EPIC Modeling System for CMAQ 12km Grids in the FEST-C V1.0

U.S. EPA Contract No. EP-W-09-023, "Operation of the Center for Community Air Quality Modeling and Analysis (CMAS)"

Prepared for: Dr. Ellen Cooter
Atmospheric Exposure Integration Branch
Atmospheric Modeling and Analysis Division
USEPA/ORD/NERL/
E243-02
Research Triangle Park, NC 27711

Prepared by: Verel Benson
Benson Consulting
200 Haywood Ct
Columbia, MO 65203

Limei Ran, Dongmei Yang
Institute for the Environment
The University of North Carolina at Chapel Hill
137 E. Franklin St., CB 6116
Chapel Hill, NC 27599-6116

Date: October 25, 2013

Table of Contents

1. Introduction

The purpose of this document is to describe the assumptions and original code developed for FORTRAN programs executed through the FEST-C tool. Most of the EPIC site generation, soil processing and management file code elements were originally written by Dr. Verel Benson, Benson Consulting in Columbia MO under the technical direction of Dr. Ellen Cooter, USEPA. The principle goal of these programs is to automate, to the greatest extent possible, the generation of the thousands of input files required to execute an EPIC simulation in a nationally consistent fashion. This document should be used as a supplement to the Fertilizer Emission Scenario Tool for CMAQ (FEST-C): User's Guide. Questions regarding its content should be directed to Dr. Ellen Cooter, cooter.ellen@epa.gov.

The EPIC modeling system uses logic, physical relationships, weather characteristics, soil characteristics, survey data and expert opinion to estimate the amount, timing and type of fertilizer applied to 21 crops. The timing, amount and type of fertilizer applied by an individual farmer will vary from these estimates because farmers are subject to illness, social events, and equipment failure that are not directly modeled; however, there is a random effect of delays and limitations added to partially compensate for these types of delays. There is no attempt to vary the type of fertilizer by crop below a regional level. Farmers do vary their fertilizer types and rates as market prices and availability change; however, capturing such variation is beyond the scope of this study because there is not a consistent source of information to estimate this variability at a 12km grid level. This EPIC modeling system, which was first designed and developed for the CMAQ 12km US1 domain, has been adapted to domain grids with different resolutions and projections within the FEST-C system. In this document, we use the CMAQ 12km grid definition while describing the development of this modeling system.

There are five components to the EPIC Modeling System:

1. Soil file creation
2. Site file delineation and site file creation
3. Delineation of soil, site, and crop linkages
4. Development of management files for each soil, site, and crop linkage.
5. Development of fertilization practices by growth stage by crop and type of fertilizer.

The management files define the tillage practice, fertilizer management practice, cropping practices, and timing of all the preceding practices. Soil selection and soil file creation are handled by the SOILMATCH programs. Site file delineation was done by UNC. The files they created contained latitude, longitude, elevation, HUC8 codes, county FIPS codes, land use fractions and other descriptive information which were used to generate the EPIC site files using the SITE-FILE-Creation program. Crop delineation by site was accomplished by the SITEBELD4HUC8.FOR program using the BELD4 data which is generated from NLCD/MODIS land cover data, USDA National Agricultural Statistics Service (NASS) and Forest Inventory Analysis (FIA) data, and Canada crop census data to create the list of sites by crop for which EPIC management must be built. The type of fertilizer applied is based on fertilizer sales by state by six month period (January to June and July to December). The state sales data are summarized for each of 62 major fertilizer types by six month period by region using 10 production regions (Northeast, Appalachia, Southeast, Lake States, Cornbelt, Delta States, Northern Plains, Southern Plains, Mountain, and Pacific). Cropping practice survey data were used to define fertilizer practices and tillage if available.

2. Soil File Creation

The soil data sets were built with soil parameters from the Baumer database built by Dr. Otto Baumer shortly after he retired from the USDA, National Resources Conservations Service (NRCS) Soils Laboratory in Lincoln, Nebraska. Dr. Baumer created the data base under contract with the Texas A&M Blackland Research Station. The EPIC soil datasets were built to represent the sample point soils selected for the 1997 USDA Natural Resources Inventory (NRI) data points. However, the Baumer database does not include complete datasets for all soils sampled by the NRI because some soils lacked key information to build the EPIC soil file. This analysis used soils identified in the Baumer database as complete. Dr. Baumer used the SOILS-5 database (Soils-5 is the name of the input form used to enter data into the Official Series Descriptions for SCS soil surveys) and soil pedon data to develop the representative EPIC data sets.

The Baumer data base includes soil information by state compiled from various sources he acquired. The files contained some information on over 200,000 soils at NRI points. A subset of nearly 45,000 soils contained potentially usable data. This information was used to create a subset of soil parameters to be used with EPIC for almost 23,000 soils. The following variables were read by the developed program to create the soil files for EPIC:

STATE= 2-DIGIT ID
FIPS= STATE FIPS CODE
SOIL= SOILS 5 NAME
MUSYB= MAPPING UNIT SYMBAL
GDFLG= (1) MEANS A COMPLETE SOIL (0) MEANS INCOMPLETE
MKIND= MAP UNIT KIND(C, A, X, U)
TEXID= SOIL TEXTURE
NUMS5= SOILS 5 NUMBER
SLOPEL= LOWER SLOPE RANGE
SLOPEU= UPPER SLOPE RANGE
UMOD= TAXONOMY UNIT MODIFIER CODE
GTGRP= TAXONOMY GREAT GROUP CODE
SBGRPM= TAXONOMY SUBGROUP CODE
PARTSZ= TAXONOMY PARTICAL SIZE CODE
MINER= TAXONOMY MINEROLOGY CODE
REACT= TAXONOMY REACTION (ACID ETC.) UNIT MODIFIER CODE
TEMP= TAXONOMY SOIL TEMPERATURE CODE
OTHER= TAXONOMY OTHER CODE
HWTDPU= HIGH WATER TABLE UPPER LIMIT IN FEET
HWTDPL= HIGH WATER TABLE LOWER LIMIT IN FEET
HWTKND= HIGH WATER TABLE KIND
HWTBEG= HIGH WATER TABLE BEGINNING MONTH

HWTEND= HIGH WATER TABLE ENDING MONTH
CPDPU= CEMENTED PAN UPPER LIMIT IN INCHES
CPDPL= CEMENTED PAN LOWER LIMIT IN INCHES
CPHARD= HARDNESS OF PAN CODE
BEDDPU= BEDROCK UPPER LIMIT IN INCHES
BEDDPL= BEDROCK LOWER LIMIT IN INCHES
BEDSPC= BEDROCK SPECIFICATION CODE
BEDHRD= HARDNESS OF BEDROCK CODE
HYDGRP= HYDROLOGIC GROUP
NSL= NUMBER OF SOIL LAYERS
DATA FOR EACH OF IL (1 T0 6) LAYERS
GOODHOR(IL)= INDICATOR THAT LAYER DATA IS COMPLETE
TEXIDL(IL)= TEXTURE
DEPTHU(IL)= UPPER BOUND OF LAYER DEPTH IN INCHES
DEPTHL(IL)= LOWER BOUND OF LAYER DEPTH IN INCHES
RFG(IL)= VOLUME PERCENTAGE OF ROCK FRAGMENTS
SAND(IL)= SILT WEIGHT PERCENT
SILT(IL)= SAND WEIGHT PERCENT
BD(IL)= MOIST BULK DENSITY M.TONS/M3
PERMEA(IL)= PERMEABILITY IN INCHES/HOUR
REACTC(IL)= PH (ARITHMETIC AVERAGE)
SAL(IL)= EC CONDUCTIVITY EL, CONDITION OF SOIL PASTE EXTRACT
CEC(IL)= CATION EXCHANGE CAPACITY
CACO3(IL)=CALCIUM CARBONATE WEIGHT PERCENT
ORGMAT(IL)= ORGANIC MATTER, WEIGHT PERCENT
CECR(IL)= CLAY ACTIVITY, CEC OF ONE GRAM OF CLAY MINERAL
WCS(IL)= WATER CONTENT ATSATUATION, VOLUME PERCENT
W3RD(IL)= WATER CONTENT AT 1/3 BAR VOLUME PERCENT
W15(IL)= WATER CONTENT AT 15 BAR VOLUME PERCENT
HFC(IL)= FIELD CAPACITY SUCTION (NOT ALWAYS 1/3 BAR) IN BAR
WFC(IL)= WATER CONTENT AT FIELDCAPACITY VOLUME PERCENT
BDDR(IL)= DRY BULK DENSITY
YINTER(IL)= INTERCEPT WATER(VOLUME PERCENT) VS SUCTION (LOG BAR)
YSLOPE(IL)=SLOPE OF WATER VS SUCTION RELATIONSHIP
SALBDR= DRY SOIL ALBEDO
RECN=RECORD NUMBER BY STATE

Not all of the variables read by the program are currently used for the EPIC soil file creation; however, some may be used at a later date. For example, soil taxonomy is international which may allow these data sets to represent an international soil in the future where only soil taxonomy is known. Not all NRI points have soils because some fall on lakes or rivers, some fall in urban areas, and some fall on mountains or deserts. Some soils may fall on many NRI points further reducing the number of soils needed to match the NRI points. Some points may have soils that have little or no available data. For example, rock outcrops have little soil and therefore little data.

The first step in developing the datasets for the EPIC simulations is to identify a representative soil series by 8-digit hydrologic unit (HU) and by crop or land use using the NRI database. The pilot efforts found that assumptions must be made to assign representative soils to all of the BELD4 categories used by CMAQ modeling because 1) the crop classification in the NRI was slightly different than BELD4, and 2) because there were cases where no NRI sample points fell on land with each BELD4 crop identified for the HU. The selection process was then modified to assign soils to12-km grid cells within the 8-digit hydrologic cataloging unit (HUC) or to the HUC containing the largest portion of the 12-km grid cell.

New soil databases may expand the EPIC, APEX, and SWAT datasets available for future analyses. However, this project was working with limited resources and choose to use this soil data because the databases had been developed for EPIC use and because they could be linked to NRI point data which has statistical weights that were used to select the most representative soil for the crop by 8-digit HUC and then link it to the 12km grid cells. Better data and linkage may be developed in the future; however, it is likely to be costly and may not be necessary to address many of the questions this project is examining.

3. Site File Delineation and Site File Creation

There are 70,169 12-km grid cells which contain crop or pasture land in the CMAQ US domain for North America. The United States has 45,950, Canada has 17,900, Mexico has 6,265 and there are 54 on islands. Currently, site files have been built for the 45,950 12-km grid sites in the CONUS with at least 40 acres of that crop within the 12km grid. For EPIC modeling the crop site information table was generated and it contains: 1) the latitude and longitude for the centroid of each 12-km grid cell; 2) elevation; 3) land slope (derived from digital elevation map (DEM) data layers); 4) the HUC8 number for the HU that contained the 12-km grid cell or the dominate part of the 12-km grid if the grid cell overlapped part of more than one HUC8; 5) the ten USDA production region code; 6) the state and county FIPS codes; 7) percentage in crops; and 8) percentage in grass.

The crop site information table was in text format and named as "EPICSites_Info.csv" for use by a program (SITE_FILE_CREATOR.exe, SITE-FILE-CREATOR.FOR) which creates 45,950 EPIC site files for the 12-km grid cells using the information in this file and "assumed values" for other EPIC inputs that were appropriate for this application. A list of all the sites is also output as the "SITELIST.DAT" file for use with EPIC and other programs later.

4. Delineation Soil, Site, and Crop Linkages

The first step in establishing the spatial linkages is to link the crops to the appropriate sites where the crops are produced. Most survey data is collected and compiled at county or state levels. Satellite data is available at the 12-km grid level or finer. Crop delineation is not precise with satellite imagery, thus a combination of data sources was used to identify the fraction of each 12-

km grid cell growing each crop to be modeled. These data were compiled in EXCEL adaptable form. These data are processed by a program (SITEBELD4HUC8.FOR.exe, SITEBELD4HUC8.FOR) which creates files with site information and crop information by each crop and grid cell. The program used the "SITELIST.DAT" file from the EPIC site file creation program output and the site crop information table generated from the BELD4 data. In the FEST-C system, this program is included in the EPIC Site File Generation tool.

The second step is to link EPIC soil datasets to the soil series from the NRI for the crop and grid cell. In some cases, additional assumptions must be made to link a soil to a particular BELD4 crop in a HU. In these instances, soil files for similar crops that fall in a similar crop category i.e. row crop, close grown crops, hay crops or pasture crop were used. The soil data was compiled by soil survey areas (usually counties, but sometimes multiple counties or part of a county). The centroid of the county was used to find the soil closest to the 8-digit HUC centroid. In a few cases the soil survey names did not match any county information that could be used to assign a latitude and longitude to the survey name. Six programs where used in succession to match each crop and site to a representative soil

Step by step soil match program functions and files – The first program file is entitled "CROPLIST.DAT". It contains the name of the file that has the site information by crop for the rainfed and irrigated crop numbers for each 12-km grid cell, for example the corn for grain file name is "CORNG-LIST.DAT".

The second file is a NRI list of SOILS 5 soils in numerical order by HUC8, NRI crop code and NRI weighting factor from highest to lowest within HUC8 by crop. It is entitled "NRI-ALL-HUC8S-ALLCROPS.prn".

The third file is the list of HUC8 site data entitled "HUC8_SITE_INFO-2REV.PRN". It contains the site information for each HUC8 including latitude, longitude, elevation, land slope and the land use code used by the USDA Soil Conservation Service (SCS) Curve Number hydrologic equations.

The fourth file is a file with a table of NRI and BELD4 crop cross reference information including crop numbers assigned for BELD4 crops not in NRI list of crops. It is entitled "NRI-crop-codes-BELD4-codes.prn". The primary purpose of the cross reference is to identify representative soils by crop type using the NRI observed crop soil combinations.

The fifth file lists soils to be linked to HUC8/BELD4 crop combinations. It is entitled "HUC8NRICROPSOIL.DAT".

The sixth file lists the latitude and longitude for each HUC8 site to be used when calculating the distance between HUC8 centroid and potential soils by crop by 12 km grid cell. It is entitled "HUCSITELATLONG.DAT".

The program (SOILMATCH1ST.exe, SOILMATCH1ST.FOR) proceeds as follows:

1. Reads CROPLIST.DAT which contains the name of the file that contains the 12-km grid cell number, the BELD4 crop number and the HUC8 number.

2. Reads the first record of the named file.

3. Reads in the “NRI-ALL-HUC8S-ALLCROPS.prn” file record by record until it finds a match to the HUC8 number and the NRI crop number cross referenced to the BELD4 number. This determines the SOILS-5 number of the desired soil. Soils are presorted by NRI weighting factor from largest to smallest.

4. Identifies HUC8 latitude and longitude and then starts through the list of soils developed from the Baumer data calculating the distance from the soil survey area centroid to the HUC8 centroid and selecting the SOILS- 5 numbered soil closest to the HUC8 centroid.

5. If no soil is matched to the grid cell number, BELD4 number and HUC8 numbers are added to a file of unmatched combinations.

6. If there is a match, the grid cell number, BELD4 number and HUC8 numbers and the soil file name of the selected soil are added to a list of soil matches (SOILSKM1.LOC).

7. A second program (SOILMATCH2ND.exe, SOILMATCH2ND.FOR) which matches soils by type of crop (row crop, close grown crop, and pasture and hay crops) uses the file of unmatched combinations from the preceding program as input and again finds soil matches (SOILSKM2.LOC).

8. Unmatched crops to soil from the second program are used as input into a third program (SOILMATCH3RD.exe, SOILMATCH3RD.FOR) except the HUCs are matched using only the first 6 digits of the HUC8 number and the crop groups (SOILSKM3.LOC).

9. Unmatched crops to soil from the third program are used as input into a fourth program (SOILMATCH4TH.exe, SOILMATCH4TH.FOR) except the HUCs are matched using only the first 6 digits of the HUC8 number allowing any crop to match the list crop(SOILSKM4.LOC).

10. Unmatched crops to soil from the fourth program are used as input into a fifth program (SOILMATCH5TH.exe, SOILMATCH5TH.FOR) except the HUCs are matched using only the first 4 digits of the HUC8 number, but crops must match at the crop number level(SOILSKM5.LOC).

11. Unmatched crops to soil from the fifth program are used as input into a sixth program (SOILMATCH6TH.exe, SOILMATCH6TH.FOR) except the HUCs are matched using only the first 2 digits of the HUC8 number allowing any crop to match the list crop (SOILSKM6.LOC).

Matches are usually found before using the last two programs. The lists of matched soil/crop files are merged into a single file called “SOILLIST.DAT”.

EPIC spinup simulations are then made for each soil, crop, and 12-km grid cell to create a soil file that has nutrient concentrations that represent the soil and climate growing the crop identified by the BELD4 data for the site using site slope and elevation determined by GIS data. The soil nutrient concentrations are an important part of nutrient balance for the year-specific simulation by crop and 12-km grid cell.

5. Development of Spin-up Management Files for Each Soil, Site, and Crop Linkage (ManGenSU.FOR, ManGenSU.exe)

The program that creates the EPIC management for each 12-km grid cell and crop combination also creates the EPICRUN file that contains the linkages for the 12-km site, weather and wind files, the soil files and the management files. The management program has 8 input files and 24 types of output files. Some of the output files just verify that the input was read correctly, but most are files to be used in the EPIC simulations.

5.1 Input Files

The following is the list of the input files for the program in the order read:

1. CROPLIST.DAT contains the name of the file that lists the sites for a particular crop both irrigated and rainfed, for example the file name for corn grain is CORNG-LIST.DAT. The file contains the data by 12-km grid cell: IGRID12A (12KM grid number), IBELD4CROP (BELD4 crop code), XLOG12A (longitude of 12km grid), YLAT12A (latitude of 12km grid), ELEV12A (elevation of 12km grid in feet), SLGRID12A (percent slope of 12km grid), IHUC8 (8-digit HUC number), IREG (production region number (1-10)), IFIPS (census state and county code), CROP (percent of 12km grid in crops), GRASS (percent of 12km grid in grass), AG (total percent agricultural land), COUNTRY (country abbreviation), CPROV (country-province abbreviation).
2. NONRISOIL6TH.DAT contains a list of 12-km grid crop combination which do not have a matching soil. Management files are not created in this case and the EPICRUN file doesn't include these grid cell/crop combinations. However, currently all 12-km grid cell/crop combinations identified by the BELD 4 data have matching soils.
3. BELD4-TILL1-09-12.prn contains tillage and harvest machinery numbers and other information by crop. It is created from BELD4-EPIC-TILL-prn-files.xls worksheet sheet. It includes the following variables: REG (region number), BELD4NUM (BELD4 code number 22-70), BELD4NM (BELD4 crop name), HARVEQUIPNUM (harvest equipment number in EPIC equipment file TILLEPA.DAT), IRREQUIPNUM (irrigation equipment number in EPIC equipment file TILLEPA.DAT), PREPLTTILLNUM (pre-plant tillage equipment number in EPIC equipment file TILLEPA.DAT), POSTPLTTILL1 (post-plant tillage 1 equipment number in EPIC equipment file TILLEPA.DAT), POSTPLTTILL2 (post plant tillage 2 equipment number in EPIC equipment file TILLEPA.DAT), HARVTILL1 (tillage after harvest equipment number in EPIC equipment file TILLEPA.DAT), PREPLTTILLTIME (days before planting when pre-plant tillage occurs), POSTPLTTILL1TIME (fraction of heat units to maturity when first post-plant tillage occurs), POSTPLTTILL2TIME (fraction of heat units to maturity when second post-plant tillage occurs), HARVTIME (fraction of heat units to maturity when harvest occurs). The kill operation to terminate a crop is number 451.

4. BELD4-EPIC04-10-12.prn contains plant population, and other variables related to planting by crop and are created from BELD4-EPIC04-10-12.xls worksheet. This file contains crop data as follows: IBELD4 (BELD4 crop code and name), IEPICCRP (EPIC crop code and name), ECROP (EPIC crop 4-character name), TOP (optimal crop temperature), TBS (base temperature when crop grows, CNY (nitrogen concentration in crop yield), CPY (phosphorus concentration in crop yield), WCY (water concentration in crop yield), IDC (epic crop characteristics code i.e. 1 for warm season annual legume, 2 for cold season annual legume, 3 for perennial legume, 4 for warm season annual, 5 for cold season annual, 6 for perennial, 7 for evergreen trees, 8 for deciduous trees, 9 for cotton, 10 for deciduous legume trees.), GMHU (heat unit collected after planting before germination occurs), PPL1 (point one on plant population curve in EPIC), PPL2 (point two on plant population curve in EPIC), ESTPLTPOP (estimated average plant population east of 100th meridian), SPFLPLT (spring fall planting code where spring=1 and fall=2), DRYDOWN (planned crop dry-down fraction of heat units to maturity), IPLTDAYS(K),K=1,10 (10 alternative variety number of days to maturity). LUN (SCS land use curve number group), PREPLTFERTDAYS (days before planting that fertilizer is applied), PREPLTFERTFRAC (fraction of fertilizer n applied pre-plant), FERTEQUIP (fertilizer application equipment number), PLTEQUIP (planter equipment number).
5. 2007YIELDSNUTRIENTS-EST.prn contains 2007 agricultural census yields and the estimated nutrients removed with those yields. This file is not currently being used directly by the EPA weather file based management file creator program.
6. CROPLIST (the first variable read in from the CROPLIST.DAT file) is the name of the file that lists of 12-km grid cells for a particular BELD4 crop, for example “CORNG-LIST.DAT” is the corn for grain file name. The file contains the data by 12-km grid cell: IGRID12A (12KM grid number), IBELD4CROP (BELD4 crop code), XLOG12A (longitude of 12km grid), YLAT12A (latitude of 12km grid), ELEV12A (elevation of 12km grid in feet), SLGRID12A (percent slope of 12km grid), IHUC8 (8-digit HUC number), IREG (production region number (1-10)), IFIPS (census state and county code), CROP (percent of 12km grid in crops), GRASS (percent of 12km grid in grass), AG (total percent agricultural land), COUNTRY (country abbreviation), CPROV (country-province abbreviation).
7. WPM1USLIST.DAT is the list of weather site files which have weather statistics, latitude, longitude, and elevation. This file contains NUMBER (EPIC sequence number for weather station), STATWTHF (weather station file name), WLAT (weather station latitude), WLONG (weather station longitude), ASTATE (2-letter state abbreviation), WTHSTANAME (abbreviated weather station name), ELEV (weather station elevation).
8. STATWTHFM contains the weather station file name of closest weather station, for example ALBANKHE.WP1 is the climatological weather statistics file for Bankhead Lock, Alabama. The spinup management program reads the mean monthly average daily maximum and minimum temperatures from the file. The weather station statistics are based on at least 20-yrs of record.
9. OPSNAME.DAT is both an input and an output file because it is a file that is used to create the name for the crop/12-km grid cell management file name. It is first written into and then rewound and read to create the name of the following OPC file for each grid cell crop as the grid cells are processed.

5.2 Spinup Management Program Steps

The spinup management program has the following steps:

1. Read CROPLIST.DAT file to load the variable CROPLIST (Name of the file that lists the sites for a particular crop both irrigated and rainfed, for example the file name for corn grain is CORNG-LIST.DAT).
2. Read in the list of 12-km grid crop combination which do not have a matching soil (NONRISOIL6TH.DAT). Management files are not created in this case and the EPICRUN file doesn't include these grid cell/crop combinations. However, currently all 12-km grid cell/crop combinations identified by the BELD 4 data have matching soils. Note this file must be captured when the soil matching program is run for each crop and placed in the path where this program is run because the file title is not crop specific.
3. Read in tillage and harvest machinery numbers and timing information by crop from BELD4-TILL1-09-12.prn.
4. Read in plant population and other crop variables related to planting by crop from BELD4-EPIC04-10-12.prn.
5. Read in estimated nutrients applied based on nutrients removed with 2007 agricultural census yields. This file (2007YIELDSNUTRIENTS-ESTrev010912.prn) is not currently being used directly by the EPA weather file based management file creator program.
6. Read in the file called CROPLIST which is the file that lists the sites for a particular crop both irrigated and rainfed for which management files will be created, for example the file name for corn grain is CORNG-LIST.DAT). This file is read one line at a time as the management files or created and written out as management data (OPC) files. It is the primary list of crops both rainfed and irrigated to be created for the entire management program.
7. Read in weather station information NUMBER (EPIC sequence number for weather station), STATWTHF (weather station file name), WLAT (weather station latitude), WLONG (weather station longitude), ASTATE (2-letter state abbreviation), WTHSTANAME (abbreviated weather station name), ELEV (weather station elevation) one record at a time from WPM1USLIST.DAT.
8. Calculate the distance from the 12km grid centroid to the weather station using equations that account for the earth's curvature impact on distances between the latitudes and longitudes for the 12km grid and the weather station.
9. Adjust distance by a factor that uses difference in elevation as well latitude and longitude. The adjusted distance is equal to 0.9 times the distance plus 0.1 time the difference in elevation divided by 10. This is not a factor to reflect additional distance due to elevation, but a factor to reflect the importance of elevation on weather. The closest weather station may not be as representative of a particular 12km grid's weather as one slightly further away with a similar elevation. Stations in nearby mountains often have different weather than stations on the plain.
10. Write out the distance difference, the elevation difference, and the adjusted distance factor in DISTANCE.DAT.
11. Proceed to the next weather station record until all weather stations are compared to the 12km grid cell, the station with the least adjusted distance is determined, and that station

is selected to represent that grid cell. The closest weather file name is stored in a variable named STATWTHFM.

12. Rewind the weather station file in preparation for the next grid cell on the grid cell list by crop.
13. Read in the monthly average daily maximum and minimum temperatures from the selected weather station file.
14. Calculate the estimated daily heat units relative to a base 0 degrees Celsius i. e. ((maximum daily temperature + minimum daily temperature)/2) -0).
15. Sum all daily heat units greater than 0 to estimate total annual heat units for that station.
16. Calculate the fraction of annual heat units by day beginning January 1st by accumulating heat units from January 1st to each day and dividing by the total heat units for the year.
17. Estimate plant date for the selected crop and weather station for the 12km grid cell. The BELD4 crop is linked to a particular EPIC crop which is straight forward except for HAY (BELD4 numbers 22 (rainfed) and 23 (irrigated)) and OTHER GRASS (BELD4 numbers 26 (rainfed) and 27 (irrigated)). These crops are linked to EPIC (78) fescue if the grid is greater than 35 degrees latitude or greater than 1500 meters in elevation. It is linked to EPIC (49) Bermuda grass if it is less than 35 degrees latitude and less than 1500 meters in elevation. New BELD4 numbers are assigned when Bermuda grass is selected i.e. HAY (BELD4 numbers 67 (rainfed) and 68 (irrigated) and OTHER GRASS (BELD4 numbers 69 (rainfed) and 70 (irrigated)). The base temperature for the linked EPIC crop selected, the alternative days to maturity, other EPIC crop variables for the selected crop are loaded.
18. Estimate day length and maximum hour of light using equations from EPIC subroutine based on the latitude of the grid cell. These equations are standard equations.
19. Estimate climatological average daily minimum temperatures from monthly mean daily minimum temperature by interpolating temperature between the midpoints of adjacent months.
20. The daily threshold temperature at which the farmer would likely plant in an average year with adjustments for day length and radiation is estimated. The threshold uses the daily minimum temperature that was interpolated from weather station monthly average minimum temperatures with adjustments for day length, and maximum daily radiation (the radiation adjustment not active at this time). The adjustment is only used for grid cells above 40 degrees latitude. The adjustment is a day length index factor that is multiplied by the temperature threshold i.e. (daily hours of light divided by 12).
21. The farmers target temperature for planting is equal to the base temperature for the crop in the EPIC crop data file with an adjustment that enhances plant date fit to USDA average data as reported in plant and harvest percentages by week from survey data. Crop base temperature could vary with variety. If the threshold minimum adjusted temperature is greater than the adjusted crop base temperature the crop is assumed to be planted. There is a soybean day length restriction on planting date below 38 degrees latitude.
22. Set up soybean day length restriction on planting date below 38 degrees latitude and use different variety days to maturity by region for soybean to reflect sensitivity to day length as well as temperature
23. Estimate planting date range, i.e., planting activity window, due to weather and farmer equipment limitations (farmer cannot afford to have equipment capable of planting all crops on optimum day). Range varies from 10 days in the northern U.S. up 30 days as

latitudes decrease by the following formula (PLTRANGE= (60.-YLAT12A)) where YLAT12A is the latitude of the grid cell. The range increases with lower latitudes because sensitivity to late frost damage is less.

24. Idaho is treated more like California because most cropland is in southern Idaho and is irrigated like California i.e. all varieties are considered.
25. Plant date variable day distribution is estimated by a subroutine from EPIC called DAGEN. The new plant date is equal to the date estimated using temperature and day length and adding the days generated by the subroutine.
26. Heat units are calculated and accumulated for each crop and each variety and the longest season variety is selected subject to dry down needs. The heat units for that variety become the heat units to maturity in the EPIC management file.
27. Set up EPIC runfiles to make the simulations for each of the grid sites for the crop being processed. Four runfiles are created: 1)EPICRUNFILERAIN.DAT is the run file used if statistical weather is used and the management is for rainfed crops, 2) EPICRUNFILEIRR.DAT is the run file used if statistical weather is used and the management is for irrigated crops, 3) EPICRUNFILERAINDW.DAT is the run file used if a measured daily weather file is used and the management is for rainfed crops, and 4) EPICRUNFILEIRRDW.DAT is the run file used if a measured daily weather file is used and the management is for irrigated crops.
28. Set up a SOILLIST.DAT file with the soil for each grid cell for the crop being processed.
29. Create the file name for the management file which is the grid cell number multiplied by 1000 plus the BELD4 crop number with the extension OPC.
30. Write the first line of descriptive information into the management file.
31. Write the second line of the management file which contains the LUN (SCS LAND USE CURVE NUMBER GROUP), and IAUI (Irrigation equipment number 500 for sprinkler).
32. Create and write the management schedule for the crop processed. Each crop has a sequence of program code that uses information from the files read earlier in the program to determine the pre-plant tillage, pre-plant and/or fall fertilizer application timing and rate by fertilizer type and depth, plant date and population density, heat units to maturity, post-plant tillage and fertilizer applications by fertilizer type and rate and depth, harvest time and method, and grazing start if appropriate. Detailed descriptions of example files for corn and hay management files are contained in the sections entitled “Detailed Description of Example Management Files Irrigated Corn” and Detailed Description of Example Management Files Rainfed Hay**,** respectively.

5.3 Output Files

The output files from the program are:

1. 12kmSITELISTTEST.DAT is for input verification only.
2. WPM1USTEST.DAT is for input verification only.
3. CLOSESTWPM1.DAT is list of closest weather stations for each of the 45,950 12-km grid cells.
4. DISTANCE.DAT contains the distance from the 12-km grid cell centroid to the closest weather station.
5. WETHTEST.DAT is for input verification only.

6. DLYPHUTEST.DAT is the daily heat units and heat unit index based on zero degrees Celsius. It is not currently printed.
7. HUC8BELD4.DAT is a list of descriptive information by grid and crop.
8. HUC8BELD4EPIC.DAT is a list of descriptive information by grid and crop for each crop or says “NO MATCH” if crop data is not found.
9. PLANTDATEPHU.DAT is a listing of plant date information used to debug the program.
10. PLANTDATE12KM.DAT is a listing of plant date information used to debug the program.
11. PLANTDATE12KMVWB.DAT is a listing of plant date information used to debug the program.
12. NOVARIETY.DAT is a file to catch any 12-km grid where the crop selected could not grow to maturity.
13. EPICRUNFILE.DAT is a list of all EPIC runs by crop both rainfed and irrigated. It is not currently used, but could be in the future if files for irrigation were changed.
14. OPSNAME.DAT is both an input and an output file because it is a file that is used to create the name for the crop/12-km grid cell management file name. It is first written into and then rewound and read to create the name of the following OPC file for each grid cell crop as the grid cells are processed.
15. “Crop and grid cell name”.OPC is the management file that is set up for each crop/12-km grid cell.
16. EPICRUNFILERAIN.DAT is a list of all EPIC runs by crop for rainfed only.
17. EPICRUNFILEIRR.DAT is a list of all EPIC runs by crop for irrigated only.
18. BELD4-TILL.DAT is for input verification only.
19. FERTILIZER.DAT is for input verification only.
20. GRIDS_OPC.DATT is the list of management file names to be used with EPIC.
21. NOMATCHVERIFY.DAT is for input verification only.
22. EPICRUNFILEDW.DAT is a list of all EPIC runs by crop both rainfed and irrigated set up to use soil data generated by spin-up runs.. It is not currently used, but could be in the future if files for irrigation were changed.
23. EPICRUNFILERAINDW.DAT is a list of all EPIC runs by crop for rainfed only set up to use soil data generated by spin-up runs.
24. EPICRUNFILEIRRDW.DAT is a list of all EPIC runs by crop for irrigated only set up to use soil data generated by spin-up runs.

6. Development of Management Files for Each Soil, Site, and Crop Linkage for EPA Year – Specific Simulations (ManGenFERT.exe, ManGenFERT.FOR)

This management program generates management files to be used in the EPIC simulations for a specific application year.

6.1 Input Files

The input files are listed in the order read:

1. CONTROL.DAT contains three variables (IBIO1, IBIO2, and IBIO3) that relate to biomass harvest. If IBIO1 equals 1 the grain harvest for corn, sorghum, spring wheat and winter wheat are changed to reflect only grain harvest with the first harvest operation, followed by a biomass harvest that harvests most of the remaining above ground biomass. IBIO2 is the BELD4 number of the crop preceding the biomass crop. IBIO3 is not defined at this time.
2. CROPLIST.DAT contains two variables: CROPLIST (Name of the file that lists the sites for a particular crop both irrigated and rainfed, for example the file name for corn grain is CORNG-LIST.DAT), and CROPFERTEST (Name of the file that contains total commercial NO3 fertilizer applied estimates from the spin-up runs, for example 5YRCORNG-SU.DAT).
3. FERT2012.DAT is the EPIC fertilizer input data for each type of fertilizer and manure modeled. DATA included in fertilizer table: FTNM (fertilizer name), FN (mineral N fraction of fertilizer), FP (mineral P fraction), FK (mineral K fraction), FNO (organic N fraction), FPO (organic P fraction), FNH3 (ammonia N fraction(FNH3/FN) FOC (organic C fraction), FSLT (salt fraction), FCST (cost of fertilizer in $/KG).
4. FERTEQUIPBYAPP.PRN contains a list of equipment used to apply fertilizer by time period and fertilizer. It has three title rows and then includes the following data for each fertilizer type: EPIC number, FNAME (fertilizer name), EQUIP(J) (equipment by time period array) Time periods are: 1-Total used to estimate manure percent applied, 2-Fall preplant and fall plant, 3-Spring after fall plant, 4-Spring preplant and plant, 5-post plant automatic application. The NO3 amount is increased by 10 percent to allow for some loss through runoff because all fertilizer in the spin-up run was incorporated. Potter et al. (2006) estimate a 10 percent loss in runoff. Potter et al. (2006) is available at: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_025895.pdf

5. 5YR*cropname*-SU.DAT (CROPFRTEST variable read from the CRPLIST,DAT file) contains the estimates of total commercial NO3 applied using the EPIC stress based applications with manure also applied where appropriate, for example 5YRCORNG-SU.DAT for corn grain. The 5YRCORNG-SU.DAT files contain many variables, however, only the first column which contains the grid cell number and the BELD4 crop number (22-70), for example 5718033 is grid cell 5718 and crop 33 (irrigated corn grain) and the FNO3 variable beginning in column 336 of the record are read.
6. NONRISOIL6TH.DAT contains a list of 12-km grid crop combination which do not have a matching soil. Management files are not created in this case and the EPICRUN file doesn't include these grid cell/crop combinations. However, currently all 12-km grid cell/crop combinations identified by the BELD 4 data have matching soils.
7. BELD4-TILL1-09-12.prn contains tillage and harvest machinery numbers and other information by crop and is created from BELD4-EPIC-TILL-prn-files.xls worksheet sheet. It includes the following variables: REG (region number), BELD4NUM (BELD4 code number 22-70), BELD4NM (BELD4 crop name), HARVEQUIPNUM (harvest equipment number in EPIC equipment file TILLEPA.DAT), IRREQUIPNUM (irrigation equipment number in EPIC equipment file TILLEPA.DAT), PREPLTTILLNUM (pre-plant tillage equipment number in EPIC

equipment file TILLEPA.DAT), POSTPLTTILL1 (post-plant tillage 1 equipment number in EPIC equipment file TILLEPA.DAT), POSTPLTTILL2 (post plant tillage 2 equipment number in EPIC equipment file TILLEPA.DAT), HARVTILL1 (tillage after harvest equipment number in EPIC equipment file TILLEPA.DAT), PREPLTTILLTIME (days before planting when pre-plant tillage occurs), POSTPLTTILL1TIME (fraction of heat units to maturity when first post-plant tillage occurs), POSTPLTTILL2TIME (fraction of heat units to maturity when second post-plant tillage occurs), HARVTIME (fraction of heat units to maturity when harvest occurs). The kill operation to terminate a crop is number 451.

8. BELD4-EPIC04-10-12.prn contains plant population and other variables related to planting by crop and is created from BELD4-EPIC04-10-12.xls worksheet. This file contains crop data as follows: IBELD4 (BELD4 crop code and name), IEPICCRP (EPIC crop code and name), ECROP (EPIC crop 4-character name), TOP (optimal crop temperature), TBS (base temperature when crop grows, CNY (nitrogen concentration in crop yield), CPY (phosphorus concentration in crop yield), WCY (water concentration in crop yield), IDC (epic crop characteristics code i.e. 1 for warm season annual legume, 2 for cold season annual legume, 3 for perennial legume, 4 for warm season annual, 5 for cold season annual, 6 for perennial, 7 for evergreen trees, 8 for deciduous trees, 9 for cotton, 10 for deciduous legume trees.), GMHU (heat unit collected after planting before germination occurs), PPL1 (point one on plant population curve in EPIC), PPL2 (point two on plant population curve in EPIC), ESTPLTPOP (estimated average plant population east of 100th meridian), SPFLPLT (spring fall planting code where spring=1 and fall=2), DRYDOWN (planned crop dry-down fraction of heat units to maturity), IPLTDAYS(K), K=1,10 (10 alternative variety number of days to maturity). LUN (SCS land use curve number group), PREPLTFERTDAYS (days before planting that fertilizer is applied), PREPLTFERTFRAC (fraction of fertilizer N applied pre-plant), FERTEQUIP (fertilizer application equipment number), PLTEQUIP (planter equipment number).
9. 2007YIELDSNUTRIENTS-EST.prn contains 2007 agricultural census yields and the estimated nutrients removed with those yields.
10. ADJUSTMENTS.DAT contains adjustment indices used to adjust fertilizer application rates by state for hay and other grass. The file contains 4 indices for each state. The variable arrays are ISFA (the state FIPS code), FERTADJHAYRF (ISFA) (the adjustment indices by state for rainfed hay), FERTADJHAYIR (ISFA) (the adjustment indices by state for irrigated hay), and FERTADJOTHGRASS(ISFA) (the adjustment indices by state for rainfed other grass). The indices are the ratio of the average of 5 years of NASS reported yields divided by the 5-year average EPIC yields from the last 5 years of the spin up runs. In some cases these indices were set to 1.00 if there were few acres of either rainfed or irrigated hay or rainfed other grass in that particular state based on the 12km grid data.
11. CROPLIST (the first variable read in from the CROPLIST.DAT file) is the name of the file that lists of 12-km grid cells for a particular BELD4 crop, for example “CORNG-LIST.DAT” is the corn for grain file name. The file contains the data by 12-km grid cell: IGRID12A (12KM grid number), IBELD4CROP (BELD4 crop code), XLOG12A (longitude of 12km grid), YLAT12A (latitude of 12km grid), ELEV12A (elevation of 12km grid in feet), SLGRID12A (percent slope of 12km

grid), IHUC8 (8-digit HUC number), IREG (production region number (1-10)), IFIPS (census state and county code), CROP (percent of 12km grid in crops), GRASS (percent of 12km grid in grass), AG (total percent agricultural land), COUNTRY (country abbreviation), CPROV (country-province abbreviation).

12. .WPM1USLIST.DAT is the list of weather site files which have weather statistics, latitude, longitude, and elevation. This file contains: NUMBER (EPIC sequence number for weather station), STATWTHF (weather station file name), WLAT (weather station latitude), WLONG (weather station longitude), ASTATE (2-letter state abbreviation), WTHSTANAME (abbreviated weather station name), ELEV (weather station elevation).
13. STATWTHFM (weather station file name of closest weather station), for example ALBANKHE.WP1 is the file for Bankhead Lock, Alabama. The monthly maximum and minimum temperatures are read from the file.
14. OPSNAME.DAT is both an input and an output file because it is a file that is used to create the name for the crop/12-km grid cell management file name. It is first written into and then rewound and read to create the name of the following OPC file for each grid cell crop as the grid cells are processed.
15. Regional fertilizer allocation files (example “REGION01.C32” is the file name for region 1, Northeast, crop 32, corn for grain rainfed) contain the variables REGION (region name), IBELD4CROPX(BELD4 (new BELD4 crop number where they are numbered from 1 to 42 versus 22 to 63),the BELD4 crop name,(not read), FERTSALESIDEPIC (fertilizer sales ID number), FERTSALESNAMEEPIC (fertilizer sales name), K (EPIC fertilizer number), TIMINGN (timing period name), I (timing period subscript) , and FERTFRAC fraction of the estimated total N applied in that form and that period). See example for region 1 rainfed corn grain Table 1.

Table 1. Example Regional Fertilizer Allocation for Rainfed Corn fo r Grain in the Northeast

Region	Crop#	Crop	Fert #	Fertilizer name	EPIC#	Period	P#	Fraction
REGION01	11	CornGrain	1	IDENTIFIED BY GRADE	22	Total	1	0.0500
REGION01	11	CornGrain	59	NITROGEN SOL 30%	46	Total	1	0.5000
REGION01	11	CornGrain	60	NITROGEN SOL 32%	47	Total	1	0.1000
REGION01	11	CornGrain	66	UREA	51	Total	1	0.1000
REGION01	11	CornGrain	66	UREA	51	Fpreplt+p	2	0.1000
REGION01	11	CornGrain	1	IDENTIFIED BY GRADE	22	S-pre&plt	4	0.0500
REGION01	11	CornGrain	59	NITROGEN SOL 30%	46	S-pre&plt	4	0.2000
REGION01	11	CornGrain	59	NITROGEN SOL 30%	46	PostpltAu	5	0.3000
REGION01	11	CornGrain	60	NITROGEN SOL 32%	47	PostpltAu	5	0.1000

6.2 Year Specific Management Program Steps

The year specific management program duplicates some of the calculations of the program that built management files for spinup. Recreating some of the variables calculated in spinup facilitates consistency in method and decreases the likelihood of errors in program logic. This duplication may be removed in the future as we gain confidence in the stability of the code. The modified program steps follow:

1. CONTROL.DAT contains three variables (IBIO1, IBIO2, and IBIO3) that relate to biomass harvest. If IBIO1 equals 1 the grain harvest for corn, sorghum, spring wheat and winter wheat are changed to reflect only grain harvest with the first harvest operation followed by a biomass harvest that harvests most of the remaining above ground biomass. IBIO2 is the BELD4 number of the crop preceding the biomass crop. IBIO3 is not defined at this time.
2. Read CROPLIST.DAT file to load the name of the file that contains the list of grids for which management data sets will be built, CROPLIST (Name of the file that lists the sites for a particular crop both irrigated and rainfed, for example the file name for corn grain is CORNG-LIST.DAT), and to load the name of the file that contains CROPFERTEST (Name of the file that contains total commercial NO3 fertilizer applied estimates from the spin-up runs for a particular crop, for example 5YRCORNG-SU.DAT).
3. Read in fertilizer data from FERT2012.DAT.
4. Read in equipment used to apply fertilizer by time period and fertilizer from FERTEQUIPBYAPP.PRN.
5. Read in the file listed as CROPFERTEST in the CROPLIST.DAT file (see input file item 11). The file is the file from spin-up that contains the estimates of total commercial NO3 applied for the crop for which management files are to be created, for example 5YRCORNG-SU.DAT for corn grain.
6. Adjust NO3 application numbers upward by 10 percent to allow for some loss through runoff because all fertilizer in the spin-up run was incorporated. The CEAP report estimated a 10 percent loss in runoff.

Steps 7 through 10 correspond to steps 2 through 5 in the spinup management description on pages 8-9.

11. Read in adjustment indices used to adjust fertilizer application rates by state for hay and other grass from ADJUSTMENTS.DAT.

Steps 12 through 38 correspond to steps 6 through 32 in the spinup management description, pages 9-11.

39. Hay and other grass fertilizer rates may be adjusted as described in the section" Simulating Fertilizer Use for Grass Hay and Other Grass"
40. The distribution of fertilizer by type and timing relative to planting is estimated in subroutines that open the appropriate regional fertilizer fraction of N applied file, calculate amount of fertilizer for type and time and then write that line into the management file. For example, the file name for irrigated corn in the Southern Plains is REGION08.C33. It contain the fraction of each fertilizer type sold in that region that is likely to be applied to irrigated corn by timing relative to planting. These fractions were estimated using fertilizer sales data, agricultural management survey data by region, reviews of literature and logical deduction. The section entitled "Creating 2006 Fertilizer Allocation by Crop by Stage Workbooks and Spreadsheets" contains a more detailed description of the process.

6.3 Simulating Fertilizer Use for Grass Hay and Other Perennial Grass

Grass hay and other perennial grass simulations pose unique challenges as compared to annual grain crops, but can account for a significant portion of manure and inorganic N use in some regions and cannot be ignored.

1. Grass hay and other grass are not single crops like corn, wheat, etc. Rather, they comprise many different plants or combination of plants across North America. We use fescue grass in the north and at high elevations, and Bermuda grass in the south to represent a variety of different grasses and combinations of grasses and forbs found in the real world.
2. Hay and other grass are grown for animal consumption and may be harvested and fed later at a different location or grazed by livestock. We simulate a combination of hay harvest and grazing without irrigation for hay and other grass, and only hay harvest for irrigated hay. No irrigated other grass was identified.
3. The survey data we use for yield comparisons is not only based on a mixture of types of grass hay; it is also based on many different management combinations particularly irrigation. Irrigated hay is classified in the source survey as irrigated as follows:

    > Irrigation refers to the application of water to land by any artificial or controlled means, such as sprinklers, furrows and ditches, spreader dikes, flooding, or sub-irrigation pipes. Irrigated includes acres that had pre-plant, partial, and supplemental irrigation. Include spreading or channeling of spring run-off or flood waters over pasture if done by manmade structures or ditches. Include the acres where lagoon waste water from livestock operations was distributed by a sprinkler or flood system.

4. EPIC simulations are set up to simulate hay production with little water or nutrient stress in our spin-up runs. The results are similar to those described in University extension publications. Survey data include hay or pasture only irrigated by spreader systems that flood fields near streams often in mountain meadows in the mountain states. Our soil selection uses the National Resource Inventory data to match soils with crop by 12km grid cells and weather data near grid cells, but the management of fertilizer connects to information at the 10 region level for the United States. The spin-up runs use the EPIC model automatic water and fertilizer scheduling system to estimate water and fertilizer use for the estimated EPIC crop yields. These yields are sometimes quite different from survey yields due to different grasses and management that may apply only partial irrigation and little or no fertilizer.
5. No nationally consistent data base has been identified that supports breaking the land use into more detailed types of hay or specific irrigation and fertilizer management.

In the absence of this data, we use the ratio of the 5 year average of NASS survey yield at the state level that combines rainfed and irrigated grass hay and other grass, to the 5yr average 12km grid cell spin-up yield to adjust our estimated fertilizer application by stage of growth and the fertilizer N maximum per crop year. EPIC uses the fertilizer N maximum per year to estimate automatic scheduling of fertilizer N applications for the EPA measured weather simulations. This ratio adjusts the total fertilizer applied and the approximate timing of application for each grid to the level of grass hay and other grass production by regions to more closely follow survey-based reports.

6.4 Detailed Description of Example Management Files - Irrigated Corn

An example irrigated corn management data set is show in Table A. The first line in Table A contains descriptive information for the user and is not used directly by EPIC. The grid cell is number 7087033 where 7087 is the 12km grid number and 33 is the BELD4 number for irrigated corn. The current extension for a management data set is ".OPC". Some files may have the extension ".OPS" (an extension for an earlier version EPIC management file). The number 33 is the BELD4 crop code and the number 2 is the corresponding EPIC crop code. CORN is the four letter name in EPIC for corn. The longitude for the 12km grid centroid is -98.3571 and 26.1511 is the latitude. The elevation is 10.4 meters. The percent slope is 0.6000. The 8-digit HUC code is 13090002. The region number is 8, which is Southern Plains. The county FIPS code is 48215. The percent of the grid in crops is 13.660. The percent of the grid in grass is 35.150. The total percent agricultural land is 48.820. The grid is in the USA and the state is US-TX, Texas.

Table A. Example management file for corn

```
7087033.OPC 33 2 CORN -98.3571 26.1511 10.4 0.6000 13090002 8 48215 13.660 35.150 48.820 USA   US-TX
  5 500   54.23
 1  1  1  266    0    2    5   222.4                                           0.045
 1  1  1  259    0    2   25    99.2                                           0.045
 1  1  1  267    0    2   58    50.2                                           0.045
 1  1  1  152    0    2                                                        0.046
 1  1  1  141    0    2        2251.                          9.00             0.050
 1  1  1  265    0    2   47   141.2                                           0.300
 1  1  1  267    0    2   76    17.0                                           0.300
 1  1  1  158    0    2                                                        0.300
 1  1  1  287    0    2                                                        1.000          0.160
 1  1  1  451    0    2
 1  1  1  259    0    2   25    44.1                                           0.835
```

Line two contains LUN (SCS LAND USE CURVE NUMBER-GROUP 5 which is for contour row crop good condition, Table C1 and C2 last column), IAUI (Irrigation equipment number 500 for sprinkler), and FNP (the amount of elemental N applied if a stress triggered application is made; currently 30% of the spinup average N applied per year which is 54.23 kg per hectare for this grid cell for irrigated corn).

Line 3 is the first line of management schedule by year, month, and day. All spring planted crops are entirely heat unit scheduled so year, month and day are set to year 1, month 1, and day 1. The fourth number in the line is the equipment number 266 which is found in the TILLEPA.DAT file and is a manure spreader. The equipment used by crop for fertilizer was read in step 4 from the "Year Specific Management Program Steps". The fifth number is for a tractor and can be set to 0 which it is in this management file. The sixth number is the EPIC crop number, which is 2 for corn.

Numbers to the right of the sixth number in each line can have different meaning depending on the function of the piece of equipment. It is analogous to a farmers decision to fertilize, plant, till, spread a pesticide, irrigate, harvest, graze, etc on a given day. The choice of function determines what the value of columns 7, 8, etc up to the heat unit scheduling column. See the EPIC0509 user's manual, page 20 found at http://epicapex.tamu.edu/downloads/user-manuals

Since this equipment is identified as a fertilizer spreader in the IHC column of the TILLEPA.DAT file, the seventh number is the type of fertilizer spread (5), in this case it is assumed to be Dairy Manure (Texas has considerable dairy, poultry, and beef cattle manure and Oklahoma has swine manure as well which makes dairy manure for this region somewhat arbitrary. In the future, the type of manure spread could be made to be a function of the estimated tons of manure produced by type of livestock per county, but that is beyond the scope of the current project.). The type of fertilizer by number is found in the FERT2012.Dat file. The eighth number is the amount of dairy manure spread, 222.4 kg per hectare 0.0% moisture content. The number to the far right is the heat unit schedule index 0.045 fraction of the average heat units per year calculated in steps 14-16 from the “Spinup Management Program Steps”.

Line 4 is the second line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 259 which an anhydrous fertilizer spreader. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 2 for corn. Since this equipment is identified as a fertilizer spreader, the seventh number is the type of fertilizer spread (25), in this case the fertilizer type is anhydrous ammonia. The eighth number is the amount of anhydrous ammonia spread, 99.2 kg per hectare. The number to the far right is the heat unit schedule index 0.045 fraction of the average heat units per year.

Line 5 is the third line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 267 which a surface fertilizer spreader. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 2 for corn. Since this equipment is identified as a fertilizer spreader, the seventh number is the type of fertilizer spread (58), in this case it is 28% nitrogen in solution. The eighth number is the amount of 28% nitrogen in solution spread, 50.2 kg per hectare. The number to the far right is the heat unit schedule index 0.045 fraction of the average heat units per year. Note: three types of fertilizer were spread on the same day because this management file represents a regional mix of fertilizers applied at this time of year. An individual farmer would likely only spread one type of fertilizer at a time. The total N applied that day is the total N per year determined in the spinup simulations multiplied by the fraction of the total in that form for that period for irrigated corn. For example, assume that the spinup simulation tells us that 30 kg-N goes on pre-plant, but USDA Survey results suggest that 33.3% of farmers in the region use manure, 33.3% use anhydrous ammonia and 33.3% use N solution. We then say preplant application = [30kg-N as manure)*.333] + [(30 kg-N as anhydrous ammonia)*.333] + [(30 kg-N as N-solution)*.333]. Once the fertilizer is applied, it loses its form-specific identity, i.e., all forms are expressed as kg-N, and its biogeochemical fate is identical with the exception of the form-specific depth of application.

Line 6 is the fourth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 152, which is a field cultivator. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 2 for corn. The number to the far right is the heat unit schedule index 0.046 fraction of the average heat units per year.

Line 7 is the fifth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 141 which row planter. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number which is 2 for corn. Since this equipment is identified as a crop planter in the IHC column of the TILLEPA.DAT file, the seventh number is the heat units to maturity, in this case there are 2,251 estimated heat units to maturity. The heat units to maturity were calculated in steps 14-26 of the "Spinup Management Program Steps". The eighth number is the plant population in plants per square meter (9.00). The crop information was read in step 9. The number to the far right is the heat unit schedule index 0.050 fraction of the average heat units per year calculated. The plant date was determined in steps 20 to 35, which converts heat units to a heat unit index.

Line 8 is the sixth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 265 which a liquid fertilizer spreader. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 2 for corn. Since this equipment is identified as a fertilizer spreader, the seventh number is the type of fertilizer spread (47), in this case it is 32% nitrogen in solution. The eighth number is the amount of 32% nitrogen in solution spread, 141.2 kg per hectare. The number to the far right is the heat unit schedule index 0.30 fraction of the heat units to maturity. For corn, this corresponds roughly to the time the plants have about 6 leaves or is just prior to the rapid growth phase. As described for the previous fertilizer application, these instructions are repeated to address all reported fertilizer forms (line 9).

Line 9 is the seventh line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 267 which a surface fertilizer spreader. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 2 for corn. Since this equipment is identified as a fertilizer spreader, the seventh number is the type of fertilizer spread (76), in this case it is liquid ammonium polyphosphate. The eighth number is the amount of liquid ammonium polyphosphate spread, 17.0 kg per hectare. The number to the far right is the heat unit schedule index 0.30 fraction of the heat units to maturity. Expert opinion and observation were used to determine the schedule index.

Line 10 is the eighth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 158, which is a row cultivator. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 2 for corn. The number to the far right is the heat unit schedule index 0.30 fraction of the heat units to maturity. Again, expert opinion and observation were used to determine the schedule index.

Line 11 is the ninth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 287, which combine harvester. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 2 for corn. The first number to the far right is the heat unit schedule index 1.00 fraction of the total heat units to maturity (see program steps 20-36) The second number is the moisture percent in grain at which it is harvested based on expert opinion and observation. EPIC harvests after the heat units to maturity are met and the grain is dried to the specified moisture content in the field.

Line 12 is the tenth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 451 which is a code which tells EPIC to terminate the crop. Some perennial crops such as hay could begin to grow again in EPIC if not terminated. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number which is 2 for corn. The heat unit index is left blank in this case.

Line 13 is the eleventh line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 259 which an anhydrous fertilizer spreader (post-harvest or “fall” application). The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number which is 2 for corn. The seventh number is the type of fertilizer spread (25), in this case it is anhydrous ammonia. The eighth number is the amount of anhydrous ammonia spread, 44.1 kg per hectare. The number to the far right is the heat unit schedule index 0.835 fraction of the average heat units per year based on 0 degrees C.

6.5 Detailed Description of Example Management Files - Rainfed Hay (grazed perennial crop)

An example rainfed hay management data set is show in Table B. The first line in Table B contains descriptive information for the user and is not used directly by EPIC. The grid cell is number 70950022 where 70950 is the 12km grid number and 22 is the BELD4 number for rainfed hay. The current extension for a management data set is “.OPC. The number 22 is the BELD4 crop code and the number 78 is the corresponding EPIC crop code. FESC is the four letter name in EPIC for fescue hay. The longitude for the 12km grid centroid is -89.7427 and 40.9203 is the latitude. The elevation is 69.5 meters. The percent slope is 0.5100. The 8-digit HUC code is 07130005. The region number is 5, which is CORN BELT. The county FIPS code is 17143. The percent of the grid in crops is 2.730. The percent of the grid in grass is 80.760. The total percent agricultural land is 83.490. The grid is in the USA and the state is US-IL, Illinois.

<u>Table B. Example management file for hay</u>

```
70950022.OPC 22 78 FESC -89.7427 40.9203 69.5 0.5100 7130005 5 17143 2.730 80.760 83.490 USA US-IL
17 500   27.58
  1  1  1  271    0   78  130   264.6                                              0.047
  1  1  1  152    0   78                                                           0.050
  1  1  1  146    0   78        1148.                         35.00  163.65   0.055
  1  1  1  267    0   78   22    55.2                                              0.300
  1  1  1  327    0   78                                                           0.600
  1  1  1  426    0   78                                                           0.000
  1 10  1  267    0   78   22    18.4                                              0.000
  1 12 31  427    0   78                                                           0.000
  1 12 31  331    0   78                                                           0.000
```

Line two contains LUN (SCS LAND USE CURVE NUMBER* GROUP 17 which is for contour close seeded meadow good condition, (see Table C1 and C2 last column), IAUI (Irrigation equipment number 500 for sprinkler), and FNP (the amount of elemental N applied if a stress triggered application is made; currently 30% of the spinup average N applied per year which is 27.58 kg per hectare for this grid cell for rainfed hay).

Line 3 is the first line of management schedule by year, month, and day. All spring planted crops are entirely heat unit scheduled so year, month and day are set to year 1, month 1, and day 1. The fourth number in the line is the equipment number 271 which is found in the TILLEPA.DAT file and is a custom fertilizer injector. The equipment used by crop for fertilizer was read in step 4 section entitled “Year Specific Management Program Steps”. The fifth number is for a tractor set to 0. The sixth number is the EPIC crop number which is 78 for fescue hay. Since this equipment is identified as a fertilizer spreader in the IHC column of the TILLEPA.DAT file, the seventh number is the type of fertilizer spread (130), in this case it is swine manure in slurry form. The type of fertilizer by number is found in the FERT2012.Dat file. The eighth number is the amount of swine slurry spread, 264.6 kg per hectare 0.0% moisture content. The number to the far right is the heat unit schedule index 0.047 fraction of the average heat units per year calculated in steps 20-22 from section entitled “Year Specific Management Program Steps”.

Line 4 is the second line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 152, which is a field cultivator. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 78 for fescue hay. The number to the far right is the heat unit schedule index 0.050 fraction of the average heat units per year.

Line 5 is the third line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 146, which is a broadcast planter. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 78 for fescue hay. Since this equipment is identified as a crop planter in the IHC column of the TILLEPA.DAT file, the seventh number is the heat units to maturity, in this case there are 1,148 estimated heat units to maturity. The heat units to maturity were calculated in steps 14 to 16. The eighth number is the plant population in plants per square meter (35.00). The ninth number is the maximum amount of mineral fertilizer that can be applied per crop year, 163.65 kg per hectare. The number to the far right is the heat unit schedule index 0.055 fraction of the average heat units per year calculated in steps 14 to 16. The plant date was determined in steps 20 to 25 which converts heat units to a heat unit index.

Line 6 is the fourth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 267 which a fertilizer spreader. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 78 for fescue hay. The seventh number is the type of fertilizer spread (22), in this case it is generic nitrogen. The eighth number is the amount of generic nitrogen spread, 55.2 kg per hectare. The number to the far right is the heat unit schedule index 0.30 fraction of the heat units to maturity.

Line 7 is the fifth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 327, which is a swather and baler harvest. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 78 for fescue hay. The first number to the far right is the heat unit schedule index 0.60 fraction of the heat units to maturity.

Line 8 is the sixth line of management schedule year 1, month 1, and day 1. The fourth number in the line is the equipment number 426, which is a code, which tells EPIC to start grazing. The intensity of grazing is determined by the stocking rate. EPIC has a function that estimates the stocking rate based on the ratio of precipitation to potential evaporation for the weather station representing the 12 km grid cell. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 78 for fescue hay. The heat unit index is set to 0.000 in this case which allows grazing to begin as soon as the crop reaches the minimum tons of above ground growth per hectare in this case 1 ton per hectare.

Line 9 is the seventh line of management schedule year 1, month 10, and day 1. The fourth number in the line is the equipment number 267 which a fertilizer spreader. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 78 for fescue hay. The seventh number is the type of fertilizer spread (22), in this case it is generic nitrogen. The eighth number is the amount of generic nitrogen spread, 18.4 kg per hectare. The number to the far right is the heat unit schedule index 0.000 fraction of the heat units to maturity.

Line 10 is the eighth line of management schedule year 1, month 12, and day 31. The fourth number in the line is the equipment number 427, which is a code to stop grazing. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 78 for fescue hay. The number to the far right is the heat unit schedule index 0.000, which allows the operation to take place on that day, December 31st.

Line 11 is the ninth line of management schedule year 1, month 12, and day 31. The fourth number in the line is the equipment number 331, which is a shredder. The fifth number (tractor) is set to 0. The sixth number is the EPIC crop number, which is 78 for fescue hay. The number to the far right is the heat unit schedule index 0.000, which allows the operation to take place on that day, December 31st. The shedder is added to reset the heat units for the next year and is an operation used to shred old growth to facilitate new growth.

Perennial crops are planted once and continue to grow until killed. Each year the heat unit is reset for the heat units to maturity calculations. There are codes in the EPIC crop parameters that define each crop as a perennial or annual and as a legume or non-legume.

6.6 Output Files

The following is the list of the output files from the management program for a simulation year:

1. SCRATCHTAPE.DAT is a file to write input data to for verification, for example the CROPLIST and CROPFERTEST which are the name of the file that lists the sites for a particular crop both irrigated and rainfed, for example the file name for corn grain is CORNG-LIST.DAT), and the name of the file that contains total commercial NO3 fertilizer applied estimates from the spin-up runs, for example 5YRCORNG-SU.DAT), respectively.
2. FERTTEST.DAT is for input verification only for the FERT2012.DAT input file.
3. EQUIPTEST.DAT is for input verification only for the FERTEQUIPBYAPP.PRN file.
4. FERTAPPTEST.DAT is for input verification only for the CROPFERTEST file, for example 5YRCORNG-SU.DAT for corn grain file. It also lists the rates after adjustment for runoff.
5. NOMATCHVERIFY.DAT is for input verification only.
6. BELD4-TILL.DAT is for input verification only for BELD4-TILL1-09-12.prn and BELD4-EPIC04-10-12.prn.
7. 12kmSITELISTTEST.DAT is for input verification only.
8. WPM1USTEST.DAT is for input verification only.
9. CLOSESTWPM1.DAT is list of closest weather stations for each of the 45,950 12-km grid cells.

10. DISTANCE.DAT contains the distance difference, the elevation difference, and the adjusted distance factor from the 12-km grid cell centroid to the closest weather station.
11. WETHTEST.DAT is for input verification only.
12. DLYPHUTEST.DAT is the daily heat units and heat unit index based on zero degrees Celsius. It is not currently printed.
13. HUC8BELD4.DAT is a list of descriptive information by grid and crop.
14. HUC8BELD4EPIC.DAT is a list of descriptive information by grid and crop for each crop or says “NO MATCH” if crop data is not found.
15. PLANTDATEPHU.DAT is a listing of plant date information used to debug the program.
16. PLANTDATE12KM.DAT is a listing of plant date information used to debug the program.
17. PLANTDATE12KMVWB.DAT is a listing of plant date information used to debug the program.
18. NOVARIETY.DAT is a file to catch any 12-km grid where the crop selected could not grow to maturity.
19. EPICRUNFILE.DAT is a list of all EPIC runs by crop both rainfed and irrigated. It is not currently used, but could be in the future if files for irrigation were changed.
20. OPSNAME.DAT is both an input and an output file because it is a file that is used to create the name for the crop/12-km grid cell management file name. It is first written into and then rewound and read to create the name of the following OPC file for each grid cell crop as the grid cells are processed.
21. “Crop and grid cell name”.OPC is the management file that is set up for each crop/12-km grid cell.
22. EPICRUNFILERAIN.DAT is a list of all EPIC runs by crop for rainfed only.
23. EPICRUNFILEIRR.DAT is a list of all EPIC runs by crop for irrigated only.
24. FERTILIZER.DAT is for input verification only.
25. GRIDS_OPC.DATist the list of management file names to be used with EPIC.
26. EPICRUNFILEDW.DAT is a list of all EPIC runs by crop both rainfed and irrigated set up to use soil data generated by spin-up runs.. It is not currently used, but could be in the future if files for irrigation were changed.
27. EPICRUNFILERAINDW.DAT is a list of all EPIC runs by crop for rainfed only set up to use soil data generated by spin-up runs.
28. EPICRUNFILEIRRDW.DAT is a list of all EPIC runs by crop for irrigated only set up to use soil data generated by spin-up runs.

Table C1. Curve number file from APEX documentation for management file.

Field	Variable	Description
LINE 1:		***Description*** *FORMAT: TWENTY (20) ALPHA CHARACTERS*
LINE 2:	*FORMAT:*	*TWENTY (20) FIELDS; FOUR (4) COLUMNS PER FIELD (INTEGER)*

1 LUN ***Land use number from NRCS Land Use-Hydrologic Soil Group Table (cols. 1-4)*** (Range: 1-35)
Refer to the column labeled Land User Number in the table below. This number along with the hydrologic soil group is used to determine the curve number.

Table C 2 : Runoff curve numbers for hydrologic soil-cover complexes

Land use	Cover Treatment or practice	Hydrologic condition	Hydrologic soil group A	B	C	D	**Land Use Number**
Fallow	Straight row	----	77	86	91	94	1
Row crops	Straight row	Poor	72	81	88	91	2
	" "	Good	67	78	85	89	3
	Contoured	Poor	70	79	84	88	4
	" "	Good	65	75	82	86	5
	Contoured & terraced	Poor	66	74	80	82	6
	" "	Good	62	71	78	81	7
Small grain	Straight row	Poor	65	76	84	88	8
	" "	Good	63	75	83	87	9
	Contoured	Poor	63	74	82	85	10
	" "	Good	61	73	81	84	11
	Contoured & terraced	Poor	61	72	79	82	12
	" "	Good	59	70	78	81	13
Close-seeded	Straight row	Poor	66	77	85	89	14
legumes[1] or	" "	Good	58	72	81	85	15
rotation meadow	Contoured	Poor	64	75	83	85	16
	" "	Good	55	69	78	83	17
	Contoured & terraced	Poor	63	73	80	83	18
	" "	Good	51	67	76	80	19
Pasture or range							
<50% groundcover or heavily grazed		Poor	68	79	86	89	20
50-75% ground cover & not heavily grazed		Fair	49	69	79	84	21
>75% ground cover & lightly grazed		Good	39	61	74	80	22
Above characteristics & Contoured		Poor	47	67	81	88	23
	" "	Fair	25	59	75	83	24
	" "	Good	6	35	70	79	25
Meadow (continuous grass, not grazed and generally mowed for hay)		Good	30	58	71	78	26
Woods							
Small trees and brush (heavy grazing & regular burning		Poor	45	66	77	83	27
Woods are grazed by not burned, some litter covers soil		Fair	36	60	73	79	28
Woods are not grazed, litter & brush cover soil		Good	25	55	70	77	29
Farmsteads		----	59	74	82	86	30

Roads (dirt)[2]	----	72	82	87	89	31
(hard surface)[2]	----	74	84	90	92	32
Sugarcane		39	61	74	80	33
Bermuda grass		49	69	79	84	34
Impervious (Pavement, urban area)	----	98	98	98	98	35

1 Close-drilled or broadcast.
2 Including right of way.

Taken from the National Engineering Handbook (U.S. Department of Agriculture, Soil Conservation Service 1972).

7. Creating 2006 Fertilizer Allocation by Crop by Stage Workbooks and Spreadsheets

In the future this process will be further automated. In most cases, the final files will be distributed to the user community on NLCD release intervals at the CMAS website. This description is provided here only to ensure complete documentation of processes and assumptions.

Initial fertilizer type percentage allocations were made for the year 2002 fertilizer use by crop by region based on fertilizer sales by state, estimated N and P removal by crops based on 2002 Agricultural Census production by state, survey data such as the cropping practices survey and expert opinions. There were many improvements made from the 2002 spreadsheets to create the 2006 spreadsheets; however the 2002 sheets for Percent P and Percent N percentage allocation were used as a starting point to create the new balances between fertilizer sales and estimated crop removal. Five workbooks were created for this process (example “Region” is the region specific workbooks that have the region name as part of the name):

A. FertilizerSales2006-5-21-13
B. Statecrops2007agcensus5-21-2013
C. NortheastStatesBELD4FertTimingN&P-5-23-13
D. “Region”PrintSheet5-23-13
E. HAY2007/hay2007-Nutrients (This worksheet is in the HAY path)

First fertilizer sales were updated from 2002 to 2006. Then the estimated N and P removal from the agricultural census data was updated from 2002 to 2007 census data. Finally, the percentages by crop by specific fertilizer by growth stage for the region are adjusted until the sales and removal of nutrients balance. The balance considers alternative nutrient sources such as manure, rainfall, irrigation, etc therefore the totals are not 100 percent of removal. All spreadsheets described below are available on request from Dr. Benson at “bensonv@missouri.edu”.

7.1 Fertilizer Sales Spreadsheet Creation

The type of fertilizer applied is based on fertilizer sales by state by six month period (January to June and July to December). The state sales data are summarized for each of 62 major fertilizer types by six month period by region using 10 production regions (Northeast, Appalachia, Southeast, Lake States, Cornbelt, Delta States, Northern Plains, Southern Plains, Mountain, and Pacific.

The fertilizer sales data was purchased from Joe Slater, Fertilizer/Ag Lime Control Services, University of Missouri, Columbia, MO 65211-8080. Joe Slater maintains a national data base that includes fertilizer sales by six month period from all states. Data for 2002 and 2006 was acquired by EPA for use in this project.

The state fertilizer sales data was processed using a FORTRAN program (FERTSALES.FOR) written by Dr. Benson to create regional summaries for all fertilizers reported in the database. A subset of 62 major fertilizers were further processed to estimate the elemental N and P applied per kg of fertilizer applied, to create records to add to the EPIC fertilizer file, to summarize the kgs of NH3 and NO3 fertilizer sold, and the phosphorus sold by six month period. These regional totals by the 62 major fertilizer types are copied into spreadsheets for each region. The spreadsheets have a column for each type of fertilizer and a row for each crop by application period (fall application, spring before plant, at planting, and post plant) as well as a total application amount.

The following steps were used to create the spreadsheet.

1. Load data from file "COUNTY.PRN" that identifies the FIPS codes for every county in the United States and has characteristics for each county such as latitude, longitude, state name, county name, water resource area codes, regional codes, region names, and other descriptive data. The following **Fertilizer Sales Program** variables are read from this file. ISTATEX (state FIPS code number), ICTYX (county FIPS code number), PRODREGX (production region number), ASTATE (state name), ACOUNTY (county name), and AREG (region name). These variables are stored in arrays for program use where: ISTATE(ISTATEX) (state number array by state number), ICTY(ISTATEX,ICTYX)is the county number array by state and county numbers), PRODREG(ISTATEX) is the production region number array by state number), STATE(ISTATEX) is the state name array by state number), CTYNAME(ISTATEX,ICTYX) is the county name array by state and county numbers, and REGNAME(PRODREGX) is the region name array by production region number).
2. Load data from file "2006FERTILIZERSALES.DAT" which was created by copying all region fertilizer files from Joe Slater into this file using DOS. The file contains the variables described in Table 3 from the fertilizer sales documentation. See Table 3.

Table 3. ASCII File Layout - CF Data Files.

Field	Type	Length	Implied Decimals	Description/Example
Fertilizer Year	numeric	2		example:85=July-June 1985

Field	**Type**	**Length**	**Implied Decimals**	**Description/Example**
Extra County Da	character	1		"X"= incomplete county data
State Abbreviat	character	2		example: "AL"=Alabama
County FIPS Cod	numeric	3		for county names see ASCIIC
Reporting Perio	numeric	2		6=Jul-Dec 12=Jan-Jun
Quantity (tons)	numeric	9	2	Amount shipped in tons
Fertilizer Code	numeric	3		for descriptions see ASCIIF
Container	numeric	1		1=bag 2=bulk 3=liquid
Use	numeric	1		1=farm 2=nonfarm
Grade: N	numeric	3	1	% nitrogen(N)
Grade: P_2O_5	numeric	3	1	% phosphate(P_2O_5)
Grade: K_2O	numeric	3	1	% potash (K_2O)

3. The fertilizer codes are listed in Table 6 from the fertilizer sales documentation. See Table 4 below.
4. The fertilizer code “0” is changed to “1” so it can be used as an array subscript.
5. As the data is loaded, it is added to the appropriate Production Region based on the state FIPS code by 6-month period, where 12 indicates January through June period 1, and 6 indicates period 2 (July through December). EPIC starts with January 1, thus fall planted crops do not produce a crop yield until year 2. This is consistent with the crop year fertilizer data that starts in July of 2005 and runs through June of 2006.

Table 4. Fertilizer Code Listing (For reference only. Use data for actual guarantees.)

CODE	NAME	N	P2O5	K2O	RANGE	CONTAINER
0	IDENTIFIED BY GRADE	0.0	0.0	0.0		DRY,LIQ
2	ANHY AMMONIA	82.0	0.0	0.0	80-83% N	LIQ
6	AQUA AMMONIA	20.5	0.0	0.0	10-30% N	LIQ
10	AMMONIUM NITRATE	34.0	0.0	0.0	33-34% N	DRY
12	AMM NIT SOLUTION	20.0	0.0	0.0	18-20% N	LIQ
13	AMM NIT LIME MIX	20.5	0.0	0.0	17-26% N	DRY
16	AMMONIUM NIT-SUL	30.0	0.0	0.0	26-30% N	DRY
20	AMMONIUM POLYSULF	20.0	0.0	0.0	18-23% N	LIQ
24	AMMONIUM SULFATE	21.0	0.0	0.0	20-21% N	DRY
25	AMM SUL SOLUTION	6.0	0.0	0.0		LIQ
27	AMMONIUM SUL-NIT	26.0	0.0	0.0		DRY,LIQ
29	AMMONIUM SUL-UREA	33.5	0.0	0.0	33-34% N	DRY
31	AMMONIUM THIOSUL	12.0	0.0	0.0		LIQ
35	CALCIUM AMM NIT	17.0	0.0	0.0	17-20.5% N	DRY,LIQ
38	CALCIUM CYANAM	20.5	0.0	0.0		DRY,LIQ
43	CALCIUM NITRATE	15.5	0.0	0.0	15-15.5% N	DRY,LIQ
46	CALCIUM NIT-UREA	33.8	0.0	0.0	30-35% N	DRY
50	FERROUS AMM-SUL	7.0	0.0	0.0	14% FE, 16% S	DRY
52	MAGNE- SIUM NIT	7.1	0.0	0.0	6.6% MG	LIQ
54	NITRIC ACID	15.0	0.0	0.0		LIQ
56	NITROGEN SOL <28%	0.0	0.0	0.0	<28% N	LIQ
58	NITROGEN SOL 28%	28.0	0.0	0.0	28-29.9% N	LIQ
59	NITROGEN SOL 30%	30.0	0.0	0.0	30-31.9% N	LIQ
60	NITROGEN SOL 32%	32.0	0.0	0.0	32-32.9% N	LIQ
61	NITROGEN SOL >32%	0.0	0.0	0.0	>32% N	LIQ
62	SODIUM NITRATE	16.0	0.0	0.0		DRY
64	SUL CTD UREA	36.0	0.0	0.0	36-38%N	DRY
66	UREA	46.0	0.0	0.0	45-46% N	DRY
67	UREA SOLUTION	20.0	0.0	0.0		LIQ
68	UREA- FORM	38.0	0.0	0.0	35-40% N	DRY
73	ZINC AMM SUL SOL	10.0	0.0	0.0	10-15% N, 10% Z, 5% S	LIQ
77	ZINC MAN AMM SUL	9.0	0.0	0.0		LIQ,DRY
97	NITROGEN NO CODE	0.0	0.0	0.0	2-44% N	DRY,LIQ
98	NITROGEN NO ID	0.0	0.0	0.0	2-44% N	DRY,LIQ
201	AMMONIUM METAPHOS	12.0	51.0	0.0		DRY
202	AMMONIUM PHOS	11.0	48.0	0.0		DRY
203	DAP	18.0	46.0	0.0	18-21% N, 46-54% P2O5	DRY
204	AMMONIUM POLY	15.0	60.0	0.0		DRY,LIQ
205	LIME PHOS	0.0	0.0	0.0	5-37% P2O5	DRY
206	AMM PHOS NITRATE	27.0	14.0	0.0		DRY
207	AMM PHOS SULFATE	16.0	20.0	0.0		DRY,LIQ
208	BASIC SLAG	0.0	9.0	0.0	8-10% P2O5	DRY
209	MONOAMM PHOS	11.0	52.0	0.0		DRY
212	BONE BLK SPENT	1.0	33.0	0.0		DRY
214	RAW BONE MEAL	3.9	22.0	0.0		DRY
216	STM BONE MEAL	2.2	27.0	0.0		DRY
218	BONE PRECIP	0.0	35.0	0.0	28-45% P2O5	DRY
223	CALCIUM METAPHOS	0.0	60.0	0.0	60-62% P2O5	DRY
228	COLLOID PHOS	0.0	2.0	0.0	2-8% P2O5	DRY
233	PHOS LIMESTNE	0.0	13.0	0.0	13-14% P2O5	DRY
238	MAG PHOS	0.0	18.0	0.0	17-18% P2O5	DRY

Table 4. Fertilizer Code Listing(Continued)

CODE	NAME	N	P2O5	K2O	RANGE	CONTAINER
241	NITRIC PHOS	0.0	0.0	0.0	14-22% N, 10-22% P2O5	DRY
243	PHOS ROCK	0.0	3.0	0.0	2-4% P2O5	DRY
248	PHOS ACID	0.0	54.0	0.0	2-75% P2O5	LIQ
249	LIQ AMM POLY	10.0	34.0	0.0	5-12% N, 17-37% P2O5	LIQ
253	PRECIP PHOS	0.0	35.0	0.0	24-45% P2O5	DRY
263	NORMAL SUPER	0.0	22.0	0.0	18-22% P2O5	DRY
265	ENRICHED SUPER	0.0	23.0	0.0	23-39% P2O5	DRY
267	TRIPLE SUPER	0.0	46.0	0.0	40-54% P2O5	DRY
273	SUPER PHOS ACD	0.0	68.0	0.0	68-75% P2O5	LIQ
297	PHOS NO CODE	0.0	0.0	0.0	1-75% P2O5	DRY,LIQ
298	PHOS NO ID	0.0	0.0	0.0	1-75% P2O5	DRY,LIQ
408	LIME-POT MIXTURES	0.0	0.0	10.0	5-10% K2O	DRY
413	MANURE SALTS	0.0	0.0	20.0	20-30% K2O	DRY
415	POTASH SUSP	0.0	0.0	0.0		LIQ
423	POT CARBON	0.0	0.0	64.0	52-69% K2O	DRY,LIQ
428	MUR OF POT 60%	0.0	0.0	60.0	59-61% K2O	DRY
430	MUR OF POT 62%	0.0	0.0	62.0		DRY
443	POT-MAG SULFATE	0.0	0.0	22.0	21-28% K2O	DRY
448	POT METAPHOS	0.0	55.0	37.0		DRY
453	POT NITRATE	14.0	0.0	44.0	12-14% N, 44-46% K2O	DRY
458	POT-SOD NITRATE	15.0	0.0	14.0		DRY,LIQ
463	POT SULFATE	0.0	0.0	50.0	48-52% K2O	DRY
478	TOBACCO STEMS	2.0	0.0	6.0		DRY
497	POTASH NO CODE	0.0	0.0	0.0	0-47% K2O	DRY,LIQ
498	POTASH NO ID	0.0	0.0	0.0	0-47% K2O	DRY,LIQ
601	DRIED BLOOD	12.0	0.0	0.0		DRY
604	CASTOR POMACE	5.0	1.0	1.0		DRY
607	COCOA SH MEAL	2.5	1.0	2.0		DRY
610	COCOA TANKAGE	4.0	1.5	2.0		DRY
613	COMPOST	2.0	2.0	1.0		DRY
615	COT SEED MEAL	6.4	2.0	1.0		DRY
617	FISH SCRAP	6.0	6.0	6.0		DRY
629	GUANO	12.0	11.0	2.0		DRY
649	MANURE	0.5	0.5	0.5		DRY
652	PEAT	1.9	0.2	0.2		DRY
661	ACT SEW SLUDGE	6.0	2.0	2.0		DRY,LIQ
663	DIG SEW SLUDGE	10.0	2.0	0.0		DRY
665	HT DRIED SEW SLGE	6.0	2.0	2.0	3-7% N, 1-7% P2O5, 1-2% K2O	DRY
667	OTH SEW SLUDGE	6.0	2.0	1.0		DRY,LIQ
671	SOYBEAN MEAL	6.0	1.0	2.0		DRY
673	ANIMAL TANKAGE	8.1	5.3	5.9		DRY
675	PROCESS TANKAGE	7.8	0.0	0.0		DRY
681	LINSEED MEAL	5.6	2.0	1.0		DRY
685	TUNG PUMACE	8.0	2.0	2.0		DRY
697	NAT ORG NO CODE	0.0	0.0	0.0		DRY
698	NAT ORG NO ID	0.0	0.0	0.0		DRY
702	ALUMINUM SULFATE	0.0	0.0	0.0		DRY
706	BORAX	0.0	0.0	0.0		DRY
710	BRUCITE	0.0	0.0	0.0		DRY
714	COBALT SULFATE	0.0	0.0	0.0		DRY
716	BLK COP OXIDE	0.0	0.0	0.0		DRY
717	RED COP OXIDE	0.0	0.0	0.0		DRY

Table 4. Fertilizer Code Listing(Continued)

CODE	NAME	N	P2O5	K2O	RANGE	CONTAINER
720	COPPER SULFATE	0.0	0.0	0.0		DRY,LIQ
722	COPPER CHELATE	0.0	0.0	0.0		LIQ,DRY
723	COPPER COMPOUND	0.0	0.0	0.0		LIQ,DRY
724	FERRIC OXIDE	0.0	0.0	0.0		DRY
726	FERRIC SULFATE	0.0	0.0	0.0		DRY
728	FERROUS SULFATE	0.0	0.0	0.0		DRY
730	IRON CHELATE	0.0	0.0	0.0		DRY,LIQ
731	IRON COMPOUND	0.0	0.0	0.0		DRY,LIQ
732	GYPSUM	0.0	0.0	0.0		DRY
733	CALCIUM CHELATE	0.0	0.0	0.0		DRY,LIQ
734	CALCIUM SUL (HY)	0.0	0.0	0.0		LIQ,DRY
736	LIME SUL SOLUTION	0.0	0.0	0.0		LIQ
742	MAGNESIA	0.0	0.0	0.0		DRY
744	EPSOM SALT	0.0	0.0	0.0		DRY
745	MAG CHELATE	0.0	0.0	0.0		DRY,LIQ
748	MANGAN AGSTONE	0.0	0.0	0.0		DRY
749	MANGAN CHELATE	0.0	0.0	0.0		DRY,LIQ
750	MANGAN OXIDE	0.0	0.0	0.0		DRY
752	MANGAN SLAG	0.0	0.0	0.0		DRY
754	MANGAN SULFATE	0.0	0.0	0.0		DRY
758	MANGAN OXIDE	0.0	0.0	0.0		DRY
762	MOLY	0.0	0.0	0.0		DRY
764	SOIL AMENDMNT	0.0	0.0	0.0		DRY,LIQ
765	SOIL ADDITIVE	0.0	0.0	0.0		DRY,LIQ
766	SOIL COND	0.0	0.0	0.0		DRY,LIQ
767	POTTING SOIL	0.0	0.0	0.0		DRY
770	SULFUR	0.0	0.0	0.0		DRY,LIQ
773	CALCIUM CHLORIDE	0.0	0.0	0.0		DRY,LIQ
774	SULFURIC ACID	0.0	0.0	0.0		LIQ
778	ZINC OXIDE	0.0	0.0	0.0		DRY
780	ZINC OXY SULFATE	0.0	0.0	0.0		DRY
782	ZINC SULFATE	0.0	0.0	0.0		DRY
783	ZINC SUL SOLUTION	0.0	0.0	0.0		LIQ
784	ZINC CHELATE	0.0	0.0	0.0		DRY,LIQ
797	SEC/MIC NO CODE	0.0	0.0	0.0		DRY,LIQ
798	SEC/MIC NO ID	0.0	0.0	0.0		DRY,LIQ
901	CALCIUM OXIDE	0.0	0.0	0.0		DRY
902	CALCIUM HYDROX	0.0	0.0	0.0		DRY
903	DOLOMITE	0.0	0.0	0.0		DRY
904	DOLOMITE 75% NEUT	0.0	0.0	0.0		DRY,LIQ
905	STD CALCITE	0.0	0.0	0.0		DRY
906	CALCITIC 75% NEUT	0.0	0.0	0.0		DRY,LIQ
907	LIME NO CODE	0.0	0.0	0.0		DRY
908	LIME NO GRADE	0.0	0.0	0.0		DRY,LIQ
910	DOL/CAL BLEND	0.0	0.0	0.0		DRY
912	LIME SUSP	0.0	0.0	0.0		LIQ
915	NON-LIME FILLER	0.0	0.0	0.0		DRY,LIQ
978	FERT NO ID	0.0	0.0	0.0		DRY,LIQ
988	SGLE-NUT NO ID	0.0	0.0	0.0		DRY,LIQ
990	SPCIALTY NO GRADE	0.0	0.0	0.0		DRY,LIQ
998	MULT-NUT NO GRADE	0.0	0.0	0.0		DRY,LIQ

6. The data is summarized by tons per region by fertilizer code and as well as tons of N, P, and K calculated by multiplying percent N, P, and K times the tons shipped from the fertilizer data in the “REGSUM.DAT” and the “REGSUMNPK.DAT” files, respectively. Tons of fertilizer is multiplied by percentages of N, P, and K in each fertilizer type.

The **FertilizerSales2006-5-21-13** workbook has 3 spreadsheets;

1. The **2006Fert SalesbyFertcode** spreadsheet was created from the REGSUM.DAT file created by the FERTSALES2006.exe Fortran program that summarizes the state level fertilizer sales data from the NASS agricultural statistics web site.
2. The **GradeFertSalesNPK** spreadsheet was created from the REGSUMNPK.DAT file created by the FERTSALES2006.exe Fortran program that summarizes the state level fertilizer sales data.
3. The **EPICfertSales** spreadsheet was created from the previous two sheets using nutrient contents by fertilizer to create summary tables of Tons of N and Tons of P2O5 by region for spring and fall application.

7.2 Agricultural Census Spreadsheet Creation

Agricultural Census data for 2002 and 2007 for most of the crops used in this project are summarized by acre and total yield by region. A set of spreadsheets were created in the worksheet (STATECROPS2007AGCENSUS3-23-2013). The following steps were used to create the spreadsheet.

1. Down load state summary data that includes acres of total cropland, total harvested cropland, total irrigated cropland, and acres and production (yield) for all BELD4 related crops.
2. Create formulas to put data in a tabular form spreadsheet for acres and yields. See worksheet entitled “statecrops2007agcensus.xls” and then spreadsheets entitled “statecrops2007agcensus”, “Yields2007”, and “2007acres” to see example data and formulas. Note: 2002 spreadsheets were built without formulas at an earlier date.
3. Create **Nitrogen** spreadsheets that multiply yields times crop parameter factors reflecting weights per unit yield, fraction of moisture in yield, and fraction of Nitrogen in zero percent moisture yield to estimate Nitrogen removed with yield. Summarize by region and calculate percentages by region by crop to compare with sales data.
4. Create **Phosphorus** spreadsheets that multiply yields times crop parameter factors reflecting weights per unit yield, fraction of moisture in yield, and fraction of Phosphorus in zero percent moisture yield to estimate Phosphorus removed with yield. Summarize by region and calculate percentages by region by crop to compare with sales data.

The **Statecrops2007agcensus5-21-2013** workbook has 10 spreadsheets:

1. The **statecrops2007agcensus** spreadsheet was created from 2007 Agricultural Census data downloaded from USDA, NASS files.
2. The **EPICcropParms** spreadsheet was created from a spreadsheet that contained EPIC crop parameters and descriptive information created by Dr. Benson earlier in his career as part of the EPIC supporting information.
3. The **2002acres** spreadsheet was created from the 2002 Agricultural Census data.
4. The **2007acres** spreadsheet was created from the 2007 Agricultural Census data.

5. The **Yields2002** spreadsheet was created from the 2007 Agricultural Census data.
6. The Yields2002disclosure-0 spreadsheet was created from the 2002 Agricultural Census data with (D) for disclosure set to 0.
7. The **Yields2007disclosure-0** spreadsheet was created from the 2007 Agricultural Census data with (D) for disclosure set to 0.
8. The **P-remov-fertEst** spreadsheet was created by converting units of yield of a standard moisture content to tons of Phosphorus (P) in the yield using unit of yield weights, nutrient P content, and moisture content from the EPICcropParms spreadsheet.
9. The **N-remov-fertEst** spreadsheet was created by converting units of yield of a standard moisture content to tons of Nitrogen (N) in the yield using unit of yield weights, nutrient N content, and moisture content from the EPICcropParms spreadsheet.
10. The **LBSofNperACRE** was created by dividing the total N removal estimate by the total acres by state. This application rate was created for comparison to other survey data and EPIC spin up results.

The **hay2007-Nutrients** workbook has 4 spreadsheets:

1. The **hay 2002** spreadsheet was created directly from agricultural census survey results.
2. The **Regional summaries** spreadsheet summarizes the agricultural census forage data by crop.
3. The **P-Removed** spreadsheet was created by converting units of yield of a standard moisture content to tons of Phosphorus (P) in the yield using unit of yield weights, nutrient P content, and moisture content from the EPIC crop parameter file.
4. The **N-Removed** spreadsheet was created by converting units of yield of a standard moisture content to tons of Nitrogen (N) in the yield using unit of yield weights, nutrient N content, and moisture content from the EPIC crop parameter file.

7.3 Estimating Fractions of Fertilizer Nitrogen Applied by Crop, Fertilizer Type, Timing by Crop Growth Stage, and Amounts

The amount of N fertilizer applied is based on the amount of N fertilizer applied in the spin-up runs. The spin-up runs use EPIC crop stress to estimate N needs by crop and soil for each 12KM grid cell over a period of 25 years. The average application for the last 5 years becomes the fertilizer N estimated amount applied. The fertilizer allocation workbook by region contains spreadsheets that are linked to estimate the percent of nitrogen applied by each fertilizer type by crop by application period. The “Region” example is explained below.

The **“Region”StatesBELD4FertTimingN&P-5-23-13** workbook has 15 spreadsheets:

1. **Cropfile-** this sheet contains the crop parameters used by EPIC to calculate nutrient removal by the crop.
2. **EPICFertFile-** this sheet contains the EPIC fertilizer file with the fractions of N in NO3 form, NH3 form, and organic form; with the fractions of P in mineral form and organic form.
3. **FertilizerSales-** this sheet contains the fertilizer sales in tons for the region considered. The data is extracted from the FertilizerSales2006-5-21-13 workbook from the EPICfertSales sheet from the spring and fall sales tables by region (column) by fertilizer type for N and P2O5.

4. **N-removal**- this sheet is linked to (STATECROPS2007AGCENSUS5-21-2013.XLS workbookYields2007disclosure-0 sheet) so the total crop production yields by crop and region can be multiplied by the crop nutrient contents from the Cropfile to create estimates of total tons of N removed by the crop in yield with a 10 percent increase to allow for some N lost to runoff and leaching.
5. **P- removal**- this sheet is linked to (STATECROPS2007AGCENSUS5-21-2013.XLS workbookYields2007disclosure-0 sheet) so the total crop production yields by crop and region can be multiplied by the crop nutrient contents from the Cropfile to create estimates of total tons of P removed by the crop in yield.
6. **Percent P**- this sheet is the primarily allocation and balance sheet for fertilizer P. Fertilizer P is first balanced and then fertilizer N is balanced.
7. **Tons-P**- this sheet calculates and sums the tons of P used based on the percent of P applied by crop and time period multiplied times the estimated P removal for that crop in that region to convert the percent into tons. These application estimates are summed by fertilizer and period and then subtracted from fertilizer P sales to determine how much of the fertilizer sales haven't been allocated to a crop for that 6-month period.
8. **Percent N with P**- is the sheet which calculates how much N is applied with fertilizers primarily used as a source of P, but are compounds that also contain N.
9. **TonsNwithP**- Fertilizer sales for fertilizers containing both N and P must be allocated to both N and P needs. This sheet uses the fertilizer formulas to estimate the amount of N applied when the blends are applied to meet P needs.
10. **Percent N-** this sheet is the primarily allocation and balance sheet for fertilizer N.
11. **Tons-N**- this sheet calculates and sums the tons of N used based on the percent of N applied by crop and time period multiplied times the estimated N removal for that crop in that region to convert the percent into tons. These application estimates are summed by fertilizer and period and then subtracted from fertilizer N sales to determine how much of the fertilizer sales haven't been allocated to a crop for that 6-month period.
12. **Percent N+N with P**- is the sheet which added N applied with a P based fertilizer to calculate total percentage of crop removal needs that are replaced.
13. **TonsN+NwithP**-Sums the tons of N applied to meet N needs and the tons of N applied with blends containing N and P applied to meet P needs.
14. **Hay2007-N**- contains the N removal estimated form NASS survey data for alfalfa, other tame hay and wild hay used to estimate N need for BELAD4 crops alfalfa, hay and other grass, respectively.
15. **Hay2007-P**- contains the P removal estimated form NASS survey data for alfalfa, other tame hay and wild hay used to estimate P need for BELAD4 crops alfalfa, hay and other grass, respectively.

The regional total sales and total crop removal were added to the regional percent allocation spreadsheets created for the 2002 fertilizer management program inputs. These sheets must then be reexamined to be sure the totals still balance by crop and region. One must begin filling in new percentages by timing by crop in the "Percent –P" sheet. The total percentages by crop and timing on the far right should approach 100 percent less any expected P from manure. Manure application is added later in the Management file generator program. Adjustments may be made for irrigation for irrigated crop to reflect fertilization potential.

7.4 Updating Regional Workbook Spreadsheets from 2002 to 2006 Data

There were numerous updates made to the 2002 spreadsheets to create the 2006 spreadsheets. The first step is to copy the existing path for a region that has been updated, paste it as a copy of the path, and then rename the path to the name of the region to be updated. The second step is to rename the regional work sheet in the new path to the region to be updated.

The regional workbook spreadsheet changes are described in detail by the following spreadsheets:

A. **EPICfertFile and Cropfile spreadsheets** are unchanged from 2002 regional Worksheet.

B. **FertilizerSales** spreadsheet is updated by copying the **FertilizerSales2006-5-21-13 workbook EPICfertSales** spreadsheet column for that region (for example Northeast Y rows 3 to 152) to N Spring Sales column D in the **FertilizerSale**s spreadsheet using paste special (values). Then copy rows 158 to 307 from the same column of the **FertilizerSales2006-5-21-13 workbook EPICfertSales** spreadsheet to N Fall Sales column E in the **FertilizerSale**s spreadsheet using paste special (values). The P table is updated by copying the **FertilizerSales2006-5-21-13 workbook EPICfertSales** spreadsheet column for that region (for example Northeast AO rows 3 to 152) to P Spring Sales column K in the **FertilizerSale**s spreadsheet using paste special (values) and then rows 158 to 307 from the same column of the **FertilizerSales2006-5-21-13 workbook EPICfertSales** spreadsheet to P Fall Sales column L in the **FertilizerSale**s spreadsheet using paste special (values). Change table titles in **FertilizerSales** spreadsheet to the current region's name.
C. **N –removal and P-removal spreadsheets** are linked directly to the **Statecrops2007agcensus5-21-2013** workbook. The formulas would need to be changed if the **Statecrops workbook** were changed to new agricultural census data
D. The **Percent-P and Percent N Spreadsheets in the Regional Workbooks** are the key spreadsheets in the fertilizer allocation process.
    1. **Percent-P and Percent N Spreadsheets** must be updated by copying rows 3 to 62 of columns D and E for N and K and L for P from the current Regional Workbook **FertilizerSales** spreadsheet using the copy and paste special commands to paste special (values and transpose) to rows 4 an 5 columns G to BN of the **Percent N and Percent-P sheets**, respectively.
    2. **Percent-P sheet** column CI rows 3 to 24 must be replaced by the values in the appropriate regional row in the table in cells columns A to Z rows 80 to 96 of the **P-removal** spreadsheet of the regional workbook. The values in columns **C to X** of that row must be copied to **Percent-P sheet** column CI rows 3 to 24 using paste special (values and transpose).
    3. **Percent-N sheet** column CI rows 3 to 24 must be replaced by the values in the appropriate regional row in the table in cells columns A to Z rows 80 to 96 of the **N-removal** spreadsheet of the regional workbook. The values in columns **C to X** of that row must be copied to **Percent-N sheet** column CI rows 3 to 24 using paste special (values and transpose). Estimated N was increased by 10 percent because farmers were expected to compensate for N lost through runoff and percolation; however, the

actual amount of N applied is based on the EPIC spin up runs plus stress triggered N application after planting. The estimates here are only used to allocate the different types of fertilizer on a regional basis.

4. **Percent-P** column CI rows 27 to 30 must be linked to the regional row in the table in cells columns CL to CR rows 1 to 16 which contains estimates of P needs based on crop removal calculated using on Census survey data from the **HAY2007-P** spreadsheet in the regional workbook. Column CP is alfalfa, CQ is other tame hay (BELD4 hay), and CR is wild hay (BELD4 other grass).
5. **Percent-N** column CI rows 27 to 30 must be linked to the regional row in the table in cells columns CL to CR rows 1 to 16 which contains estimates of N needs based on crop removal calculated using on Census survey data from the **HAY2007-P** spreadsheet in the regional workbook. Column CP is alfalfa, CQ is other tame hay (BELD4 hay), and CR is wild hay (BELD4 other grass). Estimated N was increased by 10 percent because farmers were expected to compensate for N lost through runoff and percolation; however, the actual amount of N applied is based on the EPIC spin up runs plus stress triggered N application after planting. The estimates here are only used to allocate the different types of fertilizer on a regional basis.
6. **Percent-P spreadsheet** columns G9 to BT9 and rows 9 to 197 must then be replaced by columns G9 to BT9 and rows 9 to 197 of the 2002 **Percent-P spreadsheet from the 2002 regional workbook** using copy and paste special (all) command. You must enable editing in recent Excel versions to make this copy and paste.
7. **Percent-N** columns G9 to BT9 and rows 9 to 197 must then be replaced by columns G9 to BT9 and rows 9 to 197 of the 2002 **Percent-N spreadsheet from the 2002 regional workbook** using copy and paste special (all) command. You must enable editing in recent Excel versions to make this copy and paste.
8. Then the percentage allocation are rebalanced by adjusting the percentages in the **Percent-P spreadsheet** to meet estimated P needs while using most of the fertilizer sales that contain. P. Some fertilizers can be purchased in the fall and applied in the spring such as urea, DAP, nitrate, etc. Therefore the spring and fall are examined jointly allowing fall or spring to be negative if it is offset by the opposing season sales. Anhydrous ammonia is an exception because storage costs are greater.
9. Then the percentage allocation are rebalanced by adjusting the percentages in the **Percent-N spreadsheet** to meet estimated N needs while using most of the fertilizer sales that contain. N. The sales relative to needs must be balance by using the **Percent N +N with P spreadsheet** totals. Some fertilizers can be purchased in the fall and applied in the spring such as urea, DAP, nitrate, etc. Therefore the spring and fall are examined jointly allowing fall or spring to be negative if it is offset by the opposing season sales. Anhydrous ammonia is an exception because storage costs are greater.

Fertilizer sales remaining by fertilizer type must be checked and rechecked as percent is filled in. Use expert knowledge to choose which fertilizer to assign to each crop and time period. Expert Knowledge guidelines are contained in the following checklist:

1. Allocate Phosphorus fertilizers first to determine what amount of nitrogen is applied with the Phosphorus based fertilizer.
2. Allocate anhydrous ammonia to corn and grain sorghum first.

3. Use urea for post plant nitrogen fertilizer on rice.

If the balances exceed expected goals, the percentages of fertilizer N and P by crop need to be adjusted. For some crops such as hay, silage, and pasture, it is expected that 30 to 60 percent of crop needs are met with manure fertilizer and/or livestock droppings on the pasture during grazing. Some grain crops like corn may receive 10 percent or more of the crop needs from manure applications.

Numerous sources of survey data, other studies, and conversations with agronomic experts were used to estimate the percentages by region by type of fertilizer by timing. There is variability and no single source that documents the entire fertilizer application allocation. Dr. Benson used all the information he found in a logical trial and error process. Spreadsheets were sent out for review; however, he didn’t receive any comments or criticisms. This is likely due to the absence of simultaneously collected fertilization data by crop by region by timing by type of fertilizer. Such data would be difficult and very expensive to collect. Dr. Benson has tried to incorporate both economic and agronomic logic into the allocation process.

Copies of various survey results and published papers used indirectly to make the regional estimates are available if requested.

Once the allocation spreadsheets are complete, the **Percent N+N with P** is copied to the **“Region”PrintSheet** workbook where there are multiple steps taken to prepare the spreadsheet in STEP 4 to be printed as a “.prn” file. The first step is to copy columns D to BT rows 1 to 197 of the **Percent N +N with P spreadsheet** from **Regional Workbook** the to the spreadsheet entitled **“Step1**”in the , **“Region”PrintSheet workbook** using a paste special (paste link).
The “**Step2**” spreadsheet is linked to the “**Step1**” spreadsheet and eliminates the irrigated rows. The “**Step3**” spreadsheet is linked to the “**Step2**” spreadsheet in such a way to reorder the crops for printing. The “**Step4**” spreadsheet is created by copying columns A to BT rows 4 to 23 of the “**Step3**” spreadsheet to D1 of the “**Step4**” spreadsheet using paste special (values and transpose). This process is continued for rows 24 to 43, 44 to 63, 64 to 83, 84 to 98, and 99 to 108 of “**Step3**” spreadsheet to D73, D145, D217, D289, and D361 of the “**Step4**” spreadsheet using paste special (values and transpose), respectively. **The EPIC fertilizer number for fertilizer sales IDENTIED BY GRADE must be set to 22 which is elemental N. This might be changed if the model users acquire information to make a different assignment.**

The “**Step4**” spreadsheet is then saved as a “**Formatted Text (Spaced Delimited)** file. The resulting “.prn” file is used as input into the next program that creates a set of regional fertilizer files by crop. This program will be documented separately.

7.5 Regional Program

This program converts the “.PRN” files created for each region with Excel to fertilizer application files for each region and crop that are used by the program that creates the EPIC management files, OPC, for the EPIC simulations. The main program steps are described below:

1. The Excel created PRN files are listed in a file entitled REGION-DATA-NAME.DAT show below that has the file names without extension right justified in a 50 character column followed by the region number in an 8 character field.

```
    NortheastPrintSheet06-20-13REGION01
   AppalachaiPrintSheet06-20-13REGION02
    SoutheastPrintSheet06-20-13REGION03
   LakeStatesPrintSheet06-20-13REGION04
     CornbeltPrintSheet06-20-13REGION05
  DeltaStatesPrintSheet06-20-13REGION06
NorthernPlainsPrintSheet06-20-13REGION07
SouthernPlainsPrintSheet06-20-13REGION08
     MountainPrintSheet06-20-13REGION09
             PrintSheet06-20-13REGION10
```

2. This file is read in one line at a time as each region's data is processed to create the fertilizer application files.
3. A file named "12kmFERT-VALIDATE.DAT" is opened and later used to validate that input was read correctly.
4. Program variables are initialized before processing unless they were specified earlier in DATA statements.
5. Array BELD4I(I,J) is the initial BELD4 crop number by timing (I) by crop (J) in crop group. Crops are grouped by groups of 4 or less to fit in Excel print files without exceeding Excel's built in record length.
6. Array CROP(J) is the BELD4 name of the crop by crop (J) in crop group.
7. Array TIMING(I) is the abreviated name of the application time by crop (I) in the crop group.
8. Array SPRING(I,J) is a 0/1 code where 1 means it is spring by timing (I) by crop (J) in crop group.
9. Array FALL(I,J) is a 0/1 code where 1 means it is fall by timing (I) by crop (J) in crop group.
10. Array VOID is a blank line.
11. Timing period I=1 is actually a total. SPRING(1,J) and FALL(1,J) are set to 2 to differentiate the total from spring or fall timing.
12. Array BELD4N(I,J) is the revised BELD4 crop number by timing (I) by crop (J) in crop group. BELD4 numbers were changed to start the numbering at 1 versus 22.
13. BELD4 crop numbers for irrigated crops are one digit greater than rainfed crops. Fertilizer allocation does not differentiate between rainfed and irrigated at this time so they are treated the same and the same timing is assigned to the irrigated part of the arrays.
14. Inputs are written to "12kmFERT-VALIDATE.DAT" to verify input.
15. Fertilizer codes, names, and fractions by timing by crop in crop group are read in where
    EPICFERT is the EPIC fertilizer file number
    FERTSALESIDEPIC is the fertilizer sales code NUMBER
    FERTSALESNAMEEPIC is the fertilizer sales name
    FERTFRACN(I,J) is the fertilizer application fraction by timing (I)

by crop (J) by crop group

16. There are 60 lines of fertilizer information.
17. Six lines of summary information follow each group of crops. These lines are skipped by reading VOID.
18. There six groups of fertilizers that are read and processed in sequence.
19. Begins creation of regional files by crop and region. Each line of the file has the region number for example REGION01, the BELD4 crop number, the BELD4 crop name, the C fertilizer sales number, the fertilizer sales name, the EPIC fertilizer number, the time period abbreviated name, the time period code number, and the fraction of N application met by that fertilizer in that time period. Note the total is used later when all totals are added to determine the fraction met with manure if the sum of all total is less than 1.00.

8. EPIC0509 Spinup and Application Simulation

A conscious effort was made to modify the distributed USDA code as little as possible and the first sources of EPIC code documentation should be the EPIC Users Guide v.0509 and Agricultural Policy/Environmental Extender Model Theoretical Documentation version 0604 (EPIC is the field component of APEX). Both documents are available at http://epicapex.tamu.edu/downloads/user-manuals

Although a Linux version of the EPIC0509 code was obtained, it was fairly old and we determined that it was better to convert the current DOS Fortran code to Linux ourselves. This effort was led by Limei Ran, UNC Institute for the Environment. Ultimately, very few changes were necessary and focused primarily on system I/O and the introduction of environmental variables defined in submission scripts that facilitate batch submission.

A second modification was the input of wet and dry deposition. The original code only allowed the definition of a single average annual concentration of total N in precipitation (current .8 ppm default option in the FEST-C interface). While an option to also accept an average daily value for total dry deposition has been added to other USDA model components in the EPIC family, i.e., SWAT, EPIC does not currently support dry deposition input. We modified the EPIC weather input to expect daily values of oxidized and reduced wet and dry N deposition and wet organic N deposition. If this information is not available, zero values are used (no deposition option in the FEST-C interface). The EPIC code now adds wet and dry oxidized, wet and dry reduced and wet organic atmospheric N deposition directly to the layer 2 nitrate or ammonium pools. See Fertilizer Emission Scenario Tool for CMAQ (FEST-C): User's Guide for additional information regarding creation of the year-specific input weather files. At present, the .8 ppm default option is used for all spinup runs.

EPIC output has been modified to support specific EPA needs. A new output option has been added to compute a 5-year average output file using the last 5 years of the 25 (or 100 years) spinup results. There are other more minor adjustments to output files.

Acknowledgements

The development of the FEST-C system is sponsored and directed by US EPA Atmospheric Modeling and Analysis Division (AMAD) under the U.S. EPA Contract No. EP-W-09-023, "Operation of the Center for Community Air Quality Modeling and Analysis (CMAS)" and EP-D-12-044, "Emissions, Air Quality, and Meteorological Modeling Support (EMAQ)". We thank Dr. Ellen Cooter, the EPA Work Assignment Manager for the work described in this document, for her leadership and support on this project. We also greatly appreciate the continuing and generous intellectual support we received from Dr. Jimmy R. Williams at Texas A&M AgriLife Research, Blackland Research & Extension Center (Temple, TX). We thank Joe Slater, Manager of Fertilizer/AG Lime Control Services, University of Missouri Agricultural Experiment Station at Columbia, MO, for his invaluable insights regarding fertilizer sales and use.