYSIOLOGY INFORMATION  
\*\*\*\*\*

\*\* End - press ENTER to continue.

Enter the planting date

EARLIER  
MARCH-15-22  
MARCH-23-31  
APRIL-1-6  
APRIL-7-15  
APRIL-16-30  
MAY-1-10  
MAY-11-21  
MAY-22-31  
JUNE-1-11  
LATER  
UNKNOWN

Help: \_\_\_\_\_

Select the period that is closest to the  
believed planting date.  
Select UNKNOWN only if the date of planting is  
definitely unknown.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

Enter the lowest temperature during the last growth stage in Fahrenheit.

65

Help: \_\_\_\_\_

This value comes from the observations  
of the current year.  
Punch ENTER if this temperature is unknown.  
This parameter is very important during the  
early stages of the plant.

\*\* End - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

Enter the highest temperature at NIGHT-TIME during the last growth stage in Fahrenheit.

75

Help:

This value comes from the observations of the current year.  
Punch ENTER if this temperature is unknown.  
This parameter is of low importance during the early stages of the plant, but it is very important during the late stages of the plant.

\*\* End - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

Enter the average low temperature of the SOIL during germination in Fahrenheit.

65

Help:

The soil temperature can be measured with thermometers at various levels in the soil. The values are often recorded continuously to provide more accurate data.  
This parameter is not important during the late stages of the plant, but is critical during the early stages of the plant.  
Punch ENTER if this parameter is not available.

\*\* End - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

Enter the available ground-water storage for the crop at the beginning of the season (in inches).

10

Help:

An inch of water storage is the equivalent to an inch of rain over the entire crop. The beginning of the season is the time when the corn seeds are planted. Punch ENTER if the amount of ground-water storage is unknown.

\*\* End - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

Indicate the average percentage of weekly sunny days after tassel development.

Yes  
■■■■■..... SUNNY

Help:

This value comes from the observations of the current year. This parameter is not important during the early stages of the plant, but it is critical during the late stages of the plant. Each little square is equivalent to 10%. Punch ENTER if this information is not available.

\*\* End - press ENTER to continue.

1. Use arrow key to indicate your degree of certainty.
2. To select one item, with 100% certainty, press CTRL-right arrow.
3. After making selections, press ENTER to continue.

ORIGINAL PAGE  
COLOR PHOTOGRAPH

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Indicate the percentage of leave loss of the corn plants.

Yes  
■.....

LEAVE

Help:

This value comes from the observation of the corn plants in the field.  
High leave loss may reduce the crop yield.  
This parameter is particularly important during the late stages of the plant.  
Each little square is equivalent to 10%.  
Punch ENTER if this information is not available.

\*\* End - press ENTER to continue.

1. Use arrow key to indicate your degree of certainty.
2. To select one item, with 100% certainty, press CTRL-right arrow.
3. After making selections, press ENTER to continue.

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Indicate the percentage of plants where fungi was observed.

Yes  
\* .....

PERCE

Help:

Fungi can be observed on corn plant leaves as yellowish discolorations.  
Extreme conditions of fungi can produce high levels of aflatoxin which makes the corn unusable for human consumption. This is particularly critical during and after the maturity of the plant.  
Each little square is equivalent to 10%.  
Punch ENTER if there is no available information about fungi.

\*\* End - press ENTER to continue.

1. Use arrow key to indicate your degree of certainty.
2. To select one item, with 100% certainty, press CTRL-right arrow.
3. After making selections, press ENTER to continue.



Current objective: \_\_\_\_\_

MODEL INFORMATION  
\*\*\*\*\*

\*\* End - press ENTER to continue.

Enter the dew point during the periods from late vegetative to soft dough  
in Fahrenheit

68

Help: \_\_\_\_\_

Dew point is the temperature at which small drops of moisture condense on the surface of the plant. The dew point is also used as a measure of the actual moisture the air can contain. If the dew point is large, there is a large amount of moisture in the air. Punch ENTER if this parameter is not available.

\*\* End - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

Enter the maximum value of ETP for two or more continuous days

5

Help: \_\_\_\_\_

ETP: the demand of water on the plant by the atmosphere in terms of solar heat, wind, humidity, etc.

A value of 10 for ETP is considered high.

Punch ENTER if there is no information about ETP.

\*\* End - press ENTER to continue.

1. Enter a number.
2. press ENTER to continue.

Does moderate stress have occurred since the early growth of the plants ?

YES

NO

UNKNOWN

Help: \_\_\_\_\_

Select YES if moderate stress has occurred since the emergence of the plants.

Stress is any factor that impacts the photosynthetic efficiency of the plant.

An example for "moderate stress" is soil moisture around 40 percent and temperature around 80 degrees Fahrenheit.

Select UNKNOWN if no records are available.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

Are the periods of moderate stress interrupted by light showers ?

YES  
NO  
UNKNOWN

Help: \_\_\_\_\_

An example of moderate stress is soil moisture  
arround 40 and the temperature arround 80  
degrees.

Select UNKNOWN if:

- 1) Information is not available.
- 2) There has not been moderate stress.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

Does rain occur at regular intervals ?

YES  
NO  
UNKNOWN

Help: \_\_\_\_\_

Select UNKNOWN if there is no information about  
rain events.

\*\* End - press ENTER to continue.

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.

ORIGINAL PAGE  
COLOR PHOTOGRAPH

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Enter the value of moisture (in percentage) in the top soil layer during the first two weeks after planting

70

Help:

The top soil is often referred as the soil on the surface or fresh top soil. The soil moisture can be measured in various ways. Gravimetric, where the moisture is determined by weighting a sample before and after drying. Newton Detection, where a source of nuclear radiation is used. This method is less accurate than the Gravimetric near the surface.

Enter the soil moisture in percentage of the

\*\* More - press ENTER to continue.

TOP LAYER  
PLOW LAYER  
LOWER LAYER  
SUBSOIL



1. Enter a number.
2. press ENTER to continue.

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Enter the value of soil moisture (in percentage) in the plow layer

65

Help:

under the top soil but not deeper than one foot. The soil moisture can be measured in various ways. Gravimetric, where the moisture is determined by weighting a sample before and after drying. Newton Detection, where a source of nuclear radiation is used. This method is less accurate than the Gravimetric near the surface.

Enter the soil moisture in percentage of the soil capacity. the soil capacity is the amount of water in the soil when the soil is saturated. Punch ENTER if this parameter is not available.

\*\* End - press ENTER to continue.

TOP LAYER  
PLOW LAYER  
LOWER LAYER  
SUBSOIL



1. Enter a number.
2. press ENTER to continue.

ORIGINAL PAGE  
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Enter the value of soil moisture (in percentage) in the lower layer

50

Help:

The lower layer of soil is often referred as the soil between the plow layer and the roots of the plant.

The soil moisture can be measured in various ways. Gravimetric, where the moisture is determined by weighting a sample before and after drying. Newton Detection, where a source of nuclear radiation is used.

Enter the soil moisture in percentage of the soil capacity. The soil capacity is the amount of water in the soil when the soil is saturated. Punch ENTER if this parameter is not available.

== End - press ENTER to continue.



1. Enter a number.
2. press ENTER to continue.

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Enter the value of subsoil moisture in percentage

40

Help:

The subsoil is often referred as the soil below the root of the corn plant.

The subsoil moisture can be measured in various ways. Gravimetric, where the moisture is determined by weighting a sample before and after drying. Newton Detection, where a source of nuclear radiation is used.

Enter the subsoil moisture in percentage of the subsoil capacity. The subsoil capacity is the amount of water in the subsoil when the subsoil is saturated.

Punch ENTER if this parameter is not available.

== End - press ENTER to continue.



1. Enter a number.
2. press ENTER to continue.

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Enter the highest temperature in Fahrenheit during the growing periods.

80

Help:

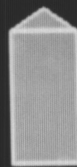
Punch ENTER if the highest temperature is unknown.

\*\* End - press ENTER to continue.

1. Enter a positive number.
2. press ENTER to continue.

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Excellent  
Good  
Fair  
Poor  
Very Poor



Conclusions:

The location of the crop field in question is as follows: 5

The production obtained from satellite information is as follows: 100

The additional information obtained from satellite data is as follows: There is positive prove of germination. The green area is either an irrigated field or picked a local shower.

The production obtained from ground information is as follows: 81.

The additional information obtained from ground data is as follows: The coloring of the plants indicates reduction of crop yield. Ample soil moisture allows reasonable growth. Reduction of crop yield due to late growth stage.

The production obtained from plant physiology information is as follows: 100

The additional information obtained from plant physiology data is as follows:  
No additional reduction of the crop yield was found in this consultation.

\*\* More - press ENTER to continue.

Conclusions:

The additional information obtained from ground data is as follows: The coloring of the plants indicates reduction of crop yield. Ample soil moisture allows reasonable growth. Reduction of crop yield due to late growth stage.

The production obtained from plant physiology information is as follows: 100

The additional information obtained from plant physiology data is as follows:  
No additional reduction of the crop yield was found in this consultation.

The production obtained from model information is as follows: 100

The additional information obtained from model data is as follows: No additional reduction of the crop yield was found in this consultation.

The updated expected percentage of the optimum crop yield is as follows: 100  
(88%) 81. (50%)

The percentage of the optimum crop yield to be used for the preliminary crop yield production is as follows: 95.25

The qualitative value of the crop yield is as follows: EXCELLENT

\*\* End - press ENTER to continue.

Consultation record:

```

Consultation log: CROPCAST OSU, Copy... ::
the percentage of the optimum crop y... :: 100
the growth stages of the corn plants... :: PRE_EMERGENCE EMERGENCE TWO_LEAVES
FOUR_TO_SIX_LEAVES EIGHT_TO_TEN_LEAVES
the number of weeks after emergence ... :: 6
flooding of the crop :: NO
the highest temperature before polli... :: 80
the moisture of the soil :: 60
the location of the crop field in qu... :: UNKNOWN
*IMPORT* :: LOCATION (5)
the AVHRR greenness counts :: 150
the L-S count :: 160
the green-red reflectance :: 150
the previous green-red reflectance :: 140
the Near Infrared Reflectance :: 100
the crop field looks :: LIKE_FOREST:70%
the green area is an isolated spot :: YES
the maximum greenness observation oc... :: NO
the Near Infrared Reflectance around... :: 150
the Visible Infrared Reflectance aro... :: 150
the color of the corn plants :: DARK-GREEN
the lower leaves of plants are fired :: YES
the height of the corn plants by July 4 :: 4
the outside row of corn plants is le... :: UNKNOWN
the corn plants recover overnight fr... :: UNKNOWN
the silks are dry :: UNKNOWN
the soil is wet or so dry that it :: sticks to your shoes
wilt in upper leaves is observed :: YES
the planting date :: APRIL-1-6
the lowest temperature registered fo... :: 55
the highest night-time temperature f... :: 75
the average low temperature of the s... :: 65
the ground-water storage available f... :: 10
the average percentage of weekly sun... :: SUNNY_DAYS:50%
the percentage of leave loss :: LEAVE_LOSS:10%
presence of fungi after maturity :: UNKNOWN
the dew point during the periods fro... :: 68
ETP :: 5
moderate stress occurred during earl... :: NO
the periods of moderate stress are i... :: NO
rain occurs at regular intervals :: UNKNOWN
the moisture in the top soil layer :: 70
the soil moisture in the plow layer :: 65
the soil moisture in the lower layer :: 50
the subsoil moisture :: 40
the highest temperature during the g... :: 80

```



Conclusions for frame: CROP-YIELD-FORECAST-1

The location of the crop field in question is as follows: 5

The production obtained from satellite information is as follows: 100

The additional information obtained from satellite data is as follows: There is positive prove of germination. The green area is either an irrigated field or picked a local shower.

The production obtained from ground information is as follows: 81.

The additional information obtained from ground data is as follows: The coloring of the plants indicates reduction of crop yield. Ample soil moisture allows reasonable growth. Reduction of crop yield due to late growth stage.

The production obtained from plant physiology information is as follows: 100

The additional information obtained from plant physiology data is as follows: No additional reduction of the crop yield was found in this consultation.

The production obtained from model information is as follows: 100

The additional information obtained from model data is as follows: No additional reduction of the crop yield was found in this consultation.

The updated expected percentage of the optimum crop yield is as follows: 100 (88%) 81. (50%)

The percentage of the optimum crop yield to be used for the preliminary crop yield production is as follows: 95.25

The qualitative value of the crop yield is as follows: EXCELLENT

## 8. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

### 8.1. Summary of Study

The development of this first phase remote sensing based expert system was founded on the notion that expert heuristic assessments often dominates in determining the crop yield production. The first phase of CROPCAST OSU was developed using THE PC Plus expert system shell. Our expert estimated a revenue of over \$13 million on a six year market projection for a workable and completely built expert system. At the end of this report, an illustration showing the use of the system for determining crop yield production is presented. The following entails the major works performed in this study:

1. The construction of knowledge base frames. The knowledge base contains a root frame, CROP-YIELD-FORECAST, and four subframes, namely, SATELLITE, PLANT-PHYSIOLOGY, GROUND, and MODEL. The subframes represent the sources of information used to determine the crop yield that are acquired from the domain expert (EarthSat). The root frame integrates all the subframes.
2. The determination of parameters. A frame groups parameters and production rules. The parameters are needed for constructing workable production rules. Each frame consists of several parameters. The properties of each parameter were defined. These properties are important for use by the client when consulting the system.
3. The development of production rules. The expertise of EarthSat regarding the crop yield information was acquired for constructing the production rules. The expert provides written preliminary rules and verbal information based on which workable production rules were developed at The Ohio State University. Numerous rules have been produced while maintaining their efficiency and accuracy.
4. The provision of an external program. An external geographic program developed by EarthSat was integrated to the system. This program has, among others, the capability of displaying the national, state, and county boundaries, and major drainage system. The display has zooming capability of any subset of counties drawn from a U.S. county data base and window-oriented on-line capability to access graphic and textual materials.

## 8.2. Conclusions

The study results in a powerful yet user friendly expert system for determining the crop yield production in a certain crop field. More specifically, the following conclusions are presented:

1. The study reveals that in order to reach an efficient and reliable expert system, much effort was placed on the development of production rules. The knowledge obtained from the expert, and compiled in preliminary rules, have experienced considerable revision and manipulation such that the uniqueness, completeness, and accuracy of each rule can be maintained. The effort results in workable and efficient rules that could provide the client with a useful tool for making decision in crop yield forecasting.
2. The technique used in constructing the knowledge base emphasizes a user friendly and highly interactive window oriented on-line system. For this purpose, abundant descriptions are incorporated and generous help statements are provided. A client having little knowledge of crop yield production should not have any problem in consulting the system. Furthermore, numerous visual displays are provided internally as well as externally. The internal displays are available through the graphic help and prompt functions. The external program was developed through a conventional graphic programming technique capable of displaying the geographical map of some states. It also has the capability in zooming the counties within a particular state.
3. Finally, the system was thoroughly and successfully tested. Some rules that were found inadequate were reassessed. The expert was consulted and the rules were improved. A runtime system was developed for use by the client to consult the system. A client can use the system independently based on each source of information or integrally based on all sources.

## 8.3. Recommendations for Future Studies

The following are recommended for future or continuing studies of the expert system:

1. The current knowledge base expert system consists of four frames, i.e., SATELLITE, GROUND, MODEL, and PHYSIOLOGICAL. The results of our research project reveals that an extended knowledge base is necessary in order to maintain a complete knowledge base for the crop yield production expert system. Four more frames are needed to accomodate the production rules obtained from

the experts. These frames are STATISTICAL, GEOGRAPHICAL, HYDROLOGICAL, and TOPOGRAPHIC. With the additional frames, the system could become a powerful and user friendly state-of-the-art tool for remote sensing based crop yield forecasting in agribusiness sectors.

2. The decision concerning crop production subsequently leads to the decision regarding price analysis. Therefore, the construction of price demand knowledge base is recommended. This knowledge base will interface with the crop yield production knowledge base as well as with external subroutines. The system should be able to provide the user with explanation and recommendation with respect to remote sensing based crop forecasting, supply demand analysis, and subsequently, price forecasting. Our recommendation for future studies includes the examination of the economic information value derived from remote sensing and evaluation of the use of economic modeling tools in the context of expert systems. This includes problems related to rate of harvesting vs. rate of marketing; measurements of on-farm storage facilities; free market assessment vs government programs; and transportation assessment concerning barge movement (e.g., reservoir management). We anticipate the development of several frames, among others, ECONOMIC-INTELLIGENCE-SURROGATES, INFORMATION-FLOW, PRICE-PATTERNS, STOCK-CHANGE, POLITICAL-SIGNAL, and CALENDER-EVENTS.

## APPENDIX A. REFERENCES

Dr. HALO III User Manual, 1988, by Media Cybernetics Inc.

Hadipriono, F. C., 1988, "Fuzzy Reasoning Expert System (FRES) for Assessing Damage of Protective Structures," Presented to Universal Energy Systems, Contract No. S-760-6MG-054, Subproject Under United States Air Force.

Hadipriono, F. C., 1989, "Cases in Construction Automation," International Association for Bridge and Structural Engineering Colloquium on Expert System in Civil Engineering, Bergamo, Italy.

Hadipriono, F. C., Lyon, J. G., and Li, W. H., 1989, "A Drainage Pattern Knowledge Based Expert System," ASPRS/ACSM Fall Convention in Cleveland.

Maloney, L. M. and Miller, R. A., 1988, "Survey of Computer Workstations and Expert System Development Tools," Report No. ERC/NSM-88-45, The Ohio State University.

Palmer, R. N. and Mar, B. W., 1988, "Expert Systems Software for Civil Engineering Applications," Journal of Civil Engineering Systems, Vol. 5.

Personal Consultant Plus Version 4.0 Reference Guide, 1988, by Texas Instruments Incorporated.

## APPENDIX B. RULES DRAFT

### SATELLITE RULES DRAFT

1. If the AVHRR of L/S reflectance in the near IR exceeds 200 counts then there is a good possibility there is green vegetation in the scene.
2. If the difference between the count values in the green/red channel and the near infrared channels exceeds 50 counts then there is positive proof that green vegetation exists.
3. If the difference between the green/red reflectance and the near infrared reflectance changes by 20 percent (45 counts) then there is a good potential that either a stress has occurred if the change is negative/improvement has occurred if change is positive or the area green leaf cover has increased or decreased.
4. If the change in greenness occurs near normal planting time then the change in greenness is probably due to increased leaf cover due to emerging plants.
5. If the change in greenness occurs at the time when the plants are approaching leaf senescence then the change in green is due to leaf loss.
6. If the period of maximum greenness occurs during the period when reproduction would normally occur (see statistics or model output) then the chances of near optimum yield are excellent.
7. If the loss in greenness as seen in either AVHRR or L/S-Spot is accompanied by a decrease in the size of small farm ponds then the loss in greenness can be related to drought in the area.
8. If the appearance of an area of crops as measured by greenness counts is equal to the greenness count of a city then the loss crop yield will be significant and may reach total loss.
9. If the appearance of an area as measured by greenness counts is equal to that of a nearby forested area then the yield potential will be near to the projected maximum.
10. If the percentage cover of the area equal to the city and forest is near 50 percent then the yield will be about 50 percent of the projected maximum yield for the area.
11. If the area of crops has maximum greenness but it is centered in an area that otherwise appears to be like a city then this is either an irrigated crop or it picked up a local shower.
12. If the shore of small farm ponds or lakes has a high reflectance(>200) in both the visible and near in bands then there is saline deposits indicating evaporation exceeded precipitation.

13. If the model and/or historical information suggests that an area has been planted by a given date and there is no evidence of greenness then there probably is poor emergence or spring greenup (in the case of winter crops).

14. AVHRR count value vs. yield reduction from optimum.

If AVHRR greenness count is:

- between 143 and 200, yields will be 50% or greater reduced from optimum.
- between 201 and 210, yields will be 30% less than optimum.
- between 211 and 223, yields will be 15% reduced from optimum,
- between 224 and 250, yields will be near optimum for a given location.

This statement assumes observations are made at or just prior to silking of corn.

#### GROUND RULES DRAFT

1. If the growth is earlier than normal for corn by 2 weeks then there is a better chance for superior yield.
2. If the growth stage for corn is later than normal by 2 weeks then there is a greater than even chance that yields will be lower.
3. If the height of the corn plants on July 4 is less than 36 inches then the chances of good yield are reduced by 25 percent.
4. If the height of the corn plants on July 4 is greater than 48 inches then the chances of good yields are increased by 25 percent.
5. If the lower leaves of the corn plant are fired but little wilt is observed in the upper leaves then the yield potential will not be greatly reduced.
6. If the corn plants wilt each day but recover overnight then the chances for any significant reduction in yield are fairly small.
7. If the silks are dried or in any way abnormal then the chance for reduced ear fill are reduced.
8. If the corn crop appears to have coloring that is not bright green then there is a good chance that yields will be reduced.
9. If the plant appears yellow early in the season and there has been flooding then the plant has been oxygen starved and yields may be reduced.
10. If the plant is brown early in the growing season then severe drought has occurred and the yield loss is irreversible.
11. If flooding has occurred in a field the area of damage will be defined by the short or poorly developed plants.
12. If the outside row of corn plants is falling down or leaning watch for poor root structure in the field.
13. If the soil sticks to your shoe then there is ample soil moisture to allow reasonable growth.
14. If the soil can be picked up by the wind then there is insufficient moisture in the surface layer for plant growth.



## MODEL RULES DRAFT

1. If the soil moisture in the lower two layers of the Cropcast model exceed 30 percent of capacity then the crop should be green and healthy in the growth stages from mid-vegetative through to harvest.
2. If the soil moisture in the top layer (the surface layer as defined in the model not the layer we now call the surface layer) has greater than 30 percent of capacity during the period from planting until two weeks after planting then good germination occurred.
3. If the subsoil moisture during the reproductive period is below 30 percent of capacity or is fluctuating around 30 percent then the chance above trend yields is significantly reduced.
4. If the soil moisture remains significantly above 90 percent during the early growth period then chances for good stand establishment and early yield potential are reduced.
5. If the growth stage progression as shown by the model is accelerated over a linear growth rate then the potential for above trend yields is reduced.
6. If the ETP estimated by the model exceeds 10 mm/day for two or more days during late vegetative period then chances of above trend yield are reduced.
7. If there are periods with dew points in excess of 70 degrees F during the period from late vegetative to soft dough (corn) and the plants are under stress during the day then the results of daytime stress will be amplified and above trend yields will be significantly reduced.
8. If there are periods very low stress (ET/ETP) at any time during the growth of the crop the chances for disease formation are increased significantly.
9. If the model indicates periods of moderate stress during the fill stages of the corn crop then the quality of the corn (or soybean) will be enhanced.
10. If the soil moisture in the plow layer (the current top layer) exceeds 85 percent of capacity during the planting period there is a good chance that planting will be delayed until the layer dries to less than about 75 percent.
11. If there are numerous periods of moderate stress extending for 2 to 3 days in length but interrupted by light showers then the stress will not reduce the yield to below trend values.
12. If significant stress occurs during early to mid vegetative in the model but not during reproductive then the yield should not be reduced to below trend levels.
13. If significant stress occurs only in the reproductive growth stage then there is a good chance that yields will be reduced below trend values.

14. Light to moderate stress throughout the lifetime of the crop will often assure an excellent yield.
15. If moderate stress occurs from just after planting to late vegetative the crop will be more tolerant to stress at reproductive then yields may not be reduced.
16. If rain events occur at regular intervals even with dry sub soil moisture then an above trend yield can be expected.

## PLANT PHYSIOLOGY RULES DRAFT

### 1. Corn Growth Stage Factors

- a. If the soil temperatures remain below 48F after planting then germination will not occur.
- b. If the temperature remains below 53F after germination has occurred good seedling growth may be impacted.
- c. If temperatures below 55F are maintained during early seedling growth then the seedling may be impacted by seed decay and fungile diseases.
- d. If flooding occurs prior to the development of good 2 leaf seedlings then plant death will occur.
- e. If the plant is in the vegetative development period (2-8 leaves) then almost all stress events can be avoided.
- f. If the plant is in the tassel and ear initiation (8-10 leaf stage to tasseling) then stress from heat and/or low soil moisture will cause serious loss in ear size, kernel size and count, etc.
- g. If the plant is at pollen shed and fertilization stage high temperatures (near 100F) or extreme stress factors may terminate the fertilization process and no kernel will be produced.
- h. If the plant is in the kernel development and maturation period a loss of 50 percent of the leaves may reduce yield reductions of 10 percent or more.
- i. If the plant is in the kernel development and maturation stage and extended periods of cloudy weather occur stalk rot potentials will increase, (stalk and root rots are the most important diseases, any factor that reduces photosynthesis can increase the potential for these diseases).
- j. If high night time temperatures occur in the period from pollination through late kernel development then yields maybe significantly reduced (example of effects of night temperatures for 52 days following pollination show that an average of 65F will provide a yield of 160 bu/A while an average of 85F will yield 100 bu/A all other things held equal).
- k. Once the corn plant is in the period Maturity/Harvest/Storage yield losses are due to mechanical or fungi processes. For example, if reports of lodging or ear droppage appear losses in useful yield will increase, similarly if mold or other fungi are reported useable yields reduced, extreme conditions of fungi can produce high levels of aflatoxoin which makes the corn unuseable for human consumption.

### 2. Effects of Planting Date on Yield

- a. If the weather is cool and moist at planting and during vegetative growth good potential yields may occur. Early planting favors these types of conditions (75 to 86F temperatures are most favorable unless moisture conditions are plentiful then 90 to 95F provides fastest growth establishment).
- b. If planting is early then the root structure is more favorable and the chances of hot conditions during tasseling and silking are reduced.
- c. If the corn silks early then greater solar energy is available during kernel fill favoring higher yields.

d. The quantitative effect of planting date is as follows:

April 16-29	97 percent of maximum relative yield
May 1-9	100 percent " " " "
May 12-20	90 percent " " " "
May 23-31	80 percent " " " "
June 1-11	72 percent " " " "

These data were assembled over 10 years at Lansing, Michigan. A fairly northern area. These dates will move back by about one week for every 300 miles south of Lansing. Local climatological variations will effect planting date.

3. Effect of Temperature on Yield

- a. If the temperatures are less than 100F and moisture is plentiful (generally reported at greater than 60 percent of capacity throughout the root profile) then the potential for good yield continues throughout the growing season.
- b. If temperatures exceed 100F during pollination and moisture is marginal (less than 35 percent of capacity) then yield potentials may be significantly reduced even if all other growing periods have had favorable yield potential results.
- c. If the growing point of the corn plant is below ground then frost will have little effect. The relationship of plant height to growing point is: the growing point is below ground until the plant reaches 12 inches in height, from 17 inches to 36 inches the growing point moves up above ground reaching 8 - 14 inches maximum height.

4. Effect of Subsoil Moisture on Corn Yield

- a. If 18 to 24 inches of water are available during the growing season then maximum yield potential is possible for the region.
- b. If the water in ground water storage is less than 9 to 12 inches then the potential for reduced yields is high. Normal growing season (April to September) rainfall ranges from 13 inches in the western corn growing areas to 22 inches in the eastern areas. If soils in the corn growing areas start out the season at capacity they have from 6 to 15 inches of water available the remaining water needs must be provided by timely rainfall, thus 12 to 18 inches of rain must fall in the 3 month period to produce a maximum yielding crop (assuming no exceptionally high daytime or nighttime temperatures).

## APPENDIX C. ROOT FRAME CROP-YIELD-FORECAST

DOMAIN :: "CROPCAST OSU, Copyright 1989, The Ohio State  
University"  
ROOT FRAME :: CROP-YIELD-FORECAST

=====  
Global KB data  
=====

FRAME STRUCTURE ::  
CROP-YIELD-FORECAST  
SATELLITE  
PLANT-PHYSIOLOGY  
GROUND  
MODEL

KB Files :: (MODEL "CROPCAST.k1" GROUND "CROPCAST.k2"  
PLANT-PHYSIOLOGY "CROPCAST.k3" SATELLITE  
"CROPCAST.k4" )

Parameter groups :: (MODEL-PARMS GROUND-PARMS PLANT-  
PHYSIOLOGY-PARMS SATELLITE-PARMS  
CROP-YIELD-FORECAST-PARMS )

Rule groups :: (MODEL-RULES GROUND-RULES  
PLANT-PHYSIOLOGY-RULES SATELLITE-RULES  
CROP-YIELD-FORECAST-RULES META-RULES )

Number of rules :: 96

Number of meta-rules :: 0

Variables :: (\$\$TITLE DOMAIN)

TEXTAGS :: ()

Functions :: ()

=====  
VARIABLES  
=====

\$\$TITLE

VALUE :: (PICTURE CROPCAST)

DOMAIN

VALUE :: "CROPCAST OSU"

```
=====
Frame :: CROP-YIELD-FORECAST
=====
```

```
IDENTIFIER :: CROP-YIELD-FORECAST-
TRANSLATION :: (Crop Yield Forecast)
GOALS :: (SATELLITE-PRODUCTION SATELLITE-COMMENTS
          GROUND-PRODUCTION GROUND-COMMENTS PHYS-
          PRODUCTION PHYS-COMMENTS MODEL-PRODUCTION
          MODEL-COMMENTS PRODUCTION INITIAL CROP )
INITIALDATA :: (INITIAL LOCATION GROWTH-STAGE WEEKS
                FLOOD HIGH-TEMP SOIL-MOISTURE )
PROMPTEVER :: (:LINE 5 :ATTR (CYAN HIGH) "Crop Yield
               Forecast" :LINE :ATTR (WHITE HIGH) :ATTR
               (YELLOW HIGH) "*****" )
DISPLAYRESULTS :: YES
PARMGROUP :: CROP-YIELD-FORECAST-PARMS
RULEGROUPS :: (CROP-YIELD-FORECAST-RULES)
OFFSPRING :: (SATELLITE PLANT-PHYSIOLOGY GROUND MODEL)
CROP-YIELD-FORECAST-PARMS :: (CROP FLOOD GROUND-
                              COMMENTS GROUND-
                              PRODUCTION GROWTH-STAGE
                              HIGH-TEMP INITIAL
                              LOCATION MODEL-COMMENTS
                              MODEL-PRODUCTION PHYS-
                              COMMENTS PHYS-PRODUCTION
                              PRODUCTION SATELLITE-
                              COMMENTS SATELLITE-
                              PRODUCTION SOIL-MOISTURE
                              WEEKS )
CROP-YIELD-FORECAST-RULES :: (RULE021 RULE022 RULE074
                              RULE075 RULE076 RULE077
                              RULE078 RULE096 )
```

```
=====
CROP-YIELD-FORECAST-PARMS
=====
```

```
CROP
====
```

```
TRANSLATION :: (the qualitative value of the crop
                yield)
TYPE :: MULTIVALUED
UPDATED-BY :: (RULE074 RULE075 RULE076 RULE077
               RULE078)
```

```
FLOOD
====
```

```
TRANSLATION :: (flooding of the crop)
PROMPT :: (:ATTR (CYAN REVERSE) "Enter YES if the crop
                was flooded before the plants had at least
```

```

        two leaves." )
TYPE :: YES/NO
ANTECEDENT-IN :: (RULE057 RULE089 RULE069 RULE003)
HELP :: ("Select UNKNOWN only if there is absolute"
:LINE "uncertainty about the occurrence of
flooding." :LINE "This parameter is":ATTR
(MAGENTA HIGH) "important" :ATTR (WHITE HIGH)
"only during the" :LINE "early stages of the
plant." )
CERTAINTY-FACTOR-RANGE :: UNKNOWN

GROUND-COMMENTS
=====
TRANSLATION :: (the additional information obtained
from ground data)
TYPE :: MULTIVALUED
UPDATED-BY :: (RULE059)
UPDATED-IN :: (RULE037 RULE057 RULE089 RULE058
RULE060 RULE061 RULE065 RULE068 RULE069
RULE067 RULE071 RULE072 RULE064 RULE070)
DEFAULT :: ("No additional reduction of the crop
yield was found in this consultation." )

GROUND-PRODUCTION
=====
TRANSLATION :: (the production obtained from ground
information)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
UPDATED-BY :: (RULE022)
UPDATED-IN :: (RULE057 RULE089 RULE058 RULE060
RULE061 RULE065 RULE068 RULE069 RULE067
RULE071 RULE072 RULE064 RULE070 )
CONTAINED-IN :: (RULE057 RULE089 RULE058 RULE060
RULE061 RULE065 RULE068 RULE069
RULE067 RULE071 RULE072 RULE064
RULE070 RULE021 RULE096 )
RANGE :: (0 100)

GROWTH-STAGE
=====
TRANSLATION :: (the growth stages of the corn plants
included in this consultation )
PROMPT :: (:ATTR (CYAN REVERSE) "Enter the growth
stages of corn plants." )
TYPE :: ASK-ALL
EXPECT :: (PRE_EMERGENCE EMERGENCE TWO_LEAVES
FOUR_TO_SIX_LEAVES EIGHT_TO_TEN_LEAVES
TWELVE_TO_FOURTEEN_LEAVES TASSEL SILK
POLLINATION FILL_STAGE MATURITY
HARVEST_STORAGE )
ANTECEDENT-IN :: (RULE036 RULE033 RULE035 RULE037
RULE038 RULE045 RULE057 RULE089

```

RULE058 RULE061 RULE068 RULE001  
 RULE002 RULE003 RULE005 RULE020  
 RULE007 RULE010 RULE009 RULE018  
 RULE019 RULE015 RULE016 RULE017  
 RULE006 RULE067 RULE071 RULE072  
 RULE094 RULE080 RULE004 RULE087  
 RULE039 RULE040 RULE011 RULE090  
 RULE012 RULE013 )

USED-BY :: (RULE042)

GHELP :: (GROWTH)

#### HIGH-TEMP

=====

TRANSLATION :: (the highest temperature before  
 pollination)

PROMPT :: (:ATTR (CYAN REVERSE) "Enter the highest  
 temperature observed before pollination in  
 Fahrenheit." )

TYPE :: SINGLEVALUED

EXPECT :: NUMBER

ANTECEDENT-IN :: (RULE041 RULE045 RULE046 RULE007  
 RULE014 RULE006 RULE087 )

HELP :: ("This value comes from the observations"  
 :LINE "of the current year." :LINE "Punch  
 ENTER if this temperature is unknown." :LINE  
 "This parameter is of low importance during  
 the" :LINE "early stages of the plant, but it  
 is very" :LINE :ATTR ( MAGENTA HIGH )  
 "important" :ATTR (WHITE HIGH) "during the  
 late stages of the plant." )

CERTAINTY-FACTOR-RANGE :: UNKNOWN

RANGE :: (60 140)

#### INITIAL

=====

TRANSLATION :: (the percentage of the optimum crop  
 yield to be used as the preliminary  
 production )

PROMPT :: (:ATTR (CYAN REVERSE) "Enter the  
 preliminary assessment of the crop yield" )

TYPE :: SINGLEVALUED

EXPECT :: POSITIVE-NUMBER

UPDATED-IN :: (RULE096)

USED-BY :: (RULE022 RULE021 RULE074 RULE075 RULE076  
 RULE077 RULE078)

HELP :: ("Enter the result of the previous  
 consultation" :LINE "in percentage of the  
 optimum crop yield." :LINE "If this is the"  
 :ATTR (MAGENTA HIGH) "first consultation"  
 :ATTR (WHITE HIGH) "enter 100." :LINE "This  
 percentage will be updated during the" :LINE  
 "consultation." )

DEFAULT :: (100)



CONTAINED-IN :: (RULE022)  
RANGE :: (0 100)

#### LOCATION

=====

TRANSLATION :: (the location of the crop field in  
question)  
TYPE :: SINGLEVALUED  
EXPECT :: NUMBER  
ANTECEDENT-IN :: (RULE005 RULE020 RULE018 RULE019  
RULE015 RULE016 RULE017 )  
RANGE :: (1 15)

#### MODEL-COMMENTS

=====

TRANSLATION :: (the additional information obtained  
from model data)  
TYPE :: MULTIVALUED  
UPDATED-BY :: (RULE042)  
UPDATED-IN :: (RULE036 RULE033 RULE034 RULE035  
RULE038 RULE041 RULE043 RULE045 RULE046  
RULE047 RULE088 RULE039 RULE040 )  
DEFAULT :: ("No additional reduction of the crop  
yield was found in this consultation." )

#### MODEL-PRODUCTION

=====

TRANSLATION :: (the production obtained from model  
information)  
TYPE :: SINGLEVALUED  
EXPECT :: POSITIVE-NUMBER  
UPDATED-BY :: (RULE022)  
UPDATED-IN :: (RULE036 RULE033 RULE034 RULE035  
RULE037 RULE038 RULE041 RULE043 RULE045  
RULE046 RULE047 RULE088 RULE039 RULE040  
)  
CONTAINED-IN :: (RULE036 RULE033 RULE034 RULE035  
RULE037 RULE038 RULE041 RULE043  
RULE045 RULE046 RULE047 RULE088  
RULE039 RULE040 RULE021 RULE096 )  
RANGE :: (0 100)

#### PHYS-COMMENTS

=====

TRANSLATION :: (the additional information obtained  
from plant physiology data )  
TYPE :: MULTIVALUED  
UPDATED-IN :: (RULE001 RULE002 RULE003 RULE005  
RULE020 RULE007 RULE010 RULE009 RULE014  
RULE018 RULE019 RULE015 RULE016 RULE017  
RULE006 RULE004 RULE087 RULE011 RULE090  
RULE012 RULE013 )  
DEFAULT :: ("No additional reduction of the crop

yield was found in this consultation." )

#### PHYS-PRODUCTION

=====

TRANSLATION :: (the production obtained from plant  
                  physiology information )  
TYPE :: SINGLEVALUED  
EXPECT :: POSITIVE-NUMBER  
UPDATED-BY :: (RULE022)  
UPDATED-IN :: (RULE001 RULE002 RULE003 RULE005  
                  RULE020 RULE007 RULE010 RULE009 RULE014  
                  RULE018 RULE019 RULE015 RULE016 RULE017  
                  RULE006 RULE004 RULE087 RULE011 RULE090  
                  RULE012 RULE013 )  
CONTAINED-IN :: (RULE002 RULE005 RULE020 RULE007  
                  RULE010 RULE009 RULE014 RULE018  
                  RULE019 RULE015 RULE016 RULE017  
                  RULE006 RULE004 RULE087 RULE021  
                  RULE096 RULE011 RULE090 RULE012  
                  RULE013 )  
RANGE :: (0 100)

#### PRODUCTION

=====

TRANSLATION :: (the updated expected percentage of  
                  the optimum crop yield )  
TYPE :: MULTIVALUED  
UPDATED-BY :: (RULE021)  
ANTECEDENT-IN :: (RULE096)  
CERTAINTY-FACTOR-RANGE :: POSITIVE

#### SATELLITE-COMMENTS

=====

TRANSLATION :: (the additional information obtained  
                  from satellite data )  
TYPE :: MULTIVALUED  
UPDATED-BY :: (RULE028 RULE031)  
UPDATED-IN :: (RULE029 RULE025 RULE091 RULE027  
                  RULE092 RULE093 RULE094 RULE023 RULE024  
                  RULE026 RULE030 RULE080 )  
DEFAULT :: ("No additional reduction of the crop  
                  yield was found in this consultation." )

#### SATELLITE-PRODUCTION

=====

TRANSLATION :: (the production obtained from satellite  
                  information)  
TYPE :: SINGLEVALUED  
EXPECT :: POSITIVE-NUMBER  
UPDATED-BY :: (RULE022)  
UPDATED-IN :: (RULE029 RULE025 RULE091 RULE027  
                  RULE081 RULE023 RULE024 RULE095 RULE026  
                  RULE030 RULE080 )

CONTAINED-IN :: (RULE029 RULE025 RULE091 RULE027  
 RULE081 RULE023 RULE024 RULE026  
 RULE030 RULE080 RULE021 RULE096 )  
 RANGE :: (0 100)

#### SOIL-MOISTURE

=====

TRANSLATION :: (the moisture of the soil)  
 PROMPT :: (:ATTR (CYAN REVERSE) "Enter the soil  
 moisture as a percentage of its capacity." )  
 TYPE :: SINGLEVALUED  
 EXPECT :: NUMBER  
 ANTECEDENT-IN :: (RULE041 RULE045 RULE046 RULE007  
 RULE014 RULE006 RULE039 )  
 USED-BY :: (RULE042)  
 HELP :: ("Soil moisture can be measured in various  
 ways." :LINE "Gravimetric, where the moisture  
 is determined by" :LINE "weighting a sample  
 before and after drying." :LINE "Newton  
 Detection, where a source of nuclear" :LINE  
 "radiation is used. This method is less  
 accurate" :LINE "than the Gravimetric near the  
 surface." :LINE "This parameter is very" :ATTR  
 (MAGENTA HIGH ) "important" :ATTR (WHITE HIGH)  
 "during the" :LINE "late stages of the plant."  
 :LINE "Punch ENTER if this parameter is not  
 available." )  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN  
 RANGE :: (0 100)

#### WEEKS

=====

TRANSLATION :: (the number of weeks after emergence  
 from the soil)  
 PROMPT :: (:ATTR (CYAN REVERSE) "Enter the number of  
 weeks after emergence from the soil" )  
 TYPE :: SINGLEVALUED  
 EXPECT :: POSITIVE-NUMBER  
 ANTECEDENT-IN :: (RULE037 RULE025 RULE071 RULE072  
 RULE027 RULE092 RULE093 RULE094  
 RULE081 RULE023 RULE024 RULE095  
 RULE026 RULE030 RULE090 )  
 USED-BY :: (RULE028)  
 HELP :: (Punch ENTER if this value is unknown.)  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN  
 RANGE :: (0 35)

=====

CROP-YIELD-FORECAST-RULES

=====

RULE021

=====

SUBJECT :: CROP-YIELD-FORECAST-RULES

DOBEFORE :: (RULE022)

DESCRIPTION :: (PROD=SAT-PROD,GROUND-PROD,MODEL-  
PROD,PLANT-PHYS)

If the percentage of the optimum crop yield to be used as the preliminary production is greater than 0,

Then 1) there is weakly suggestive evidence (40%) that the updated expected percentage of the optimum crop yield is [1 times the production obtained from satellite information], and

2) there is suggestive evidence (50%) that the updated expected percentage of the optimum crop yield is [1 times the production obtained from ground information], and

3) there is suggestive evidence (60%) that the updated expected percentage of the optimum crop yield is [1 times the production obtained from plant physiology information], and

4) there is suggestive evidence (50%) that the updated expected percentage of the optimum crop yield is [1 times the production obtained from model information].

IF :: (INITIAL > 0)

THEN :: (PRODUCTION = (1 \* SATELLITE-PRODUCTION) CF  
40 AND PRODUCTION = (1 \* GROUND-PRODUCTION )  
CF 50 AND PRODUCTION = (1 \* PHYS-PRODUCTION )  
CF 60 AND PRODUCTION = (1 \* MODEL-PRODUCTION )  
CF 50 )

RULE022

=====

SUBJECT :: CROP-YIELD-FORECAST-RULES

DESCRIPTION :: (CONSIDERFRAME SATELLITE, GROUND,  
PLANT-PHYSIOLOGY, MODEL )

If the percentage of the optimum crop yield to be used as the preliminary production is greater than or equal to 0,

Then 1) call a DOS program named C:\CROPCAST\NSEW.EXE, and

2) retrieve data from an external source, and

3) it is definite (100%) that the production obtained from satellite information is [1 times the percentage of the optimum crop yield to be used as the preliminary production], and

4) it is definite (100%) that the production obtained from ground information is [1 times the percentage of the optimum crop yield to be used as the preliminary production], and

- 5) it is definite (100%) that the production obtained from plant physiology information is [1 times the percentage of the optimum crop yield to be used as the preliminary production], and
- 6) it is definite (100%) that the production obtained from model information is [1 times the percentage of the optimum crop yield to be used as the preliminary production], and
- 7) instantiate the frame crop yield forecast from satellite information if appropriate, and
- 8) instantiate the frame crop yield forecast from ground information if appropriate, and
- 9) instantiate the frame crop yield forecast from plant physiology information if appropriate, and
- 10) instantiate the frame crop yield forecast from model information if appropriate.

```

IF      :: (INITIAL >= 0)
THEN    :: (DOS-CALL "C:\\CROPCAST\\NSEW.EXE" "" AND
            READ-DOS-FILE "C:\\CROPCAST\\ZONE.RD" LOCATION
            AND SATELLITE-PRODUCTION = (1 * INITIAL) AND
            GROUND-PRODUCTION = (1 * INITIAL) AND PHYS-
            PRODUCTION = (1 * INITIAL) AND MODEL-
            PRODUCTION = (1 * INITIAL) AND CONSIDERFRAME
            SATELLITE AND CONSIDERFRAME GROUND AND
            CONSIDERFRAME PLANT-PHYSIOLOGY AND
            CONSIDERFRAME MODEL )

```

#### RULE074

=====

```

SUBJECT :: CROP-YIELD-FORECAST-RULES
DOBEFORE :: (RULE096)
DESCRIPTION :: (IF PROD>90 THEN CROP=EXCELLENT)

```

If the percentage of the optimum crop yield to be used as the preliminary production is greater than or equal to 90,  
Then 1) it is definite (100%) that the qualitative value of the crop yield is EXCELLENT, and  
2) display a graphic picture.

```

IF      :: (INITIAL >= 90)
THEN    :: (CROP = EXCELLENT AND PICTURE EXCELLEN)

```

#### RULE075

=====

```

SUBJECT :: CROP-YIELD-FORECAST-RULES
DOBEFORE :: (RULE096)
DESCRIPTION :: (IF PROD BT 80 90 THEN CROP=GOOD)

```

If the percentage of the optimum crop yield to be used as the preliminary production is less than 90 but greater than or equal to 80,  
Then 1) it is definite (100%) that the qualitative value of the crop yield is GOOD, and  
2) display a graphic picture.

IF :: (INITIAL BT 80 90)  
THEN :: (CROP = GOOD AND PICTURE GOOD)

#### RULE076

=====

SUBJECT :: CROP-YIELD-FORECAST-RULES

DOBEFORE :: (RULE096)

DESCRIPTION :: (IF PROD BT 60 80 THEN CROP=FAIR)

If the percentage of the optimum crop yield to be used as the preliminary production is less than 80 but greater than or equal to 60,

Then 1) it is definite (100%) that the qualitative value of the crop yield is FAIR, and  
2) display a graphic picture.

IF :: (INITIAL BT 60 80)  
THEN :: (CROP = FAIR AND PICTURE FAIR)

#### RULE077

=====

SUBJECT :: CROP-YIELD-FORECAST-RULES

DOBEFORE :: (RULE096)

DESCRIPTION :: (IF PROD BT 40 60 THEN CROP=POOR)

If the percentage of the optimum crop yield to be used as the preliminary production is less than 60 but greater than or equal to 40,

Then 1) it is definite (100%) that the qualitative value of the crop yield is POOR, and  
2) display a graphic picture.

IF :: (INITIAL BT 40 60)  
THEN :: (CROP = POOR AND PICTURE POOR)

#### RULE078

=====

SUBJECT :: CROP-YIELD-FORECAST-RULES

DOBEFORE :: (RULE096)

DESCRIPTION :: (IF PROD<40 THEN PROD=VERY POOR)

If the percentage of the optimum crop yield to be used as the preliminary production is less than 40,

Then 1) it is definite (100%) that the qualitative value of the crop yield is VERY POOR, and  
2) display a graphic picture.

IF :: (INITIAL < 40)  
THEN :: (CROP = VERY POOR AND PICTURE VERYPoor)

#### RULE096

=====

SUBJECT :: CROP-YIELD-FORECAST-RULES

ANTECEDENT :: YES

DOBEFORE :: (RULE021)

DESCRIPTION :: (Calculate new INITIAL for next  
consultation)

If the updated expected percentage of the optimum crop  
yield is known,  
Then it is definite (100%) that the percentage of the  
optimum crop yield to be used as the preliminary production  
is [[[[[the production obtained from satellite information  
times 0.4] plus [the production obtained from ground  
information times 0.5]] plus [the production obtained from  
plant physiology information times 0.6]] plus [the  
production obtained from model information times 0.5]]  
divided by 2].

IF :: (PRODUCTION IS KNOWN)  
THEN :: (INITIAL = (((((SATELLITE-PRODUCTION \* 0.4) +  
( GROUND-PRODUCTION \* 0.5 ) ) + (PHYS-  
PRODUCTION \* 0.6) ) + ( MODEL-PRODUCTION \* 0.5  
 ) ) / 2 ) )

## APPENDIX D. SUBFRAME SATELLITE

```
=====
Frame :: SATELLITE
=====
```

```
IDENTIFIER :: "SATELLITE-"
TRANSLATION :: (crop yield forecast from satellite
                information)
PARENTS :: (CROP-YIELD-FORECAST)
GOALS :: (SATELLITE-PRODUCTION SATELLITE-COMMENTS)
INITIALDATA :: (AVHRR L-S GREEN-RED GREEN-RED-PREVIOUS
                NIR FOREST CENTERED MAXIMUM POND-NIR
                POND-VIR )
PROMPTEVER :: (:LINE 6 :ATTR (CYAN HIGH) "SATELLITE
                INFORMATION" :LINE :ATTR (YELLOW HIGH)
                "*****" )
PARMGROUP :: SATELLITE-PARMS
RULEGROUPS :: (SATELLITE-RULES)
ANTECEDENT :: YES
SATELLITE-PARMS :: (AVHRR CENTERED FOREST GREEN-RED
                    GREEN-RED-PREVIOUS L-S MAXIMUM NIR
                    POND-NIR POND-VIR )
SATELLITE-RULES :: (RULE023 RULE024 RULE025 RULE026
                    RULE027 RULE028 RULE029 RULE030
                    RULE031 RULE080 RULE081 RULE091
                    RULE092 RULE093 RULE094 RULE095 )
```

```
=====
SATELLITE-PARMS
=====
```

```
AVHRR
=====
```

```
TRANSLATION :: (the AVHRR greenness counts)
PROMPT :: (:ATTR (CYAN HIGH) Enter the AVHRR greenness
           counts)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: (RULE025 RULE091 RULE081 RULE023
                  RULE024 RULE095 RULE026 RULE030 )
HELP :: ("AVHRR (Advanced Very High Resolution
          Radiometer)" :LINE "greenness counts are
          digital values derived from" :LINE "the AVHRR
          sensor digital tapes." :LINE "High values of
          AVHRR greenness counts indicate" :LINE "that a
          high percentage of the crop field is" :LINE
          "covered by green vegetation." :LINE "A value
          of 250 for AVHRR is considered" :LINE "high,
```



```

while 100 is considered low" :LINE "Punch
ENTER if the AVHRR greenness count is not"
:LINE "available." )
CERTAINTY-FACTOR-RANGE :: UNKNOWN
RANGE :: (0 300)

```

#### CENTERED

=====

```

TRANSLATION :: (the green area is an isolated spot)
PROMPT :: (:ATTR (CYAN HIGH) Is the green area an
isolated spot)
TYPE :: YES/NO
USED-BY :: (RULE031)
HELP :: ("The green area can be observed in the AVHRR"
:LINE "digital tapes as greenness counts or in
the" :LINE "AVHRR photographic images as
green-red" :LINE "reflectance." :LINE "Select
UNKNOWN if undecided." )
CERTAINTY-FACTOR-RANGE :: UNKNOWN
GPROMPT :: "GREEN"

```

#### FOREST

=====

```

TRANSLATION :: (the percentage of area that looks like
forest)
PROMPT :: (:ATTR (CYAN HIGH) "Indicate how close is
the greenness of the crop field to that of a
forest" )
TYPE :: SINGLEVALUED
EXPECT :: (LIKE_FOREST)
ANTECEDENT-IN :: (RULE081 RULE095)
HELP :: ("To compare the greenness count of the crop
field" :LINE "and the greenness count of a
city, observe the" :LINE "AVHRR photographic
images." :LINE "You can use greenness counts
from digital tapes" :LINE "or green-red
reflectance from photographic" :LINE "images."
:LINE "Punch ENTER if this value is not
available." )
GPROMPT :: "CITYCOUN"
CERTAINTY-FACTOR-RANGE :: POSITIVE
CONTAINED-IN :: (RULE081 RULE095)

```

#### GREEN-RED

=====

```

TRANSLATION :: (the green-red reflectance)
PROMPT :: (:ATTR (CYAN HIGH) "Enter the green-red
reflectance for the crop field" )
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: (RULE025 RULE091 RULE027 RULE092
RULE093 RULE094 RULE081 RULE023
RULE024 RULE095 RULE026 RULE030 )

```

```

USED-BY :: (RULE028)
HELP :: ("The value of green-red reflectance is a
visual" :LINE "estimate of the AVHRR counts
using photographic" :LINE "images." :LINE "High
values of green-red reflectance indicate"
:LINE "abundant green vegetation." :LINE "A
value of 250 for AVHRR is considered" :LINE
"high, while 100 is considered low" :LINE
"Punch ENTER if this value is not available."
)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
RANGE :: (0 300)
GPROMPT :: "CITYCOUN"

```

#### GREEN-RED-PREVIOUS

=====

```

TRANSLATION :: (the previous green-red reflectance)
PROMPT :: (:ATTR (CYAN HIGH) "Enter the previous
green-red reflectance for the crop field" )
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: (RULE027 RULE092 RULE093 RULE094)
USED-BY :: (RULE028)
HELP :: ("The previous green-red reflectance
observation" :LINE "is obtained from the
previous AVHRR information." :LINE "The value
of green-red reflectance is a visual" :LINE
"estimate of the AVHRR counts using
photographic" :LINE "images." :LINE "High
values of green-red reflectance indicate"
:LINE "abundant green vegetation." :LINE "A
value of 250 for AVHRR is considered" :LINE
"high, while 100 is considered low" :LINE
"Punch ENTER if this value is not available."
)
GHELP :: (COUNT)
RANGE :: (0 300)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

#### L-S

===

```

TRANSLATION :: (the L-S count)
PROMPT :: (:ATTR (CYAN HIGH) Enter the value of the
L-S count)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: (RULE025 RULE081 RULE023 RULE024
RULE095 RULE026 RULE030 )
HELP :: ("This observation can be obtained from
digital" :LINE "tapes provided by the Landsat
information." :LINE "High values of L-S count
indicate that a high" :LINE "percentage of the
crop field is covered by" :LINE "green

```

vegetation." :LINE "Punch ENTER if this value  
is not available." )  
CERTAINTY-FACTOR-RANGE :: UNKNOWN  
RANGE :: (0 300)

#### MAXIMUM

=====

TRANSLATION :: (the maximum greenness observation  
occurred during this period )  
PROMPT :: (:ATTR (CYAN HIGH) "Is this the maximum  
greenness observation for this season ?" )  
TYPE :: YES/NO  
ANTECEDENT-IN :: (RULE080)  
HELP :: ("The greenness can be observed from AVHRR  
digital" :LINE "tapes as greenness counts or  
from AVHRR" :LINE "photographic images as  
green-red reflectance." :LINE "Answer YES if  
the greenness started to decline" :LINE  
"during this period." :LINE "If a decline in  
the greenness has not been" :LINE "observed,  
the maximum green-area probably has" :LINE  
"not been reached yet." )  
CERTAINTY-FACTOR-RANGE :: UNKNOWN  
GHELP :: (COUNT)

#### NIR

=====

TRANSLATION :: (the Near Infrared Reflectance)  
PROMPT :: (:ATTR (CYAN HIGH) "Enter the observation  
for Near Infrared Reflectance" )  
TYPE :: SINGLEVALUED  
EXPECT :: POSITIVE-NUMBER  
ANTECEDENT-IN :: (RULE025 RULE081 RULE023 RULE024  
RULE095 RULE026 RULE030 )  
HELP :: ("The Near Infrared Reflectance (NIR) is the"  
:LINE "reflected energy received at the  
satellite in" :LINE "the NIR spectrum." :LINE  
"The NIR spectrum is the part of the" :LINE  
"micrometer spectrum that cannot be observed  
by" :LINE "human vision." :LINE "High values  
of NIR" :LINE "indicate poor vegetation on the  
crop field." :LINE "A value of 200 for NIR is  
considered high." :LINE "Punch ENTER if the  
NIR value is not available." )  
CERTAINTY-FACTOR-RANGE :: UNKNOWN  
RANGE :: (0 300)

#### POND-NIR

=====

TRANSLATION :: (the Near Infrared Reflectance around  
ponds)  
PROMPT :: (:ATTR (CYAN HIGH) "Enter the observation of  
Near Infrared Reflectance (NIR) around

```

        ponds" )
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: (RULE029 RULE093)
HELP :: ("The Near Infrared Reflectance (NIR) is the"
:LINE "reflected energy received at the
satellite in" :LINE "the NIR spectrum." :LINE
"The NIR spectrum is the part of the" :LINE
"micrometer spectrum that cannot be observed
by" :LINE "human vision." :LINE "High values
of NIR around ponds indicate" :LINE "severe
evaporation of water." :LINE "A value of 200
for NIR is considered high." :LINE "Punch
ENTER if this value is not available." )
CERTAINTY-FACTOR-RANGE :: UNKNOWN
RANGE :: (0 300)

```

#### POND-VIR

```
=====
```

```

TRANSLATION :: (the Visible Infrared Reflectance
around ponds)
PROMPT :: (:ATTR (CYAN HIGH) "Enter the observation of
Visible Infrared Reflectance around ponds" )
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ANTECEDENT-IN :: (RULE029 RULE093)
HELP :: ("The Visible Infrared Reflectance (VIR) is
the" :LINE "reflected energy received at the
satellite in" :LINE "the VIR spectrum." :LINE
"The VIR spectrum is that part of the" :LINE
"micrometer spectrum that can be observed by
the" :LINE "human vision." :LINE "High values
of VIR around ponds indicate" :LINE "severe
evaporation of water." :LINE "A value of 200
for VIR is considered high." :LINE "Punch
ENTER if this value is not available." )
CERTAINTY-FACTOR-RANGE :: UNKNOWN
RANGE :: (0 300)

```

```

=====
SATELLITE-RULES
=====

```

#### RULE023

```
=====
```

```

SUBJECT :: SATELLITE-RULES
ANTECEDENT :: YES
DESCRIPTION :: (13)
If 1) the number of weeks after emergence from the soil is
less than 4 but greater than or equal to 2, and
2) 1) the AVHRR greenness counts is less than 80, or
2) the L-S count is less than 80, or

```

3) [the green-red reflectance minus the Near Infrared Reflectance] is less than 25,  
 Then 1) it is definite (100%) that the production obtained from satellite information is [0.9 times the production obtained from satellite information], and  
 2) it is definite (100%) that the additional information obtained from satellite data is Poor emergence or spring greenup..

IF :: (WEEKS BT 2 4 AND (AVHRR < 80 OR L-S < 80 OR (GREEN-RED - NIR) < 25 ) )  
 THEN :: (SATELLITE-PRODUCTION = (0.9 \* SATELLITE-PRODUCTION) AND SATELLITE-COMMENTS = "Poor emergence or spring greenup." )

#### RULE024

=====

SUBJECT :: SATELLITE-RULES  
 ANTECEDENT :: YES  
 DESCRIPTION :: (13)  
 If 1) the number of weeks after emergence from the soil is less than 2 but greater than or equal to 1, and  
 2) 1) [the green-red reflectance minus the Near Infrared Reflectance] is less than 20, or  
 2) the AVHRR greenness counts is less than 50, or  
 3) the L-S count is less than 50,  
 Then 1) it is definite (100%) that the production obtained from satellite information is [0.8 times the production obtained from satellite information], and  
 2) it is definite (100%) that the additional information obtained from satellite data is Poor emergence or spring greenup..

IF :: (WEEKS BT 1 2 AND ((GREEN-RED - NIR) < 20 OR AVHRR < 50 OR L-S < 50 ) )  
 THEN :: (SATELLITE-PRODUCTION = (0.8 \* SATELLITE-PRODUCTION) AND SATELLITE-COMMENTS = "Poor emergence or spring greenup." )

#### RULE025

=====

SUBJECT :: SATELLITE-RULES  
 ANTECEDENT :: YES  
 DESCRIPTION :: (1 and 2)  
 If 1) the number of weeks after emergence from the soil is less than 11 but greater than or equal to 8, and  
 2) 1) the AVHRR greenness counts is less than 201, or  
 2) the L-S count is less than 201, or  
 3) [the green-red reflectance minus the Near Infrared Reflectance] is less than 50,  
 Then 1) it is definite (100%) that the production obtained from satellite information is [0.5 times the production obtained from satellite information], and

2) it is definite (100%) that the additional information obtained from satellite data is Extremely low greenness..

IF :: (WEEKS BT 8 11 AND (AVHRR < 201 OR L-S < 201  
OR (GREEN-RED - NIR ) < 50 ) )  
THEN :: (SATELLITE-PRODUCTION = (0.5 \* SATELLITE-  
PRODUCTION) AND SATELLITE-COMMENTS =  
"Extremely low greenness." )

#### RULE026

=====

SUBJECT :: SATELLITE-RULES  
ANTECEDENT :: YES  
DESCRIPTION :: (1 and 2)

If 1) the number of weeks after emergence from the soil is less than 11 but greater than or equal to 8, and  
2) 1) [the green-red reflectance minus the Near Infrared Reflectance] is less than 55 but greater than or equal to 50, or  
2) the AVHRR greenness counts is less than 210 but greater than or equal to 201, or  
3) the L-S count is less than 210 but greater than or equal to 201,  
Then 1) it is definite (100%) that the production obtained from satellite information is [0.7 times the production obtained from satellite information], and  
2) it is definite (100%) that the additional information obtained from satellite data is Very low greenness..

IF :: (WEEKS BT 8 11 AND ((GREEN-RED - NIR) BT 50 55  
OR AVHRR BT 201 210 OR L-S BT 201 210 ) )  
THEN :: (SATELLITE-PRODUCTION = (0.7 \* SATELLITE-  
PRODUCTION) AND SATELLITE-COMMENTS = "Very low greenness." )

#### RULE027

=====

SUBJECT :: SATELLITE-RULES  
ANTECEDENT :: YES  
DESCRIPTION :: (3)

If 1) [the green-red reflectance minus the previous green-red reflectance] is less than -45, and  
2) the number of weeks after emergence from the soil is less than 11 but greater than or equal to 1,  
Then 1) it is definite (100%) that the production obtained from satellite information is [the production obtained from satellite information times 0.8], and  
2) it is definite (100%) that the additional information obtained from satellite data is Severe stress has occurred..

```

IF      :: ((GREEN-RED - GREEN-RED-PREVIOUS) < -45 AND
            WEEKS BT 1 11)
THEN    :: (SATELLITE-PRODUCTION = (SATELLITE-PRODUCTION
            * 0.8) AND SATELLITE-COMMENTS = "Severe stress
            has occurred." )

```

#### RULE028

=====

```

SUBJECT :: SATELLITE-RULES
DESCRIPTION :: (2 and 5)
If      1) the green-red reflectance is less than the previous
        green-red reflectance, and
        2) the number of weeks after emergence from the soil is
        greater than 11,
Then it is definite (100%) that the additional information
obtained from satellite data is The crop is under normal
leaf loss and drying..

```

```

IF      :: (GREEN-RED < GREEN-RED-PREVIOUS AND WEEKS >
            11)
THEN    :: (SATELLITE-COMMENTS = "The crop is under
            normal leaf loss and drying." )

```

#### RULE029

=====

```

SUBJECT :: SATELLITE-RULES
ANTECEDENT :: YES
DESCRIPTION :: (12)
If      1) the Near Infrared Reflectance around ponds is
        greater than 200, and
        2) the Visible Infrared Reflectance around ponds is
        greater than 200,
Then 1) it is definite (100%) that the production obtained
        from satellite information is [the production
        obtained from satellite information times 0.9], and
        2) it is definite (100%) that the additional
        information obtained from satellite data is High
        evaporation of water from neighboring crop field
        ponds..

```

```

IF      :: (POND-NIR > 200 AND POND-VIR > 200)
THEN    :: (SATELLITE-PRODUCTION = (SATELLITE-PRODUCTION
            * 0.9) AND SATELLITE-COMMENTS = "High
            evaporation of water from neighboring crop
            field ponds." )

```

#### RULE030

=====

```

SUBJECT :: SATELLITE-RULES
ANTECEDENT :: YES
DESCRIPTION :: (1 and 2)
If      1) the number of weeks after emergence from the soil is
        less than 11 but greater than or equal to 8, and

```

2) 1) [the green-red reflectance minus the Near Infrared Reflectance] is less than 60 but greater than or equal to 55, or  
 2) the AVHRR greenness counts is less than 223 but greater than or equal to 210, or  
 3) the L-S count is less than 223 but greater than or equal to 210,  
 Then 1) it is definite (100%) that the production obtained from satellite information is [the production obtained from satellite information times 0.85], and  
 2) it is definite (100%) that the additional information obtained from satellite data is Low greenness..

IF :: (WEEKS BT 8 11 AND ((GREEN-RED - NIR) BT 55 60 OR AVHRR BT 210 223 OR L-S BT 210 223 ) )  
 THEN :: (SATELLITE-PRODUCTION = (SATELLITE-PRODUCTION \* 0.85) AND SATELLITE-COMMENTS = "Low greenness." )

#### RULE031

=====

SUBJECT :: SATELLITE-RULES

DESCRIPTION :: (11)

If the green area is an isolated spot,  
 Then it is definite (100%) that the additional information obtained from satellite data is The green area is either an irrigated field or picked a local shower..

IF :: (CENTERED)

THEN :: (SATELLITE-COMMENTS = "The green area is either an irrigated field or picked a local shower." )

#### RULE080

=====

SUBJECT :: SATELLITE-RULES

ANTECEDENT :: YES

DESCRIPTION :: (6)

If 1) the growth stages of the corn plants included in this consultation is not POLLINATION, and  
 2) the growth stages of the corn plants included in this consultation is not SILK, and  
 3) the maximum greenness observation occurred during this period,  
 Then 1) it is definite (100%) that the production obtained from satellite information is [0.9 times the production obtained from satellite information], and  
 2) it is definite (100%) that the additional information obtained from satellite data is The maximum greenness of the crop was not reached at the optimum time..



```

IF      :: (GROWTH-STAGE != POLLINATION AND GROWTH-STAGE
            != SILK AND MAXIMUM )
THEN    :: (SATELLITE-PRODUCTION = (0.9 * SATELLITE-
            PRODUCTION) AND SATELLITE-COMMENTS = "The
            maximum greenness of the crop was not reached
            at the optimum time." )

```

#### RULE081

=====

```

SUBJECT :: SATELLITE-RULES
ANTECEDENT :: YES
DOBEFORE :: (RULE025 RULE026 RULE030 RULE091)
DESCRIPTION :: (8 and 10)
If      1) the number of weeks after emergence from the soil is
        less than 11 but greater than or equal to 7, and
        2) there is no evidence that the percentage of area
        that looks like forest is not LIKE_FOREST, and
        3) 1) the AVHRR greenness counts is known, or
            2) the L-S count is known, or
            3) 1) the green-red reflectance is known, and
                2) the Near Infrared Reflectance is known,
Then it is definite (100%) that the production obtained from
satellite information is [[the production obtained from
satellite information plus the measure of certainty
associated with the percentage of area that looks like
forest] divided by 2].

```

```

IF      :: (WEEKS BT 7 11 AND FOREST IS MIGHTBE
            LIKE_FOREST AND (AVHRR IS KNOWN OR L-S IS
            KNOWN OR (GREEN-RED IS KNOWN AND NIR IS KNOWN)
            ) )
THEN    :: (SATELLITE-PRODUCTION = ((SATELLITE-PRODUCTION
            + CERTAINTY FOREST ) / 2 ) )

```

#### RULE091

=====

```

SUBJECT :: SATELLITE-RULES
ANTECEDENT :: YES
DESCRIPTION :: (1 and 2)
If      1) the AVHRR greenness counts is greater than 250, or
        2) the green-red reflectance is greater than 250,
Then 1) it is definite (100%) that the production obtained
        from satellite information is [1.1 times the
        production obtained from satellite information], and
        2) it is definite (100%) that the additional
        information obtained from satellite data is Crop
        yield may be above optimum..

IF      :: (AVHRR > 250 OR GREEN-RED > 250)
THEN    :: (SATELLITE-PRODUCTION = (1.1 * SATELLITE-
            PRODUCTION) AND SATELLITE-COMMENTS = "Crop
            yield may be above optimum." )

```

# RULE092

=====

SUBJECT :: SATELLITE-RULES

ANTECEDENT :: YES

DESCRIPTION :: (3)

If 1) [the green-red reflectance minus the previous green-red reflectance] is greater than 45, and  
2) the number of weeks after emergence from the soil is less than 11 but greater than or equal to 1,  
Then it is definite (100%) that the additional information obtained from satellite data is Satisfactory growth is observed..

IF :: ((GREEN-RED - GREEN-RED-PREVIOUS) > 45 AND WEEKS BT 1 11)

THEN :: (SATELLITE-COMMENTS = Satisfactory growth is observed.)

# RULE093

=====

SUBJECT :: SATELLITE-RULES

ANTECEDENT :: YES

DESCRIPTION :: (7)

If 1) the green-red reflectance is less than the previous green-red reflectance, and  
2) the number of weeks after emergence from the soil is less than 11 but greater than or equal to 1, and  
3) 1) the Near Infrared Reflectance around ponds is greater than 200, or  
2) the Visible Infrared Reflectance around ponds is greater than 200,  
Then it is definite (100%) that the additional information obtained from satellite data is The reduction in greenness is due to drought in the area..

IF :: ( GREEN-RED < GREEN-RED-PREVIOUS AND WEEKS BT 1 11 AND ( POND-NIR > 200 OR POND-VIR > 200 ) )

THEN :: (SATELLITE-COMMENTS = "The reduction in greenness is due to drought in the area." )

# RULE094

=====

SUBJECT :: SATELLITE-RULES

ANTECEDENT :: YES

DESCRIPTION :: (3 and 4)

If 1) 1) the growth stages of the corn plants included in this consultation is PRE\_EMERGENCE, or  
2) the growth stages of the corn plants included in this consultation is EMERGENCE, or  
3) the number of weeks after emergence from the soil is less than 3 but greater than or equal to 1, and

2) the green-red reflectance is greater than the previous green-red reflectance,  
Then it is definite (100%) that the additional information obtained from satellite data is There is positive prove of germination..

```
IF    :: ((GROWTH-STAGE = PRE_EMERGENCE OR GROWTH-STAGE
           = EMERGENCE OR WEEKS BT 1 3 ) AND GREEN-RED >
           GREEN-RED-PREVIOUS )
THEN  :: (SATELLITE-COMMENTS = There is positive prove
           of germination.)
```

RULE095

=====

```
SUBJECT :: SATELLITE-RULES
ANTECEDENT :: YES
DESCRIPTION :: (8 and 10)
```

If

- 1) the number of weeks after emergence from the soil is less than 11 but greater than or equal to 7, and
- 2) there is no evidence that the percentage of area that looks like forest is not LIKE\_FOREST, and
- 3)
  - 1) the measure of certainty associated with the AVHRR greenness counts is less than 100, or
  - 2) the measure of certainty associated with the L-S count is less than 100, or
  - 3)
    - 1) the measure of certainty associated with the green-red reflectance is less than 100, and
    - 2) the measure of certainty associated with the Near Infrared Reflectance is less than 100,

Then it is definite (100%) that the production obtained from satellite information is the measure of certainty associated with the percentage of area that looks like forest.

```
IF    :: (WEEKS BT 7 11 AND FOREST IS MIGHTBE
           LIKE_FOREST AND (( CERTAINTY AVHRR ) < 100 OR
           (CERTAINTY L-S) < 100 OR (( CERTAINTY GREEN-
           RED ) < 100 AND (CERTAINTY NIR) < 100 ) ) )
THEN  :: (SATELLITE-PRODUCTION = (CERTAINTY FOREST))
```

## APPENDIX E. SUBFRAME PLANT-PHYSIOLOGY

=====

Frame :: PLANT-PHYSIOLOGY

=====

```

IDENTIFIER :: "PLANT-PHYSIOLOGY-"
TRANSLATION :: (crop yield forecast from plant
                physiology information)
PARENTS :: (CROP-YIELD-FORECAST)
GOALS :: (PHYS-PRODUCTION PHYS-COMMENTS)
INITIALDATA :: (PLANTING-DATE LOW-TEMP NIGHT-TEMP SOIL-
                TEMP WATER-STORAGE SUN LEAVES FUNGI )
PROMPTEVER :: (:LINE 7 :ATTR (CYAN HIGH) "PLANT
                PHYSIOLOGY INFORMATION" :LINE :ATTR
                (YELLOW HIGH)
                "*****" )
PARMGROUP :: PLANT-PHYSIOLOGY-PARMS
RULEGROUPS :: (PLANT-PHYSIOLOGY-RULES)
ANTECEDENT :: YES
PLANT-PHYSIOLOGY-PARMS :: (FUNGI LEAVES LOW-TEMP NIGHT-
                           TEMP PLANTING-DATE SOIL-TEMP
                           SUN WATER-STORAGE )
PLANT-PHYSIOLOGY-RULES :: (RULE001 RULE002 RULE003
                           RULE004 RULE005 RULE006
                           RULE007 RULE009 RULE010
                           RULE011 RULE012 RULE013
                           RULE014 RULE015 RULE016
                           RULE017 RULE018 RULE019
                           RULE020 RULE087 RULE090 )

```

=====

PLANT-PHYSIOLOGY-PARMS

=====

FUNGI

=====

```

TRANSLATION :: (presence of fungi after maturity)
PROMPT :: (:ATTR (YELLOW HIGH) "Indicate the
           percentage of plants" :ATTR (WHITE HIGH)
           :ATTR (YELLOW HIGH) "where fungi was
           observed." )
TYPE :: SINGLEVALUED
EXPECT :: (PERCENTAGE_OF_FUNGI)
ANTECEDENT-IN :: (RULE012)
HELP :: ("Fungi can be observed on corn plant leaves
         as" :LINE "yellowish discolorations." :LINE
         "Extreme conditions of fungi can produce high"
         :LINE "levels of aflatoxin which makes the

```

```

corn" :LINE "unusable for human consumption.
This is" :LINE "particularly" :ATTR (MAGENTA
HIGH) "critical" :ATTR (WHITE HIGH ) "during
and after the" :LINE "maturity of the
plant." :LINE "Each little square is equivalent
to 10%." :LINE "Punch ENTER if there is no
available" :LINE "information about fungi." )
CERTAINTY-FACTOR-RANGE :: POSITIVE
CONTAINED-IN :: (RULE012)

```

#### LEAVES

=====

```

TRANSLATION :: (the percentage of leave loss)
PROMPT :: (:ATTR (YELLOW HIGH) "Indicate the
percentage of leave loss of the corn
plants." )
TYPE :: SINGLEVALUED
EXPECT :: (LEAVE_LOSS)
ANTECEDENT-IN :: (RULE013)
HELP :: ("This value comes from the observation of
the" :LINE "corn plants in the field." :LINE
"High leave loss may reduce the crop yield."
:LINE "This parameter is particularly" :ATTR (
MAGENTA HIGH ) "important" :ATTR (WHITE HIGH)
"during" :LINE "the late stages of the plant."
:LINE "Each little square is equivalent to
10%." :LINE "Punch ENTER if this information
is not" :LINE "available." )
CERTAINTY-FACTOR-RANGE :: POSITIVE

```

#### LOW-TEMP

=====

```

TRANSLATION :: (the lowest temperature registered for
the last growth stage )
PROMPT :: (:ATTR (YELLOW HIGH) "Enter the lowest
temperature during the last growth stage in
Fahrenheit." )
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
ANTECEDENT-IN :: (RULE002 RULE007 RULE014 RULE006
RULE004)
HELP :: ("This value comes from the observations"
:LINE "of the current year." :LINE "Punch
ENTER if this temperature is unknown." :LINE
"This parameter is very" :ATTR (MAGENTA HIGH)
"important":ATTR (WHITE HIGH) "during the"
:LINE "early stages of the plant." )
RANGE :: (-10 80)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

#### NIGHT-TEMP

=====

```

TRANSLATION :: (the highest night-time temperature

```

for the last growth stage )  
 PROMPT :: (:ATTR (YELLOW HIGH) "Enter the highest  
 temperature at NIGHT-TIME during the last  
 growth stage" :LINE "in" :ATTR ( WHITE HIGH  
 ) :ATTR (YELLOW HIGH) "Fahrenheit." )  
 TYPE :: SINGLEVALUED  
 EXPECT :: NUMBER  
 ANTECEDENT-IN :: (RULE007 RULE010 RULE009 RULE014)  
 HELP :: ("This value comes from the observations"  
 :LINE "of the current year." :LINE "Punch  
 ENTER if this temperature is unknown." :LINE  
 "This parameter is of low importance during  
 the" :LINE "early stages of the plant, but it  
 is very" :LINE :ATTR ( MAGENTA HIGH )  
 "important" :ATTR (WHITE HIGH) "during the  
 late stages of the plant." )  
 RANGE :: (30 90)  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN

#### PLANTING-DATE

=====

TRANSLATION :: (the planting date)  
 PROMPT :: (:ATTR (YELLOW HIGH) Enter the planting  
 date)  
 TYPE :: SINGLEVALUED  
 EXPECT :: (MARCH-15-22 MARCH-23-31 APRIL-1-6 APRIL-7-  
 15 APRIL-16-30 MAY-1-10 MAY-11-21 MAY-22-31  
 JUNE-1-11 )  
 ANTECEDENT-IN :: (RULE018 RULE019 RULE015 RULE016  
 RULE017)  
 HELP :: ("Select the period that is closest to the"  
 :LINE "believed planting date." :LINE "Select  
 UNKNOWN" :ATTR (MAGENTA HIGH) "only" :ATTR  
 (WHITE HIGH) "if the date of planting is"  
 :LINE "definitely unknown." )  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN

#### SOIL-TEMP

=====

TRANSLATION :: (the average low temperature of the  
 soil during germination )  
 PROMPT :: (:ATTR (YELLOW HIGH) "Enter the average low  
 temperature of the SOIL during germination"  
 :LINE "in" :ATTR (WHITE HIGH) :ATTR (YELLOW  
 HIGH ) "Fahrenheit." )  
 TYPE :: SINGLEVALUED  
 EXPECT :: NUMBER  
 ANTECEDENT-IN :: (RULE001)  
 HELP :: ("The soil temperature can be measured with"  
 :LINE "termometers at various levels in the  
 soil. The" :LINE "values are often recorded  
 continuously to" :LINE "provide more accurate  
 data." :LINE "This parameter is not important

during the late" :LINE "stages of the plant,  
but is" :ATTR (MAGENTA HIGH) "critical":ATTR  
(WHITE HIGH) "during the" :LINE "early stages  
of the plant." :LINE "Punch ENTER if this  
parameter is not available." )

RANGE :: (-10 80)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

SUN

===

TRANSLATION :: (the average percentage of weekly  
sunny days after tassel development )

PROMPT :: (:ATTR (YELLOW HIGH) "Indicate the average  
percentage of weekly sunny days" :LINE  
"after tassel" :ATTR (WHITE HIGH):ATTR  
(YELLOW HIGH) "development." )

TYPE :: SINGLEVALUED

EXPECT :: (SUNNY\_DAYS)

ANTECEDENT-IN :: (RULE011 RULE090)

HELP :: ("This value comes from the observations"  
:LINE "of the current year." :LINE "This  
parameter is not important during the  
early":LINE "stages of the plant, but it is"  
:ATTR (MAGENTA HIGH) "critical" :ATTR (WHITE  
HIGH) "during" :LINE "the late stages of the  
plant." :LINE "Each little square is  
equivalent to 10%." :LINE "Punch ENTER if this  
information is not" :LINE "available." )

CERTAINTY-FACTOR-RANGE :: POSITIVE

WATER-STORAGE

=====

TRANSLATION :: (the ground-water storage available  
for the crop at the beginning of the  
season )

PROMPT :: (:ATTR (YELLOW HIGH) "Enter the available  
ground-water storage for the crop at the  
beginning of" :LINE "the season (in" :ATTR  
(WHITE HIGH) :ATTR (YELLOW HIGH) "inches)."  
)

TYPE :: SINGLEVALUED

EXPECT :: NUMBER

ANTECEDENT-IN :: (RULE005 RULE020)

HELP :: ("An" :ATTR (MAGENTA HIGH) "inch of water"  
:ATTR (WHITE HIGH) "storage is the equivalent  
to" :LINE "an inch of rain over the entire  
crop." :LINE "The" :ATTR (MAGENTA HIGH)  
"beginning of the season" :ATTR (WHITE HIGH)  
"is the time when the" :LINE "corn seeds are  
planted." :LINE "Punch ENTER if the amount of  
ground-water" :LINE "storage is unknown." )

RANGE :: (0 30)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

=====
      PLANT-PHYSIOLOGY-RULES
=====

```

RULE001

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (1.a)

- If    1) the growth stages of the corn plants included in  
           this consultation is PRE\_EMERGENCE, and  
       2) the average low temperature of the soil during  
           germination is less than 48,  
 Then 1) it is definite (100%) that the production obtained  
           from plant physiology information is 0, and  
       2) it is definite (100%) that the additional  
           information obtained from plant physiology data is  
           There was no germination due to cold temperatures  
           after planting and before germination..

IF     :: (GROWTH-STAGE = PRE\_EMERGENCE AND SOIL-TEMP <  
           48)

THEN :: (PHYS-PRODUCTION = 0 AND PHYS-COMMENTS =  
           "There was no germination due to cold  
           temperatures after planting and before  
           germination." )

RULE002

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (1.c)

- If    1) the growth stages of the corn plants included in  
           this consultation is TWO\_LEAVES, and  
       2) the lowest temperature registered for the last  
           growth stage is less than 55,  
 Then 1) it is definite (100%) that the additional  
           information obtained from plant physiology data is  
           Cold temperatures may cause seed decay and fungle  
           diseases., and  
       2) it is definite (100%) that the production obtained  
           from plant physiology information is [the production  
           obtained from plant physiology information times  
           0.8].

IF     :: (GROWTH-STAGE = TWO\_LEAVES AND LOW-TEMP < 55)

THEN :: (PHYS-COMMENTS = "Cold temperatures may cause  
           seed decay and fungle diseases." AND PHYS-  
           PRODUCTION = (PHYS-PRODUCTION \* 0.8 ) )



# RULE003

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (1.d)

- If 1) 1) the growth stages of the corn plants included in this consultation is EMERGENCE, or  
2) the growth stages of the corn plants included in this consultation is TWO\_LEAVES, and  
2) flooding of the crop,

- Then 1) it is definite (100%) that the production obtained from plant physiology information is 0, and  
2) it is definite (100%) that the additional information obtained from plant physiology data is Plant death due to early flooding..

IF :: ((GROWTH-STAGE = EMERGENCE OR GROWTH-STAGE = TWO\_LEAVES) AND FLOOD )

THEN :: (PHYS-PRODUCTION = 0 AND PHYS-COMMENTS = "Plant death due to early flooding." )

# RULE004

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (3.c)

- If 1) the growth stages of the corn plants included in this consultation is not PRE\_EMERGENCE, and  
2) the growth stages of the corn plants included in this consultation is not EMERGENCE, and  
3) the growth stages of the corn plants included in this consultation is not TWO\_LEAVES, and  
4) the lowest temperature registered for the last growth stage is less than 33,

- Then 1) it is definite (100%) that the production obtained from plant physiology information is [the production obtained from plant physiology information times 0.9], and  
2) it is definite (100%) that the additional information obtained from plant physiology data is Reduction of crop yield due to late frost..

IF :: (GROWTH-STAGE != PRE\_EMERGENCE AND GROWTH-STAGE != EMERGENCE AND GROWTH-STAGE != TWO\_LEAVES AND LOW-TEMP < 33 )

THEN :: (PHYS-PRODUCTION = (PHYS-PRODUCTION \* 0.9) AND PHYS-COMMENTS = " Reduction of crop yield due to late frost." )

# RULE005

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

```

DESCRIPTION :: (4.b)
If 1) 1) 1) the ground-water storage available for the
      crop at the beginning of the season is less
      than 9, and
      2) 1) the location of the crop field in
            question is 1, or
            2) the location of the crop field in
            question is 2, or
      2) 1) the ground-water storage available for the
      crop at the beginning of the season is less
      than 12, and
      2) 1) the location of the crop field in
            question is 3, or
            2) the location of the crop field in
            question is 4, and
      2) the growth stages of the corn plants included in
      this consultation is PRE_EMERGENCE,
Then 1) it is definite (100%) that the production obtained
      from plant physiology information is [the production
      obtained from plant physiology information times
      0.7], and
      2) it is definite (100%) that the additional
      information obtained from plant physiology data is
      There is a high chance of future drought..

IF    :: (((WATER-STORAGE < 9 AND (LOCATION = 1 OR
      LOCATION = 2)) OR ( WATER-STORAGE < 12 AND
      (LOCATION = 3 OR LOCATION = 4) ) ) AND
      GROWTH-STAGE = PRE_EMERGENCE )
THEN  :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.7)
      AND PHYS-COMMENTS = "There is a high chance of
      future drought." )

```

RULE006

=====

```

SUBJECT :: PLANT-PHYSIOLOGY-RULES
ANTECEDENT :: YES
DESCRIPTION :: (1.g, 3.b)
If 1) the growth stages of the corn plants included in
      this consultation is POLLINATION, and
      2) 1) the highest temperature before pollination is
            greater than 100, or
            2) the lowest temperature registered for the last
            growth stage is greater than 85, or
            3) the moisture of the soil is less than 35,
Then 1) it is definite (100%) that the production obtained
      from plant physiology information is [the production
      obtained from plant physiology information times
      0.6], and
      2) it is definite (100%) that the additional
      information obtained from plant physiology data is
      Production of kernel may have been seriously
      affected by extreme stress..

```

```

IF      :: (GROWTH-STAGE = POLLINATION AND (HIGH-TEMP >
100 OR LOW-TEMP > 85 OR SOIL-MOISTURE < 35 ) )
THEN    :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.6)
AND PHYS-COMMENTS = "Production of kernel may
have been seriously affected by extreme
stress." )

```

#### RULE007

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (1.f)

```

If      1) 1) the growth stages of the corn plants included
           in this consultation is EIGHT_TO_TEN_LEAVES, or
           2) the growth stages of the corn plants included
           in this consultation is
           TWELVE_TO_FOURTEEN_LEAVES, or
           3) the growth stages of the corn plants included
           in this consultation is TASSEL, and
2) 1) the highest temperature before pollination is
    greater than 100, or
    2) the lowest temperature registered for the last
    growth stage is greater than 85, or
    3) the highest night-time temperature for the last
    growth stage is greater than 85, and
3) the moisture of the soil is less than 35,
Then 1) it is definite (100%) that the production obtained
    from plant physiology information is [the production
    obtained from plant physiology information times
    0.8], and
2) it is definite (100%) that the additional
    information obtained from plant physiology data is
    Serious loss in ear size, kernel size and count due
    to extreme stress..

```

```

IF      :: ((GROWTH-STAGE = EIGHT_TO_TEN_LEAVES OR
GROWTH-STAGE = TWELVE_TO_FOURTEEN_LEAVES OR
GROWTH-STAGE = TASSEL ) AND ( HIGH-TEMP > 100
OR LOW-TEMP > 85 OR NIGHT-TEMP > 85 ) AND
SOIL-MOISTURE < 35 )
THEN    :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.8)
AND PHYS-COMMENTS = "Serious loss in ear size,
kernel size and count due to extreme stress."
)

```

#### RULE009

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (1.j)

```

If      1) 1) the growth stages of the corn plants included
           in this consultation is FILL_STAGE, or

```

2) the growth stages of the corn plants included in this consultation is POLLINATION, and

2) the highest night-time temperature for the last growth stage is less than 85 but greater than or equal to 75,

Then 1) it is definite (100%) that the production obtained from plant physiology information is [the production obtained from plant physiology information times 0.85], and

2) it is definite (100%) that the additional information obtained from plant physiology data is Reduction of crop yield due to night temperatures above 75 F..

IF :: ((GROWTH-STAGE = FILL\_STAGE OR GROWTH-STAGE = POLLINATION) AND NIGHT-TEMP BT 75 85 )

THEN :: (PHYS-PRODUCTION = (PHYS-PRODUCTION \* 0.85) AND PHYS-COMMENTS = "Reduction of crop yield due to night temperatures above 75 F." )

#### RULE010

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (1.j)

If 1) 1) the growth stages of the corn plants included in this consultation is FILL\_STAGE, or

2) the growth stages of the corn plants included in this consultation is POLLINATION, and

2) the highest night-time temperature for the last growth stage is greater than 85,

Then 1) it is definite (100%) that the production obtained from plant physiology information is [the production obtained from plant physiology information times 0.7], and

2) it is definite (100%) that the additional information obtained from plant physiology data is Reduction of the crop yield due to night temperatures above 85 F..

IF :: ((GROWTH-STAGE = FILL\_STAGE OR GROWTH-STAGE = POLLINATION) AND NIGHT-TEMP > 85 )

THEN :: (PHYS-PRODUCTION = (PHYS-PRODUCTION \* 0.7) AND PHYS-COMMENTS = "Reduction of the crop yield due to night temperatures above 85 F." )

#### RULE011

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (1.i)

If 1) 1) the growth stages of the corn plants included in this consultation is FILL\_STAGE, or

2) the growth stages of the corn plants included in this consultation is MATURITY, and

2) the measure of certainty associated with the average percentage of weekly sunny days after tassel development is less than or equal to 30,

Then 1) it is definite (100%) that the production obtained from plant physiology information is [the production obtained from plant physiology information times 0.8], and

2) it is definite (100%) that the additional information obtained from plant physiology data is There is a potential development of STALK and ROOT ROTS diseases due to cloudy weather..

```
IF    :: ((GROWTH-STAGE = FILL_STAGE OR GROWTH-STAGE =
          MATURITY) AND ( CERTAINTY SUN ) <= 30 )
THEN  :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.8)
          AND PHYS-COMMENTS = " There is a potential
          development of STALK and ROOT ROTS diseases
          due to cloudy weather." )
```

#### RULE012

=====

```
SUBJECT :: PLANT-PHYSIOLOGY-RULES
ANTECEDENT :: YES
DESCRIPTION :: (1.k)

If    1) 1) the growth stages of the corn plants included
        in this consultation is MATURITY, or
        2) the growth stages of the corn plants included
        in this consultation is HARVEST_STORAGE, and
    2) the measure of certainty associated with presence
        of fungi after maturity is greater than 10,
Then 1) it is definite (100%) that the production obtained
        from plant physiology information is [the production
        obtained from plant physiology information times [1
        minus [the measure of certainty associated with
        presence of fungi after maturity divided by 100]]],
        and
    2) it is definite (100%) that the additional
        information obtained from plant physiology data is
        Reduction of crop yield due to fungi after
        maturity..
```

```
IF    :: ((GROWTH-STAGE = MATURITY OR GROWTH-STAGE =
          HARVEST_STORAGE) AND (CERTAINTY FUNGI) > 10 )
THEN  :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * (1 -
          (CERTAINTY FUNGI / 100 ) ) ) AND PHYS-COMMENTS
          = "Reduction of crop yield due to fungi after
          maturity." )
```

#### RULE013

=====

```
SUBJECT :: PLANT-PHYSIOLOGY-RULES
```

```

ANTECEDENT :: YES
DESCRIPTION :: (1.h)
If 1) 1) the growth stages of the corn plants included
      in this consultation is FILL_STAGE, or
      2) the growth stages of the corn plants included
      in this consultation is MATURITY, and
   2) the measure of certainty associated with the
      percentage of leave loss is greater than or equal to
      50,
Then 1) it is definite (100%) that the production obtained
      from plant physiology information is [the production
      obtained from plant physiology information times
      0.9], and
   2) it is definite (100%) that the additional
      information obtained from plant physiology data is
      Reduction of crop yield due to high leave loss..

IF    :: ((GROWTH-STAGE = FILL_STAGE OR GROWTH-STAGE =
          MATURITY) AND ( CERTAINTY LEAVES ) >= 50 )
THEN  :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.9)
          AND PHYS-COMMENTS = "Reduction of crop yield
          due to high leave loss." )

```

#### RULE014

=====

```

SUBJECT :: PLANT-PHYSIOLOGY-RULES
ANTECEDENT :: YES
DESCRIPTION :: (2.a)
If 1) the highest temperature before pollination is less
      than 75, and
   2) 1) the lowest temperature registered for the last
      growth stage is less than 66, or
      2) the highest night-time temperature for the last
      growth stage is less than 66, and
   3) the moisture of the soil is greater than 70,
Then 1) it is definite (100%) that the production obtained
      from plant physiology information is [the production
      obtained from plant physiology information times
      0.8], and
   2) it is definite (100%) that the additional
      information obtained from plant physiology data is
      Reduction in the crop yield due to extremely low
      stress..

IF    :: (HIGH-TEMP < 75 AND (LOW-TEMP < 66 OR NIGHT-
          TEMP < 66) AND SOIL-MOISTURE > 70 )
THEN  :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.8)
          AND PHYS-COMMENTS = "Reduction in the crop
          yield due to extremely low stress." )

```

#### RULE015

=====

```

SUBJECT :: PLANT-PHYSIOLOGY-RULES

```

```

ANTECEDENT :: YES
DESCRIPTION :: (2.b., 2.d.IF PLANTING=APRIL-16-30 AND
                ZONE=1 THEN PROD=.97 )
If 1) the growth stages of the corn plants included in
    this consultation is PRE_EMERGENCE, and
    2) 1) 1) the planting date is APRIL-16-30, and
        2) the location of the crop field in question
           is 1, or
        2) 1) the planting date is APRIL-7-15, and
           2) the location of the crop field in question
              is 2, or
        3) 1) the planting date is APRIL-1-6, and
           2) the location of the crop field in question
              is 3, or
        4) 1) the planting date is MARCH-23-31, and
           2) the location of the crop field in question
              is 4,
Then 1) it is definite (100%) that the production obtained
    from plant physiology information is [the production
    obtained from plant physiology information times
    0.97], and
    2) it is definite (100%) that the additional
    information obtained from plant physiology data is
    Planting was a little early. Early planting favors
    root structure of the plants..

IF    :: (GROWTH-STAGE = PRE_EMERGENCE AND ((PLANTING-
        DATE = APRIL-16-30 AND LOCATION = 1 ) OR
        (PLANTING-DATE = APRIL-7-15 AND LOCATION = 2 )
        OR (PLANTING-DATE = APRIL-1-6 AND LOCATION =
        3) OR ( PLANTING-DATE = MARCH-23-31 AND
        LOCATION = 4 ) ) )
THEN :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.97)
        AND PHYS-COMMENTS = "Planting was a little
        early. Early planting favors root structure of
        the plants." )

```

#### RULE016

=====

```

SUBJECT :: PLANT-PHYSIOLOGY-RULES
ANTECEDENT :: YES
DESCRIPTION :: (2.b, 2.d.IF PLANTING=APRIL-7-15 AND
                ZONE=1 THEN PROD=.9 )
If 1) the growth stages of the corn plants included in
    this consultation is PRE_EMERGENCE, and
    2) 1) 1) the planting date is APRIL-7-15, and
        2) the location of the crop field in question
           is 1, or
        2) 1) the planting date is APRIL-1-6, and
           2) the location of the crop field in question
              is less than 3 but greater than or equal to
              1, or
        3) 1) the planting date is MARCH-23-31, and

```

- 2) the location of the crop field in question is less than 4 but greater than or equal to 1, or
  - 4) the planting date is MARCH-15-22,
- Then 1) it is definite (100%) that the production obtained from plant physiology information is [the production obtained from plant physiology information times 0.9], and
- 2) it is definite (100%) that the additional information obtained from plant physiology data is Planting was too early. Early planting favors root structure of the plants..

```

IF    :: (GROWTH-STAGE = PRE_EMERGENCE AND ((PLANTING-
        DATE = APRIL-7-15 AND LOCATION = 1 ) OR
        (PLANTING-DATE = APRIL-1-6 AND LOCATION BT 1 3
        ) OR (PLANTING-DATE = MARCH-23-31 AND LOCATION
        BT 1 4) OR PLANTING-DATE = MARCH-15-22 ) )
THEN  :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.9) AND
        PHYS-COMMENTS = "Planting was too early. Early
        planting favors root structure of the plants."
        )

```

#### RULE017

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (2.b, 2.d.IF PLANTING=MAY-11-21 AND  
ZONE=1 THEN PROD=.9)

- If
- 1) the growth stages of the corn plants included in this consultation is PRE\_EMERGENCE, and
  - 2) 1) 1) the planting date is MAY-11-21, and
    - 2) the location of the crop field in question is 1, or
  - 2) 1) the planting date is MAY-1-10, and
    - 2) the location of the crop field in question is 2, or
  - 3) 1) the planting date is APRIL-16-30, and
    - 2) the location of the crop field in question is 3, or
  - 4) 1) the planting date is APRIL-7-15, and
    - 2) the location of the crop field in question is 4,
- Then 1) it is definite (100%) that the production obtained from plant physiology information is [the production obtained from plant physiology information times 0.9], and
- 2) it is definite (100%) that the additional information obtained from plant physiology data is Planting was too late. Chances of hot conditions during tasseling and silking..

```

IF    :: (GROWTH-STAGE = PRE_EMERGENCE AND ((PLANTING-

```



```

DATE = MAY-11-21 AND LOCATION = 1 ) OR
(PLANTING-DATE = MAY-1-10 AND LOCATION = 2 )
OR (PLANTING-DATE = APRIL-16-30 AND LOCATION =
3) OR ( PLANTING-DATE = APRIL-7-15 AND
LOCATION = 4 ) ) )
THEN :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.9)
AND PHYS-COMMENTS = "Planting was too late.
Chances of hot conditions during tasseling and
silking." )

```

#### RULE018

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

ANTECEDENT :: YES

DESCRIPTION :: (2.b, 2.d.IF PLANTING=MAY-22-31 AND  
ZONE=1 THEN PROD=.8)

```

If  1) the growth stages of the corn plants included in
      this consultation is PRE_EMERGENCE, and
    2) 1) 1) the planting date is MAY-22-31, and
        2) the location of the crop field in question
           is 1, or
        2) 1) the planting date is MAY-11-21, and
           2) the location of the crop field in question
              is 2, or
        3) 1) the planting date is MAY-1-10, and
           2) the location of the crop field in question
              is 3, or
        4) 1) the planting date is APRIL-16-30, and
           2) the location of the crop field in question
              is 4,
Then 1) it is definite (100%) that the production obtained
      from plant physiology information is [the production
      obtained from plant physiology information times
      0.8], and
    2) it is definite (100%) that the additional
      information obtained from plant physiology data is
      Planting was too late. High chances of hot
      conditions during tasseling and silking..

```

```

IF   :: (GROWTH-STAGE = PRE_EMERGENCE AND ((PLANTING-
DATE = MAY-22-31 AND LOCATION = 1 ) OR
(PLANTING-DATE = MAY-11-21 AND LOCATION = 2 )
OR (PLANTING-DATE = MAY-1-10 AND LOCATION = 3)
OR ( PLANTING-DATE = APRIL-16-30 AND LOCATION
= 4 ) ) )

```

```

THEN :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.8)
AND PHYS-COMMENTS = "Planting was too late.
High chances of hot conditions during
tasseling and silking." )

```

#### RULE019

=====

SUBJECT :: PLANT-PHYSIOLOGY-RULES

```

ANTECEDENT :: YES
DESCRIPTION :: (2.b, 2.d.IF PLANTING=JUNE-1-11 AND
                ZONE=1 THEN PROD=.72 )
If 1) the growth stages of the corn plants included in
    this consultation is PRE_EMERGENCE, and
    2) 1) 1) the planting date is JUNE-1-11, and
        2) the location of the crop field in question
            is less than 5 but greater than or equal to
            1, or
        2) 1) the planting date is MAY-22-31, and
            2) the location of the crop field in question
                is less than 5 but greater than or equal to
                2, or
        3) 1) the planting date is MAY-11-21, and
            2) the location of the crop field in question
                is less than 5 but greater than or equal to
                3, or
        4) 1) the planting date is MAY-1-10, and
            2) the location of the crop field in question
                is 4,
Then 1) it is definite (100%) that the production obtained
    from plant physiology information is [the production
    obtained from plant physiology information times
    0.72], and
    2) it is definite (100%) that the additional
    information obtained from plant physiology data is
    Planting was too late. Very high chances of hot
    conditions during tasseling and silking..

IF      :: (GROWTH-STAGE = PRE_EMERGENCE AND ((PLANTING-
        DATE = JUNE-1-11 AND LOCATION BT 1 5 ) OR
        (PLANTING-DATE = MAY-22-31 AND LOCATION BT 2 5
        ) OR (PLANTING-DATE = MAY-11-21 AND LOCATION
        BT 3 5 ) OR (PLANTING-DATE = MAY-1-10 AND
        LOCATION = 4) ) )
THEN    :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.72)
    AND PHYS-COMMENTS = "Planting was too late.
    Very high chances of hot conditions during
    tasseling and silking." )

```

#### RULE020

=====

```

SUBJECT :: PLANT-PHYSIOLOGY-RULES
ANTECEDENT :: YES
DESCRIPTION :: (4.b)
If 1) 1) 1) the ground-water storage available for the
    crop at the beginning of the season is less
    than 12 but greater than or equal to 9, and
        2) 1) the location of the crop field in
            question is 1, or
            2) the location of the crop field in
                question is 2, or
        2) 1) the ground-water storage available for the

```

crop at the beginning of the season is less than 18 but greater than or equal to 12, and

- 2) 1) the location of the crop field in question is 3, or
- 2) the location of the crop field in question is 4, and
- 2) the growth stages of the corn plants included in this consultation is PRE\_EMERGENCE,

Then 1) it is definite (100%) that the production obtained from plant physiology information is [the production obtained from plant physiology information times 0.85], and

- 2) it is definite (100%) that the additional information obtained from plant physiology data is There is a chance of future drought..

```
IF    :: (((WATER-STORAGE BT 9 12 AND (LOCATION = 1 OR
LOCATION = 2)) OR (WATER-STORAGE BT 12 18 AND
(LOCATION = 3 OR LOCATION = 4) ) ) AND
GROWTH-STAGE = PRE_EMERGENCE )
THEN  :: (PHYS-PRODUCTION = (PHYS-PRODUCTION * 0.85)
AND PHYS-COMMENTS = "There is a chance of
future drought." )
```

#### RULE087

=====

```
SUBJECT :: PLANT-PHYSIOLOGY-RULES
ANTECEDENT :: YES
DESCRIPTION :: (1.b)
```

If 1) the growth stages of the corn plants included in this consultation is EMERGENCE, and

- 2) the highest temperature before pollination is less than 53,

Then 1) it is definite (100%) that the production obtained from plant physiology information is [0.9 times the production obtained from plant physiology information], and

- 2) it is definite (100%) that the additional information obtained from plant physiology data is Low temperatures may have affected normal seedling growth..

```
IF    :: (GROWTH-STAGE = EMERGENCE AND HIGH-TEMP < 53)
THEN  :: (PHYS-PRODUCTION = (0.9 * PHYS-PRODUCTION)
AND PHYS-COMMENTS = "Low temperatures may have
affected normal seedling growth." )
```

#### RULE090

=====

```
SUBJECT :: PLANT-PHYSIOLOGY-RULES
ANTECEDENT :: YES
DESCRIPTION :: (2.c)
```

If 1) the measure of certainty associated with the

average percentage of weekly sunny days after tassel development is less than or equal to 30, and

- 2) the growth stages of the corn plants included in this consultation is SILK, and
- 3) the number of weeks after emergence from the soil is less than 10,

Then

- 1) it is definite (100%) that the production obtained from plant physiology information is [1.1 times the production obtained from plant physiology information], and
- 2) it is definite (100%) that the additional information obtained from plant physiology data is Early silking decreases the effect of cloudy weather during kernel fill..

```

IF      :: ((CERTAINTY SUN) <= 30 AND GROWTH-STAGE =
           SILK AND WEEKS < 10)
THEN    :: (PHYS-PRODUCTION = (1.1 * PHYS-PRODUCTION) AND
           PHYS-COMMENTS = "Early silking decreases the
                           effect of cloudy weather during kernel fill."
           )

```

## APPENDIX F. SUBFRAME GROUND

```
=====
Frame :: GROUND
=====
```

```
IDENTIFIER :: "GROUND-"
TRANSLATION :: (crop yield forecast from ground
                information)
PARENTS :: (CROP-YIELD-FORECAST)
GOALS :: (GROUND-PRODUCTION GROUND-COMMENTS)
INITIALDATA :: (COLOR FIRED HEIGHT LEAN RECOVER-
                OVERNIGHT SILK-DRY SOIL-STICK WILT )
PROMPTEVER :: (:LINE 7 :ATTR (CYAN HIGH) "
                GROUND INFORMATION" :LINE :ATTR (YELLOW
                HIGH) "*****" )
PARMGROUP :: GROUND-PARMS
RULEGROUPS :: (GROUND-RULES)
ANTECEDENT :: YES
GROUND-PARMS :: (COLOR FIRED HEIGHT LEAN RECOVER-
                OVERNIGHT SILK-DRY SOIL-STICK WILT )
GROUND-RULES :: (RULE057 RULE058 RULE059 RULE060
                RULE061 RULE064 RULE065 RULE067 RULE068
                RULE069 RULE070 RULE071 RULE072
                RULE089)
```

```
=====
GROUND-PARMS
=====
```

```
COLOR
=====
```

```
TRANSLATION :: (the color of the corn plants)
PROMPT :: (:ATTR (YELLOW HIGH) Select the color of the
           corn plants)
TYPE :: SINGLEVALUED
EXPECT :: (BRIGHT-GREEN DARK-GREEN YELLOW BROWN)
ANTECEDENT-IN :: (RULE061 RULE068 RULE069)
HELP :: ("The color of the corn plants is the main
         color" :LINE "of the plant. It can be
         brightly green, dark" :LINE "green, yellow,
         or brown." :LINE "Select UNKNOWN if there is
         no information about":LINE "this variable.")
CERTAINTY-FACTOR-RANGE :: UNKNOWN
```

```
FIRED
=====
```

```
TRANSLATION :: (the lower leaves of plants are fired)
PROMPT :: (:ATTR (YELLOW HIGH) "Are the lower leaves
```

```

        of the plants fired ?" )
TYPE :: YES/NO
ANTECEDENT-IN :: (RULE065)
HELP :: ("When the leaves of plants are fired, the"
        :LINE "surface of the leaves are extremely
        dry and are" :LINE "not green." :LINE "Select
        UNKNOWN if there is no information about"
        :LINE "it." )
CERTAINTY-FACTOR-RANGE :: UNKNOWN

HEIGHT
=====
TRANSLATION :: (the height of the corn plants by July
                4)
PROMPT :: (:ATTR (YELLOW HIGH) "Enter the height of
            the plant by July 4 (in feet)" )
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
ANTECEDENT-IN :: (RULE064 RULE070)
HELP :: ("Punch ENTER if the height of corn plants
        was not" :LINE "measured." )
RANGE :: (0 12)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

LEAN
====
TRANSLATION :: (the outside row of corn plants is
                leaning or falling down )
PROMPT :: (:ATTR (YELLOW HIGH) "Is the outside row of
            corn plants leaning or falling down ?" )
TYPE :: YES/NO
ANTECEDENT-IN :: (RULE058)
HELP :: (Select UNKNOWN if there is no information
        about :LINE it.)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

RECOVER-OVERNIGHT
=====
TRANSLATION :: (the corn plants recover overnight from
                wilt)
PROMPT :: (:ATTR (YELLOW HIGH) "Do the corn plants
            recover overnight from wilt ?" )
TYPE :: YES/NO
ANTECEDENT-IN :: (RULE065)
HELP :: ("When the plant wilts, it becomes less
        fresh," :LINE "bends, and starts to die."
        :LINE "Select UNKNOWN if there is no
        information about" :LINE "it." )
GHELP :: (RECOVERY)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

# SILK-DRY

=====

TRANSLATION :: (the silks are dry)  
PROMPT :: (:ATTR (YELLOW HIGH) Are the silks dry ?)  
TYPE :: YES/NO  
ANTECEDENT-IN :: (RULE067)  
HELP :: (Select UNKNOWN if there is no information  
about :LINE it.)  
CERTAINTY-FACTOR-RANGE :: UNKNOWN

# SOIL-STICK

=====

TRANSLATION :: (the soil is wet or so dry that it)  
PROMPT :: (:ATTR (YELLOW HIGH) The soil is wet or so  
dry that it...)  
TYPE :: SINGLEVALUED  
EXPECT :: (sticks to your shoes is picked up by the  
wind)  
ANTECEDENT-IN :: (RULE060)  
USED-BY :: (RULE059)  
HELP :: (Select UNKNOWN if undecided)  
CERTAINTY-FACTOR-RANGE :: UNKNOWN

# WILT

=====

TRANSLATION :: (wilt in upper leaves is observed)  
PROMPT :: (:ATTR (YELLOW HIGH) Is wilt observed in the  
upper leaves ?)  
TYPE :: YES/NO  
ANTECEDENT-IN :: (RULE065)  
HELP :: ("When the plant wilts, it becomes less  
fresh," :LINE "bends, and start to die."  
:LINE 2 "Punch UNKNOWN if there is no  
information about" :LINE "it." )  
GHELP :: (UPWILT)  
CERTAINTY-FACTOR-RANGE :: UNKNOWN

=====

# GROUND-RULES

=====

# RULE057

=====

SUBJECT :: GROUND-RULES  
ANTECEDENT :: YES  
DESCRIPTION :: (11.)

- If
- 1) flooding of the crop, and
  - 2) 1) the growth stages of the corn plants included in  
this consultation is not PRE\_EMERGENCE, or  
2) the growth stages of the corn plants included in  
this consultation is not EMERGENCE, or  
3) the growth stages of the corn plants included in

this consultation is not TWO\_LEAVES,  
 Then 1) it is definite (100%) that the production obtained  
 from ground information is [the production obtained  
 from ground information times 0.8], and  
 2) it is definite (100%) that the additional  
 information obtained from ground data is The area of  
 flood damage is defined by the short of poorly  
 developed plants..

IF :: (FLOOD AND (GROWTH-STAGE != PRE\_EMERGENCE OR  
 GROWTH-STAGE != EMERGENCE OR GROWTH-STAGE !=  
 TWO\_LEAVES ) )  
 THEN :: (GROUND-PRODUCTION = (GROUND-PRODUCTION \* 0.8)  
 AND GROUND-COMMENTS = "The area of flood  
 damage is defined by the short or poorly  
 developed plants." )

#### RULE058

=====

SUBJECT :: GROUND-RULES  
 ANTECEDENT :: YES  
 DESCRIPTION :: (12.)

If 1) 1) the growth stages of the corn plants included in  
 this consultation is EIGHT\_TO\_TEN\_LEAVES, or  
 2) the growth stages of the corn plants included in  
 this consultation is TWELVE\_TO\_FOURTEEN\_LEAVES,  
 or  
 3) the growth stages of the corn plants included in  
 this consultation is TASSEL, or  
 4) the growth stages of the corn plants included in  
 this consultation is SILK, or  
 5) the growth stages of the corn plants included in  
 this consultation is POLLINATION, and  
 2) the growth stages of the corn plants included in  
 this consultation is not HARVEST\_STORAGE, and  
 3) the outside row of corn plants is leaning or falling  
 down,  
 Then 1) it is definite (100%) that the production obtained  
 from ground information is [the production obtained  
 from ground information times 0.9], and  
 2) it is definite (100%) that the additional  
 information obtained from ground data is Poor root  
 structure of the plants..

IF :: ((GROWTH-STAGE = EIGHT\_TO\_TEN\_LEAVES OR  
 GROWTH-STAGE = TWELVE\_TO\_FOURTEEN\_LEAVES OR  
 GROWTH-STAGE = TASSEL OR GROWTH-STAGE = SILK  
 OR GROWTH-STAGE = POLLINATION ) AND GROWTH-  
 STAGE != HARVEST\_STORAGE AND LEAN )  
 THEN :: (GROUND-PRODUCTION = (GROUND-PRODUCTION \*  
 0.9) AND GROUND-COMMENTS = "Poor root  
 structure of the plants." )



# RULE059

=====

SUBJECT :: GROUND-RULES

DESCRIPTION :: (13.)

If the soil is wet or so dry that it is sticks to your shoes,  
Then it is definite (100%) that the additional information obtained from ground data is Ample soil moisture allows reasonable growth..

IF :: (SOIL-STICK = sticks to your shoes)  
THEN :: (GROUND-COMMENTS = "Ample soil moisture allows reasonable growth." )

# RULE060

=====

SUBJECT :: GROUND-RULES

ANTECEDENT :: YES

DESCRIPTION :: (14.)

If the soil is wet or so dry that it is is picked up by the wind,

Then 1) it is definite (100%) that the production obtained from ground information is [the production obtained from ground information times 0.8], and  
2) it is definite (100%) that the additional information obtained from ground data is There is insufficient moisture in the surface layer for plant growth..

IF :: (SOIL-STICK = is picked up by the wind)  
THEN :: (GROUND-PRODUCTION = (GROUND-PRODUCTION \* 0.8)  
AND GROUND-COMMENTS = "There is insufficient moisture in the surface layer for plant growth." )

# RULE061

=====

SUBJECT :: GROUND-RULES

ANTECEDENT :: YES

DESCRIPTION :: (10.)

If 1) the color of the corn plants is BROWN, and  
2) 1) the growth stages of the corn plants included in this consultation is EMERGENCE, or  
2) the growth stages of the corn plants included in this consultation is TWO\_LEAVES, or  
3) the growth stages of the corn plants included in this consultation is FOUR\_TO\_SIX\_LEAVES, or  
4) the growth stages of the corn plants included in this consultation is EIGHT\_TO\_TEN\_LEAVES, and  
3) the growth stages of the corn plants included in this consultation is not HARVEST\_STORAGE,

Then 1) it is definite (100%) that the additional information obtained from ground data is Severe drought has occurred and the yield loss is irreversible., and  
 2) it is definite (100%) that the production obtained from ground information is [0.8 times the production obtained from ground information].

IF :: (COLOR = BROWN AND (GROWTH-STAGE = EMERGENCE OR GROWTH-STAGE = TWO\_LEAVES OR GROWTH-STAGE = FOUR\_TO\_SIX\_LEAVES OR GROWTH-STAGE = EIGHT\_TO\_TEN\_LEAVES ) AND GROWTH-STAGE != HARVEST\_STORAGE )  
 THEN :: (GROUND-COMMENTS = "Severe drought has occurred and the yield loss is irreversible."  
 AND GROUND-PRODUCTION = (0.8 \* GROUND-PRODUCTION ) )

#### RULE064

=====

SUBJECT :: GROUND-RULES  
 ANTECEDENT :: YES  
 DESCRIPTION :: (3.)

If 1) the height of the corn plants by July 4 is less than 3, and  
 2) the number of weeks after emergence from the soil is greater than 5,  
 Then 1) it is definite (100%) that the production obtained from ground information is [0.8 times the production obtained from ground information], and  
 2) it is definite (100%) that the additional information obtained from ground data is Reduction of crop yield due to short growth..

IF :: (HEIGHT < 3 AND WEEKS > 5)  
 THEN :: (GROUND-PRODUCTION = (0.75 \* GROUND-PRODUCTION) AND GROUND-COMMENTS = "Reduction of crop yield due to short growth." )

#### RULE065

=====

SUBJECT :: GROUND-RULES  
 ANTECEDENT :: YES  
 DESCRIPTION :: (5. 6.)

If 1) the lower leaves of plants are fired, and  
 2) wilt in upper leaves is observed, and  
 3) the corn plants recover overnight from wilt is not true,  
 Then 1) it is definite (100%) that the production obtained from ground information is [0.9 times the production obtained from ground information], and  
 2) it is definite (100%) that the additional information obtained from ground data is Reduction

of crop yield due to wilt..

```
IF    :: (FIRED AND WILT AND ! RECOVER-OVERNIGHT)
THEN  :: (GROUND-PRODUCTION = (0.9 * GROUND-PRODUCTION)
          AND GROUND-COMMENTS = "Reduction of crop yield
          due to wilt." )
```

#### RULE067

=====

```
SUBJECT :: GROUND-RULES
ANTECEDENT :: YES
DESCRIPTION :: (7.)
```

```
If  1)  1) the growth stages of the corn plants included in
        this consultation is SILK, or
        2) the growth stages of the corn plants included in
        this consultation is POLLINATION, and
    2) the silks are dry,
Then 1) it is definite (100%) that the production obtained
        from ground information is [1.1 times the production
        obtained from ground information], and
    2) it is definite (100%) that the additional
        information obtained from ground data is Dry silks
        reduce the chance of low crop yield..
```

```
IF    :: ((GROWTH-STAGE = SILK OR GROWTH-STAGE =
          POLLINATION) AND SILK-DRY )
THEN  :: (GROUND-PRODUCTION = (1.1 * GROUND-
          PRODUCTION) AND GROUND-COMMENTS = "Dry silks
          reduce the chance of low crop yield." )
```

#### RULE068

=====

```
SUBJECT :: GROUND-RULES
ANTECEDENT :: YES
DESCRIPTION :: (8.)
```

```
If  1) the color of the corn plants is not BRIGHT-GREEN,
    and
    2)  1) the growth stages of the corn plants included in
        this consultation is EMERGENCE, or
        2) the growth stages of the corn plants included in
        this consultation is TWO_LEAVES, or
        3) the growth stages of the corn plants included in
        this consultation is FOUR_TO_SIX_LEAVES, or
        4) the growth stages of the corn plants included in
        this consultation is EIGHT_TO_TEN_LEAVES, or
        5) the growth stages of the corn plants included in
        this consultation is TWELVE_TO_FOURTEEN_LEAVES,
        or
        6) the growth stages of the corn plants included in
        this consultation is TASSEL,
Then 1) it is definite (100%) that the production obtained
        from ground information is [0.9 times the production
        obtained from ground information], and
```

2) it is definite (100%) that the additional information obtained from ground data is The coloring of the plants indicates reduction of crop yield..

```
IF    :: (COLOR != BRIGHT-GREEN AND (GROWTH-STAGE =
      EMERGENCE OR GROWTH-STAGE = TWO_LEAVES OR
      GROWTH-STAGE = FOUR_TO_SIX_LEAVES OR GROWTH-
      STAGE = EIGHT_TO_TEN_LEAVES OR GROWTH-STAGE =
      TWELVE_TO_FOURTEEN_LEAVES OR GROWTH-STAGE =
      TASSEL ) )
THEN  :: (GROUND-PRODUCTION = (0.9 * GROUND-
      PRODUCTION) AND GROUND-COMMENTS = "The
      coloring of the plants indicates reduction of
      crop yield." )
```

#### RULE069

=====

```
SUBJECT :: GROUND-RULES
ANTECEDENT :: YES
DESCRIPTION :: (9.)
If    1) the color of the corn plants is YELLOW, and
      2) flooding of the crop,
Then  1) it is definite (100%) that the production obtained
      from ground information is [0.9 times the production
      obtained from ground information], and
      2) it is definite (100%) that the additional
      information obtained from ground data is The plants
      have been oxygen starved during flooding..
```

```
IF    :: (COLOR = YELLOW AND FLOOD)
THEN  :: (GROUND-PRODUCTION = (0.9 * GROUND-PRODUCTION)
      AND GROUND-COMMENTS = "The plants have been
      oxygen starved during flooding." )
```

#### RULE070

=====

```
SUBJECT :: GROUND-RULES
ANTECEDENT :: YES
DESCRIPTION :: (4.)
If    1) the height of the corn plants by July 4 is greater
      than 4, and
      2) the number of weeks after emergence from the soil is
      less than 5,
Then  1) it is definite (100%) that the production obtained
      from ground information is [1.1 times the production
      obtained from ground information], and
      2) it is definite (100%) that the additional
      information obtained from ground data is Increase of
      crop yield due to high growth..
```

```
IF    :: (HEIGHT > 4 AND WEEKS < 5)
THEN  :: (GROUND-PRODUCTION = (1.25 * GROUND-
```

PRODUCTION) AND GROUND-COMMENTS = "Increase  
of crop yield due to high growth." )

RULE071

=====

SUBJECT :: GROUND-RULES

ANTECEDENT :: YES

DESCRIPTION :: (1.)

If 1) 1) the growth stages of the corn plants included in  
this consultation is FILL\_STAGE, and  
2) the number of weeks after emergence from the  
soil is less than 9,  
or  
2) 1) the growth stages of the corn plants included in  
this consultation is POLLINATION, and  
2) the number of weeks after emergence from the  
soil is less than or equal to 8, or  
3) 1) the growth stages of the corn plants included in  
this consultation is SILK, and  
2) the number of weeks after emergence from the  
soil is less than or equal to 7, or  
4) 1) the growth stages of the corn plants included in  
this consultation is TASSEL, and  
2) the number of weeks after emergence from the  
soil is less than or equal to 6, or  
5) 1) the growth stages of the corn plants included in  
this consultation is TWELVE\_TO\_FOURTEEN\_LEAVES,  
and  
2) the number of weeks after emergence from the  
soil is less than 5,  
or  
6) 1) the growth stages of the corn plants included in  
this consultation is EIGHT\_TO\_TEN\_LEAVES, and  
2) the number of weeks after emergence from the  
soil is less than 3,  
or  
7) 1) the growth stages of the corn plants included in  
this consultation is FOUR\_TO\_SIX\_LEAVES, and  
2) the number of weeks after emergence from the  
soil is less than or equal to 1,  
Then 1) it is definite (100%) that the production obtained  
from ground information is [1.1 times the production  
obtained from ground information], and  
2) it is definite (100%) that the additional  
information obtained from ground data is Increase of  
crop yield due to early growth stage..

IF :: ((GROWTH-STAGE = FILL\_STAGE AND WEEKS < 9) OR  
(GROWTH-STAGE = POLLINATION AND WEEKS <= 8 )  
OR (GROWTH-STAGE = SILK AND WEEKS <= 7 ) OR  
(GROWTH-STAGE = TASSEL AND WEEKS <= 6) OR  
(GROWTH-STAGE = TWELVE\_TO\_FOURTEEN\_LEAVES AND  
WEEKS < 5 ) OR (GROWTH-STAGE =

EIGHT\_TO\_TEN\_LEAVES AND WEEKS < 3 ) OR  
 (GROWTH-STAGE = FOUR\_TO\_SIX\_LEAVES AND WEEKS  
 <= 1 ) )  
 THEN :: (GROUND-PRODUCTION = (1.1 \* GROUND-PRODUCTION)  
 AND GROUND-COMMENTS = "Increase of crop yield  
 due to early growth stage." )

# RULE072

=====

SUBJECT :: GROUND-RULES

ANTECEDENT :: YES

DESCRIPTION :: (2.)

- If
- 1) 1) the growth stages of the corn plants included in this consultation is FILL\_STAGE, and
  - 2) the number of weeks after emergence from the soil is greater than or equal to 14, or
  - 2) 1) the growth stages of the corn plants included in this consultation is POLLINATION, and
  - 2) the number of weeks after emergence from the soil is greater than or equal to 13, or
  - 3) 1) the growth stages of the corn plants included in this consultation is SILK, and
  - 2) the number of weeks after emergence from the soil is greater than or equal to 12, or
  - 4) 1) the growth stages of the corn plants included in this consultation is TASSEL, and
  - 2) the number of weeks after emergence from the soil is greater than or equal to 10, or
  - 5) 1) the growth stages of the corn plants included in this consultation is TWELVE\_TO\_FOURTEEN\_LEAVES, and
  - 2) the number of weeks after emergence from the soil is greater than or equal to 8, or
  - 6) 1) the growth stages of the corn plants included in this consultation is EIGHT\_TO\_TEN\_LEAVES, and
  - 2) the number of weeks after emergence from the soil is greater than or equal to 6, or
  - 7) 1) the growth stages of the corn plants included in this consultation is FOUR\_TO\_SIX\_LEAVES, and
  - 2) the number of weeks after emergence from the soil is greater than or equal to 4, or
  - 8) 1) the growth stages of the corn plants included in this consultation is TWO\_LEAVES, and
  - 2) the number of weeks after emergence from the soil is greater than or equal to 3,
- Then
- 1) it is definite (100%) that the production obtained from ground information is [0.9 times the production obtained from ground information], and
  - 2) it is definite (100%) that the additional information obtained from ground data is Reduction of crop yield due to late growth stage..

```

IF    :: ((GROWTH-STAGE = FILL_STAGE AND WEEKS >= 14)
          OR (GROWTH-STAGE = POLLINATION AND WEEKS >=
13 ) OR (GROWTH-STAGE = SILK AND WEEKS >= 12
          ) OR (GROWTH-STAGE = TASSEL AND WEEKS >= 10)
          OR (GROWTH-STAGE = TWELVE_TO_FOURTEEN_LEAVES
AND WEEKS >= 8 ) OR (GROWTH-STAGE =
EIGHT_TO_TEN_LEAVES AND WEEKS >= 6 ) OR
          (GROWTH-STAGE = FOUR_TO_SIX_LEAVES AND WEEKS
>= 4 ) OR (GROWTH-STAGE = TWO_LEAVES AND
WEEKS >= 3 ) )
THEN  :: (GROUND-PRODUCTION = (0.9 * GROUND-
PRODUCTION) AND GROUND-COMMENTS = "Reduction
of crop yield due to late growth stage." )

```

#### RULE089

=====

```

SUBJECT :: GROUND-RULES
ANTECEDENT :: YES
DESCRIPTION :: (11.)
If      1) flooding of the crop, and
        2) 1) the growth stages of the corn plants included in
            this consultation is PRE_EMERGENCE, or
            2) the growth stages of the corn plants included in
            this consultation is EMERGENCE, or
            3) the growth stages of the corn plants included in
            this consultation is TWO_LEAVES,
Then 1) it is definite (100%) that the production obtained
        from ground information is [0.4 times the production
        obtained from ground information], and
        2) it is definite (100%) that the additional
        information obtained from ground data is Early flood
        caused great damage to the crop..

IF      :: (FLOOD AND (GROWTH-STAGE = PRE_EMERGENCE OR
GROWTH-STAGE = EMERGENCE OR GROWTH-STAGE =
TWO_LEAVES ) )
THEN    :: (GROUND-PRODUCTION = (0.4 * GROUND-
PRODUCTION) AND GROUND-COMMENTS = "Early
flood caused great damage to the crop.")

```

# APPENDIX G. SUBFRAME MODEL

```
=====
Frame :: MODEL
=====
```

```
IDENTIFIER :: "MODEL-"
TRANSLATION :: (crop yield forecast from model
                information)
PARENTS :: (CROP-YIELD-FORECAST)
GOALS :: (MODEL-PRODUCTION MODEL-COMMENTS)
INITIALDATA :: (DEW-POINT ETP EARLY-STRESS MODERATE-
                STRESS-EXTEND RAIN-FREQ SOIL-MOISTURE-
                TOP SOIL-MOISTURE-PLOW SOIL-MOISTURE-
                LOWER SUBSOIL-MOISTURE TEMPERATURE )
PROMPTEVER :: (:LINE 7 :ATTR (CYAN HIGH) "
                MODEL INFORMATION" :LINE :ATTR (YELLOW
                HIGH) "*****" )
PARMGROUP :: MODEL-PARMS
RULEGROUPS :: (MODEL-RULES)
ANTECEDENT :: YES
MODEL-PARMS :: (DEW-POINT EARLY-STRESS ETP MODERATE-
                STRESS-EXTEND RAIN-FREQ SOIL-MOISTURE-
                LOWER SOIL-MOISTURE-PLOW SOIL-MOISTURE-
                TOP SUBSOIL-MOISTURE TEMPERATURE )
MODEL-RULES :: (RULE033 RULE034 RULE035 RULE036 RULE037
                RULE038 RULE039 RULE040 RULE041 RULE042
                RULE043 RULE045 RULE046 RULE047 RULE088)
```

```
=====
MODEL-PARMS
=====
```

## DEW-POINT

```
=====
```

```
TRANSLATION :: (the dew point during the periods from
                late vegetative to soft dough )
PROMPT :: (:ATTR (YELLOW HIGH) "Enter the dew point
                during the periods from late vegetative to
                soft dough in Fahrenheit" )
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
ANTECEDENT-IN :: (RULE036)
HELP :: ("Dew point is the temperature at which small"
        :LINE "drops of moisture condense on the
        surface" :LINE "of the plant. The dew point is
        also used as a" :LINE "measure of the actual
        moisture the air can" :LINE "contain. If the
        dew point is large, there is" :LINE "a large
```



amount of moisture in the air." :LINE "Punch  
 ENTER if this parameter is not available." )  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN  
 RANGE :: (40 99)

#### EARLY-STRESS

=====

TRANSLATION :: (moderate stress occurred during early  
 growth)  
 PROMPT :: (:ATTR (YELLOW HIGH) "Does moderate stress  
 have occurred since the early growth of the  
 plants ?" )  
 TYPE :: YES/NO  
 ANTECEDENT-IN :: (RULE088)  
 HELP :: ("Select YES if moderate stress has occurred  
 since" :LINE "the emergence of the plants."  
 :LINE "Stress is any factor that impacts the"  
 :LINE "photosynthetic efficiency of the  
 plant." :LINE "An example of Moderate stress is  
 soil moisture" :LINE "around 40 percent and  
 temperature around 80" :LINE "percent." :LINE  
 "Select UNKNOWN if no records are available."  
 )  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN

#### ETP

===

TRANSLATION :: (ETP)  
 PROMPT :: (:ATTR (YELLOW HIGH) "Enter the maximum  
 value of ETP for two or more continuous  
 days" )  
 TYPE :: SINGLEVALUED  
 EXPECT :: NUMBER  
 ANTECEDENT-IN :: (RULE036 RULE038)  
 HELP :: ("ETP: the demand of water on the plant by  
 the" :LINE "atmosphere in terms of solar heat,  
 wind," :LINE "humidity, etc." :LINE 2 "Punch  
 ENTER if there is no information about" :LINE  
 "ETP." )  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN  
 RANGE :: (0 100)

#### MODERATE-STRESS-EXTEND

=====

TRANSLATION :: (the periods of moderate stress are  
 interrupted by light showers )  
 PROMPT :: (:ATTR (YELLOW HIGH) "Are the periods of  
 moderate stress interrupted by light showers  
 ?" )  
 TYPE :: YES/NO  
 ANTECEDENT-IN :: (RULE043)  
 HELP :: ("An example of moderate stress is soil  
 moisture" :LINE "arround 40 and the

```

        temperature arround 80" :LINE "degrees." :LINE
        "Select UNKNOWN if:" :LINE "1) There is the
        information is not available." :LINE "2) There
        has not been moderate stress." )
    CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

#### RAIN-FREQ

=====

```

    TRANSLATION :: (rain occurs at regular intervals)
    PROMPT :: (:ATTR (YELLOW HIGH) Does rain occur at
        regular intervals ?)
    TYPE :: YES/NO
    ANTECEDENT-IN :: (RULE046 RULE047 RULE088)
    HELP :: ("Select UNKNOWN if there is no information
        about" :LINE "rain events." )
    CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

#### SOIL-MOISTURE-LOWER

=====

```

    TRANSLATION :: (the soil moisture in the lower layer)
    PROMPT :: (:ATTR (YELLOW HIGH) "Enter the value of
        soil moisture in the lower layer" )
    TYPE :: SINGLEVALUED
    EXPECT :: NUMBER
    ANTECEDENT-IN :: (RULE034)
    HELP :: ("The lower layer of soil is often refered as
        the" :LINE "soil between the plow layer and
        the roots of the" :LINE "plant.":LINE "Soil
        moisture can be measured in various ways."
        :LINE "Gravimetric, where the moisture is
        determined by" :LINE "weighting a sample
        before and after drying." :LINE "Newton
        Detection, where a source of nuclear" :LINE
        "radiation is used." :LINE "Enter the soil
        moisture in percentage of the": LINE "soil
        capacity. The soil capacity is the amount of
        water": LINE "in the soil when the soil is
        saturated" :LINE "Punch ENTER if this
        parameter is not available." )
    CERTAINTY-FACTOR-RANGE :: UNKNOWN
    RANGE :: (0 100)
    GHELP :: (SOIL)

```

#### SOIL-MOISTURE-PLOW

=====

```

    TRANSLATION :: (the soil moisture in the plow layer)
    PROMPT :: (:ATTR (YELLOW HIGH) "Enter the value of
        soil moisture in the plow layer" )
    TYPE :: SINGLEVALUED
    EXPECT :: NUMBER
    ANTECEDENT-IN :: (RULE034 RULE035)
    HELP :: ("The plow layer is often refered as the
        soil" :LINE "under the top soil but not deeper

```

than one feet." :LINE "Soil moisture can be  
measured in various ways." :LINE "Gravimetric,  
where the moisture is determined by" :LINE  
"weighting a sample before and after drying."  
:LINE "Newton Detection, where a source of  
nuclear" :LINE "radiation is used. This method  
is less accurate":LINE "than the Gravimetric  
near the surface." :LINE "Enter the soil  
moisture in percentage of the": LINE "soil  
capacity. The soil capacity is the amount of  
water": LINE "in the soil when the soil is  
saturated" :LINE "Punch ENTER if this  
parameter is not available." )

CERTAINTY-FACTOR-RANGE :: UNKNOWN

RANGE :: (0 100)

GHELP :: (SOIL)

#### SOIL-MOISTURE-TOP

=====

TRANSLATION :: (the moisture in the top soil layer)

PROMPT :: (:ATTR (YELLOW HIGH) "Enter the value of  
moisture in the top soil layer during the  
two first" :LINE "weeks" :ATTR (WHITE HIGH )  
:ATTR (YELLOW HIGH) "after" :ATTR (WHITE  
HIGH) :ATTR (YELLOW HIGH ) "planting" )

TYPE :: SINGLEVALUED

EXPECT :: NUMBER

ANTECEDENT-IN :: (RULE033)

HELP :: ("The top soil is often refered as the soil  
on the" :LINE "surface or fresh top soil."  
:LINE "Soil moisture can be measured in  
various ways." :LINE "Gravimetric, where the  
moisture is determined by" :LINE "weighting a  
sample before and after drying." :LINE "Newton  
Detection, where a source of nuclear" :LINE  
"radiation is used. This method is less  
accurate":LINE "than the Gravimetric near the  
surface." :LINE "Enter the soil moisture in  
percentage of the": LINE "soil capacity. The  
soil capacity is the amount of water": LINE  
"in the soil when the soil is saturated" :LINE  
"Punch ENTER if this parameter is not  
available." )

CERTAINTY-FACTOR-RANGE :: UNKNOWN

RANGE :: (0 100)

GPROMPT :: "SOIL"

#### SUBSOIL-MOISTURE

=====

TRANSLATION :: (the subsoil moisture)

PROMPT :: (:ATTR (YELLOW HIGH) Enter the value of  
subsoil moisture)

TYPE :: SINGLEVALUED

EXPECT :: NUMBER  
 ANTECEDENT-IN :: (RULE047 RULE040)  
 HELP :: ("The subsoil is often refered as the soil  
 below" :LINE "the root of the corn plant."  
 :LINE "Soil moisture can be measured in  
 various ways." :LINE "Gravimetric, where the  
 moisture is determined by" :LINE "weighting a  
 sample before and after drying." :LINE "Newton  
 Detection, where a source of nuclear":LINE  
 "radiation is used." :LINE "Enter the subsoil  
 moisture in percentage of the": LINE "subsoil  
 capacity. The subsoil capacity is the amount  
 of water": LINE "in the subsoil when the  
 subsoil is saturated" :LINE "Punch ENTER if  
 this parameter is not available." )  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN  
 RANGE :: (0 100)  
 GHELP :: (SOIL)

#### TEMPERATURE

=====

TRANSLATION :: (the highest temperature during the  
 growing periods)  
 PROMPT :: (:ATTR (YELLOW HIGH) "Enter the highest  
 temperature in Fahrenheit during the growing  
 periods." )  
 TYPE :: SINGLEVALUED  
 EXPECT :: POSITIVE-NUMBER  
 ANTECEDENT-IN :: (RULE041 RULE045 RULE046)  
 USED-BY :: (RULE042)  
 HELP :: (Punch ENTER if the highest temperature is  
 :LINE unknown.)  
 CERTAINTY-FACTOR-RANGE :: UNKNOWN  
 RANGE :: (50 140)

=====

#### MODEL-RULES

=====

#### RULE033

=====

SUBJECT :: MODEL-RULES  
 ANTECEDENT :: YES  
 DESCRIPTION :: (2.)

- If
- 1) the moisture in the top soil layer is less than 30,  
and
  - 2)
    - 1) the growth stages of the corn plants included  
in this consultation is PRE\_EMERGENCE, or
    - 2) the growth stages of the corn plants included  
in this consultation is EMERGENCE, or
    - 3) the growth stages of the corn plants included  
in this consultation is TWO\_LEAVES,

Then 1) it is definite (100%) that the production obtained from model information is [0.9 times the production obtained from model information], and  
 2) it is definite (100%) that the additional information obtained from model data is Good germination may have been impacted by low moisture in the top soil..

IF :: (SOIL-MOISTURE-TOP < 30 AND (GROWTH-STAGE = PRE\_EMERGENCE OR GROWTH-STAGE = EMERGENCE OR GROWTH-STAGE = TWO\_LEAVES ) )  
 THEN :: (MODEL-PRODUCTION = (0.9 \* MODEL-PRODUCTION) AND MODEL-COMMENTS = "Good germination may have been impacted by low moisture in the top soil." )

#### RULE034

=====

SUBJECT :: MODEL-RULES  
 ANTECEDENT :: YES  
 DESCRIPTION :: (1.)

If 1) the soil moisture in the lower layer is less than 30, or  
 2) the soil moisture in the plow layer is less than 30,  
 Then 1) it is definite (100%) that the production obtained from model information is [0.9 times the production obtained from model information], and  
 2) it is definite (100%) that the additional information obtained from model data is Crop health from mid-vegetative to harvest may have been affected by low moisture in the lower layer of soil..

IF :: (SOIL-MOISTURE-LOWER < 30 OR SOIL-MOISTURE-PLOW < 30)  
 THEN :: (MODEL-PRODUCTION = (0.9 \* MODEL-PRODUCTION) AND MODEL-COMMENTS = "Crop health from mid-vegetative to harvest may have been affected by low moisture in the lower layer of soil." )

#### RULE035

=====

SUBJECT :: MODEL-RULES  
 ANTECEDENT :: YES  
 DESCRIPTION :: (10.)

If 1) the soil moisture in the plow layer is greater than 85, and  
 2) the growth stages of the corn plants included in this consultation is PRE\_EMERGENCE,  
 Then 1) it is definite (100%) that the production obtained from model information is [0.8 times the production obtained from model information], and  
 2) it is definite (100%) that the additional

information obtained from model data is Planting should have been delayed until the layer dries to less than 75 percent..

```
IF    :: (SOIL-MOISTURE-PLOW > 85 AND GROWTH-STAGE =
          PRE_EMERGENCE)
THEN  :: (MODEL-PRODUCTION = (0.8 * MODEL-PRODUCTION)
          AND MODEL-COMMENTS = "Planting should have
          been delayed until the layer dries to less
          than 75 percent." )
```

#### RULE036

=====

```
SUBJECT :: MODEL-RULES
ANTECEDENT :: YES
DESCRIPTION :: (7.)
```

```
If  1) the dew point during the periods from late
      vegetative to soft dough is greater than 70, and
    2) 1) the growth stages of the corn plants included
        in this consultation is EIGHT_TO_TEN_LEAVES, or
        2) the growth stages of the corn plants included
        in this consultation is
        TWELVE_TO_FOURTEEN_LEAVES, or
        3) the growth stages of the corn plants included
        in this consultation is TASSEL, or
        4) the growth stages of the corn plants included
        in this consultation is SILK, or
        5) the growth stages of the corn plants included
        in this consultation is POLLINATION, or
        6) the growth stages of the corn plants included
        in this consultation is FILL_STAGE, and
    3) ETP is greater than 10,
Then 1) it is definite (100%) that the additional
      information obtained from model data is the results
      of daytime stress will be amplified and reduction of
      crop yield due to high dew point., and
    2) it is definite (100%) that the production obtained
      from model information is [0.9 times the production
      obtained from model information].
```

```
IF    :: (DEW-POINT > 70 AND (GROWTH-STAGE =
          EIGHT_TO_TEN_LEAVES OR GROWTH-STAGE =
          TWELVE_TO_FOURTEEN_LEAVES OR GROWTH-STAGE =
          TASSEL OR GROWTH-STAGE = SILK OR GROWTH-STAGE
          = POLLINATION OR GROWTH-STAGE = FILL_STAGE )
          AND ETP > 10 )
THEN  :: (MODEL-COMMENTS = "the results of daytime
          stress will be amplified and reduction of crop
          yield due to high dew point." AND MODEL-
          PRODUCTION = (0.9 * MODEL-PRODUCTION) )
```

RULE037

=====

SUBJECT :: MODEL-RULES

ANTECEDENT :: YES

DESCRIPTION :: (5.)

- If
- 1) 1) the growth stages of the corn plants included in this consultation is MATURITY, and  
2) the number of weeks after emergence from the soil is less than 16,  
or
  - 2) 1) the growth stages of the corn plants included in this consultation is HARVEST\_STORAGE, and  
2) the number of weeks after emergence from the soil is less than 18,  
or
  - 3) 1) the growth stages of the corn plants included in this consultation is FILL\_STAGE, and  
2) the number of weeks after emergence from the soil is less than 14,  
or
  - 4) 1) the growth stages of the corn plants included in this consultation is POLLINATION, and  
2) the number of weeks after emergence from the soil is less than 10,  
or
  - 5) 1) the growth stages of the corn plants included in this consultation is SILK, and  
2) the number of weeks after emergence from the soil is less than 9,  
or
  - 6) 1) the growth stages of the corn plants included in this consultation is TASSEL, and  
2) the number of weeks after emergence from the soil is less than 8,  
or
  - 7) 1) the growth stages of the corn plants included in this consultation is  
TWELVE\_TO\_FOURTEEN\_LEAVES, and  
2) the number of weeks after emergence from the soil is less than 7,  
or
  - 8) 1) the growth stages of the corn plants included in this consultation is EIGHT\_TO\_TEN\_LEAVES, and  
2) the number of weeks after emergence from the soil is less than 5,  
or
  - 9) 1) the growth stages of the corn plants included in this consultation is FOUR\_TO\_SIX\_LEAVES, and  
2) the number of weeks after emergence from the soil is less than 3,  
or
  - 10) 1) the growth stages of the corn plants included in this consultation is TWO\_LEAVES, and

2) the number of weeks after emergence from the soil is less than 1,  
 Then 1) it is definite (100%) that the production obtained from model information is [0.9 times the production obtained from model information], and  
 2) it is definite (100%) that the additional information obtained from ground data is reduction of crop yield due to accelerated growth rate..

```

IF    :: ((GROWTH-STAGE = MATURITY AND WEEKS < 16) OR
          (GROWTH-STAGE = HARVEST_STORAGE AND WEEKS < 18
           ) OR (GROWTH-STAGE = FILL_STAGE AND WEEKS < 14
           ) OR (GROWTH-STAGE = POLLINATION AND WEEKS <
           10 ) OR (GROWTH-STAGE = SILK AND WEEKS < 9) OR
          (GROWTH-STAGE = TASSEL AND WEEKS < 8 ) OR
          (GROWTH-STAGE = TWELVE_TO_FOURTEEN_LEAVES AND
           WEEKS < 7 ) OR (GROWTH-STAGE =
           EIGHT_TO_TEN_LEAVES AND WEEKS < 5 ) OR
          (GROWTH-STAGE = FOUR_TO_SIX_LEAVES AND WEEKS <
           3 ) OR (GROWTH-STAGE = TWO_LEAVES AND WEEKS <
           1 ) )
THEN  :: (MODEL-PRODUCTION = (0.9 * MODEL-PRODUCTION)
          AND GROUND-COMMENTS = "reduction of crop yield
          due to accelerated growth rate." )

```

#### RULE038

=====

```

SUBJECT :: MODEL-RULES
ANTECEDENT :: YES
DESCRIPTION :: (6.)
If  1) ETP is greater than or equal to 10, and
    2)  1) the growth stages of the corn plants included
          in this consultation is EIGHT_TO_TEN_LEAVES, or
        2) the growth stages of the corn plants included
          in this consultation is
          TWELVE_TO_FOURTEEN_LEAVES, or
Then 1) it is definite (100%) that the production obtained
       from model information is [0.9 times the production
       obtained from model information], and
    2) it is definite (100%) that the additional
       information obtained from model data is reduction
       of crop yield due to high ETP..

IF    :: (ETP >= 10 AND (GROWTH-STAGE =
          EIGHT_TO_TEN_LEAVES OR GROWTH-STAGE =
          TWELVE_TO_FOURTEEN_LEAVES ) )
THEN  :: (MODEL-PRODUCTION = (0.9 * MODEL-PRODUCTION)
          AND MODEL-COMMENTS = "reduction of crop yield
          due to high ETP." )

```



# RULE039

=====

SUBJECT :: MODEL-RULES

ANTECEDENT :: YES

DESCRIPTION :: (4.)

If 1) the moisture of the soil is greater than or equal to 95, and

- 2) 1) the growth stages of the corn plants included in this consultation is PRE\_EMERGENCE, or
- 2) the growth stages of the corn plants included in this consultation is EMERGENCE, or
- 3) the growth stages of the corn plants included in this consultation is TWO\_LEAVES, or
- 4) the growth stages of the corn plants included in this consultation is FOUR\_TO\_SIX\_LEAVES,

Then 1) it is definite (100%) that the production obtained from model information is [0.9 times the production obtained from model information], and

- 2) it is definite (100%) that the additional information obtained from model data is Reduction of crop yield due to excessive soil moisture during early growth..

IF :: (SOIL-MOISTURE >= 95 AND (GROWTH-STAGE = PRE\_EMERGENCE OR GROWTH-STAGE = EMERGENCE OR GROWTH-STAGE = TWO\_LEAVES OR GROWTH-STAGE = FOUR\_TO\_SIX\_LEAVES ) )

THEN :: (MODEL-PRODUCTION = (0.9 \* MODEL-PRODUCTION) AND MODEL-COMMENTS = "Reduction of crop yield due to excessive soil moisture during early growth." )

# RULE040

=====

SUBJECT :: MODEL-RULES

ANTECEDENT :: YES

DESCRIPTION :: (3.)

If 1) the subsoil moisture is less than 35, and

- 2) 1) the growth stages of the corn plants included in this consultation is POLLINATION, or
- 2) the growth stages of the corn plants included in this consultation is SILK,

Then 1) it is definite (100%) that the production obtained from model information is [0.8 times the production obtained from model information], and

- 2) it is definite (100%) that the additional information obtained from model data is reduction of crop yield due to low subsoil moisture during reproduction..

IF :: (SUBSOIL-MOISTURE < 35 AND (GROWTH-STAGE = POLLINATION OR GROWTH-STAGE = SILK ) )

THEN :: (MODEL-PRODUCTION = (0.8 \* MODEL-PRODUCTION)

AND MODEL-COMMENTS = "reduction of crop yield  
due to low subsoil moisture during  
reproduction." )

RULE041

=====

SUBJECT :: MODEL-RULES

ANTECEDENT :: YES

DESCRIPTION :: (8.)

If 1) the moisture of the soil is greater than or equal to  
70, and  
2) 1) the highest temperature during the growing  
periods is less than 80,  
or  
2) the highest temperature before pollination is  
less than 60,  
Then 1) it is definite (100%) that the additional  
information obtained from model data is The chances  
for disease formations are increased significantly  
due to very low stress., and  
2) it is definite (100%) that the production obtained  
from model information is [0.8 times the production  
obtained from model information].

IF :: (SOIL-MOISTURE >= 70 AND (TEMPERATURE < 80 OR  
HIGH-TEMP < 60))

THEN :: (MODEL-COMMENTS = "The chances for disease  
formations are increased significantly due to  
very low stress." AND MODEL-PRODUCTION = (0.8  
\* MODEL-PRODUCTION) )

RULE042

=====

SUBJECT :: MODEL-RULES

DESCRIPTION :: (9.)

If 1) the moisture of the soil is less than 70 but greater  
than or equal to  
50, and  
2) the highest temperature during the growing periods  
is less than 90 but greater than or equal to 60, and  
3) the growth stages of the corn plants included in  
this consultation is FILL\_STAGE,  
Then it is definite (100%) that the additional information  
obtained from model data is Moderate stress enhances the  
quality of the corn.

IF :: (SOIL-MOISTURE BT 50 70 AND TEMPERATURE BT 60  
90 AND

GROWTH-STAGE = FILL\_STAGE )

THEN :: (MODEL-COMMENTS = "Moderate stress enhances  
the quality of the corn" )

# RULE046

=====

SUBJECT :: MODEL-RULES

ANTECEDENT :: YES

DESCRIPTION :: (14.)

- If    1) the moisture of the soil is less than 50 but  
          greater than or equal to 30, and  
      2) the highest temperature during the growing periods  
          is less than 95 but greater than or equal to 75, and  
      3) the highest temperature before pollination is less  
          than 85 but greater than or equal to 65, and  
      4) rain occurs at regular intervals,  
Then 1) it is definite (100%) that the production obtained  
          from model information is [1.1 times the production  
          obtained from model information], and  
      2) it is definite (100%) that the additional  
          information obtained from model data is Increase of  
          crop yield due to light to moderate stress  
          throughout the lifetime of the crop..

IF     :: (SOIL-MOISTURE BT 30 50 AND TEMPERATURE BT 75  
          95 AND HIGH-TEMP BT 65 85 AND RAIN-FREQ )

THEN :: (MODEL-PRODUCTION = (1.1 \* MODEL-PRODUCTION)  
          AND MODEL-COMMENTS = "Increase of crop yield  
          due to light to moderate stress throughout the  
          lifetime of the crop." )

# RULE047

=====

SUBJECT :: MODEL-RULES

ANTECEDENT :: YES

DESCRIPTION :: (16.)

- If    1) rain occurs at regular intervals, and  
      2) the subsoil moisture is less than 30,  
Then 1) it is definite (100%) that the production obtained  
          from model information is [1.1 times the production  
          obtained from model information], and  
      2) it is definite (100%) that the additional  
          information obtained from model data is Increase of  
          crop yield due to regular rain..

IF     :: (RAIN-FREQ AND SUBSOIL-MOISTURE < 30)

THEN :: (MODEL-PRODUCTION = (1.1 \* MODEL-PRODUCTION)  
          AND MODEL-COMMENTS = "Increase of crop yield  
          due to regular rain." )

# RULE088

=====

SUBJECT :: MODEL-RULES

ANTECEDENT :: YES

DESCRIPTION :: (15.)

- If    1) moderate stress occurred during early growth, and  
      2) rain occurs at regular intervals,

Then 1) it is definite (100%) that the production obtained from model information is [1.1 times the production obtained from model information], and  
2) it is definite (100%) that the additional information obtained from model data is Early stress made the corn plants very resistant to stress during reproduction..

```
IF      :: (EARLY-STRESS AND RAIN-FREQ)
THEN    :: (MODEL-PRODUCTION = (1.1 * MODEL-PRODUCTION)
            AND MODEL-COMMENTS = "Early stress made the
            corn plants very resistant to stress during
            reproduction." )
```

## APPENDIX H. GLOSSARY

### AVHRR:

Advanced Very High Resolution Radiometer. This is a scanning satellite sensor flying on the National Oceanographic and Atmospheric Administration which has observing capabilities in the visible, near infrared and far infrared portion of the electromagnetic spectrum. It is also a parameter used in the program to store the value of the AVHRR observation.

### Capacity:

Refers to the water content of the soil when it is saturated.

### CENTERED:

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the green area observed from satellite observation is an isolated area.

### COLOR:

A parameter used in the program. It stores the color of the leaves of the corn plants.

### CROP:

A parameter used in the program. It stores the qualitative value of the crop yield.

### DEW-POINT:

A parameter used in the program. It stores the value of the dew point observation.

### Dew point:

The temperature at which the air moisture condense on the surface of the plant leaves.

### Ear:

The part of the corn plant that contains the kernels.

### Ear Fill:

The process where the kernels of corn fill the ear following the tasseling and pollination period. Good fill results in high corn yields.

### EARLY-STRESS:

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the corn plants experienced moderate stress during the early growth periods.

### ET:

The actual transpiration of the plant or rate of water used by the plant.

**ETP:**

The water demand on the plant by the atmosphere. It is also a parameter used in the program to store the value of the ETP observation.

**FIRE:**

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the lower leaves of the plants are fired.

**FLOOD:**

A parameter used in the program. It stores the event of flooding occurrence.

**FOREST:**

A parameter used in the program. It stores the percentage of the area that looks like forest in the satellite observations.

**Frame:**

A structure that provides for the collection of several types of data about the knowledge base.

**FUNGI:**

A parameter used in the program. It stores the fungi degree observed in the corn.

**Fungi:**

Any of a major group of saprophytic and parasitic lower plants that lack chlorophyll and includes molds and rusts. Fungi can be observed in corn plants as yellowish discolorations.

**GREEN-RED:**

A parameter used in the program. It stores the value of the green/red reflectance.

**Green/Red Channel:**

Refers to the response of sensor channel on various sensing systems in electromagnetic terms.

**GREEN-RED-PREVIOUS:**

A parameter used in the program. It stores the value of the green/red reflectance of the previous consultation.

**Greenness Count:**

The index relating the visible to infrared reflectance ratios that is used to determine how green an agricultural field or plant or a city of forest is. The city or forest counts form the end points to calibrate counts over agricultural regions.

**GROUND-COMMENTS:**

A parameter used in the program. It stores additional commentaries about the expected crop yield obtained in the subframe GROUND.

**GROUND-PRODUCTION:**

A parameter used in the program. It stores the expected crop yield obtained in the subframe GROUND.

**GROWTH-STAGE:**

A parameter used in the program. It stores the growth stages of the corn plant that are included in the consultation.

**HEIGHT:**

A parameter used in the program. It stores the height of the plants by July 4, in inches.

**HIGH-TEMP:**

A parameter used in the program. It stores the value of the highest temperature observed before pollination.

**INITIAL:**

A parameter used in the program. It stores the percentage of the optimum production of the crop field to be used as the preliminary value for the corn production.

**Kernel:**

The grains of corn.

**L/S:**

Shorthand for LandSat. It is also a parameter used in the program to store the value of the L/S greenness observation.

**LandSat:**

Satellite operated by the EOSAT company which provides visible, near infrared and far infrared portions of the electromagnetic spectrum.

**LEAN:**

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the outside row of corn plants is leaning or falling down.

**LEAVES:**

A parameter used in the program. It stores the percentage of leave loss of the plants.

**LOCATION:**

A parameter used in the program. It stores the location of the crop field.

**LOW-TEMP:**

A parameter used in the program. It stores the lowest

temperature observed for the crop.

**MAXIMUM:**

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the actual greenness observation is the maximum for the year in that particular crop field.

**MODEL-COMMENTS:**

A parameter used in the program. It stores additional comments about the expected crop yield obtained in the subframe COMMENTS.

**MODEL-PRODUCTION:**

A parameter used in the program. It stores the expected crop yield obtained in the subframe MODEL.

**MODERATE-STRESS-EXTEND:**

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the plants experienced periods of moderate stress interrupted by light showers.

**Near Infrared:**

Indicates that portion of the electromagnetic spectrum that is just beyond that used by human vision.

**NIGHT-TEMP:**

A parameter used in the program. It stores the highest night time temperature observed for the crop.

**NIR:**

A parameter used in the program. It stores the value of the near infrared reflectance observation.

**Parameter:**

An individual piece of knowledge that keeps information about certain factor.

**PHYS-COMMENTS:**

A parameter used in the program. It stores additional comments about the expected crop yield obtained in the subframe PLANT-PHYSIOLOGY.

**PHYS-PRODUCTION:**

A parameter used in the program. It stores the expected crop yield obtained in the subframe PLANT-PHYSIOLOGY.

**PLANTING-DATE:**

A parameter used in the program. It stores the planting date of the crop.



**POND-NIR:**

A parameter used in the program. It stores the value of the near infrared reflectance observation around small ponds in the area.

**POND-VIR:**

A parameter used in the program. It stores the value of the visible infrared reflectance observation around small ponds in the area.

**PRODUCTION:**

A parameter used in the program. It stores the combination of the expected crop yield obtained in each subframe.

**Property:**

Refers to a structure that contains information that describe frames, parameters or rules.

**RAIN-FREQ:**

A parameter used in the program. It provides the client with the yes/no option indicating whether or not rain occurred with regular frequency.

**RECOVER-OVERNIGHT:**

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the corn plants recover overnight from wilt.

**Reflectance:**

Refers to the reflectance of sunlight from earth surface objects in those parts of the electromagnetic spectrum.

**Root Rots:**

A type of corn disease that has a higher potential of occurrence when there is low photosynthesis.

**Rule:**

Element of a knowledge base that express relationship between parameters and conclusions about them.

**SATELLITE-COMMENTS:**

A parameter used in the program. It stores additional comments about the expected crop yield obtained in the subframe SATELLITE.

**SATELLITE-PRODUCTION:**

A parameter used in the program. It stores the expected crop yield obtained in the subframe SATELLITE.

**Significant Stress:**

The stress that has impact on the vegetation appearance or plant health.

**Silk:**

The part of the corn plant that grows on the tip of the ear. This part is directly involved in the pollination process.

**SILK-DRY:**

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the silks of the plants are dry.

**SOIL-MOISTURE:**

A parameter used in the program. It stores the value of the soil moisture.

**SOIL-MOISTURE-LOWER:**

A parameter used in the program. It stores the moisture content of the lower layer of soil.

**SOIL-MOISTURE-PLOW:**

A parameter used in the program. It stores the moisture content of the plow layer of soil.

**SOIL-MOISTURE-TOP:**

A parameter used in the program. It stores the moisture content of the upper layer of soil.

**SOIL-STICK:**

A parameter used in the program. It provides the client with the options "the soil sticks to your shoes" or "the soil can be picked by the wind".

**SOIL-TEMP:**

A parameter used in the program. It stores the average soil temperature during germination.

**Stalk:**

A type of corn disease that has a higher potential of occurrence when there is low photosynthesis.

**Stress:**

The plant stress measured as a function of the ratio ET/ETP. A plant that cannot meet the demand of the atmosphere by drawing moisture in the soil will go under stress and may change the appearance from green to yellow or brown as the water leaves its leaf cells.

**SUBSOIL-MOISTURE:**

A parameter used in the program. It stores the moisture content of the subsoil.

**SUN:**

A parameter used in the program. It stores the weekly average percentage of sunny days after tassel development.

**Tassel:**

The part of the corn plant located in the crest of the plant and has a yellowish color. This part of the plant contains the pollen and is directly involved in the reproduction process.

**TEMPERATURE:**

A parameter used in the program. It stores the highest temperature observed for the crop.

**Visible Infrared:**

Indicates that portion of the electromagnetic spectrum that is used by human vision.

**WATER-STORAGE:**

A parameter used in the program. It stores the ground water storage available for the crop at the beginning of the season.

**WEEKS:**

A parameter used in the program. It stores the number of weeks after emergence of the soil.

**WILT:**

A parameter used in the program. It provides the client with the yes/no option indicating whether or not the plants wilt.

**Wilt:**

Referred to the process of the plants when the leaves become less fresh and start to die. Wilt is frequently due to stress and high temperatures.