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REMOTELY SENSED PLANT HEIGHT INPUT TO COTTON GROWTH MODEL IN GIS FRAMEWORK

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Abstract

The ability to predict yield in advance of harvest would be of great benefit to producers in terms of risk management and overall profitability. Crop growth models have proven to be useful, but they are not suited to use on a site-specific basis. Remote sensing provides site-specific data, but alone it is lacking in utility for producers. However, together these two technologies can conceivably provide for site-specific prediction of yield. A computer interface between the Arcview GIS (geographic information system) and the cotton growth model, Gossym, was developed to allow the model to accept inputs and provide predictive outputs on a site-specific basis. The relationship between remote-sensing data and cotton plant height was studied, and a means to input remote-sensing-based plant-height estimates to Gossym was implemented in the GIS interface. Based on this research, it appears to be reasonable to use remote-sensing data to estimate plant height, and then to use the estimate as real-world feedback to improve Gossym's yield predictions. The results of this work facilitate the entire process of combining remote-sensing data with the cotton growth model, Gossym, in a GIS framework.

Introduction

Background

Precision agriculture is the common term for using site-specific information to manage agricultural production in a way that can optimize profit and minimize environmental impact by allowing precise application of production inputs in only the necessary amounts and locations. In order to successfully implement precision agriculture on a commercial farm, a producer must have site-specific information such as remotely sensed image data, the ability to understand and make decisions based on the information such as with the aid of crop growth models, and the ability to apply site-specific management decisions such as with VRT (variable-rate technology) sprayers. While VRT field equipment has become commercially available, efficient data collection methods and reliable decision aids for precision agriculture need to be further developed to become viable in commercial farming.

As a means of collecting site-specific data, remote sensing is efficient in terms of the level of cost, the amount of time required, and the level of tedious labor required. Remote sensing provides information on current crop status, and it can potentially be used with other data to predict yield site-specifically. As decision-making aids, crop growth models can use available information to predict yields, and thus profits. They can also be used to make input recommendations. However, neither remote sensing nor crop growth models have been widely adopted in production agriculture, even though a lot of research has been done on both. Both approaches have shortcomings. Crop-growth models typically require a great deal of field data collection, and they require evaluation and calibration before confidence can be gained in their predictions. Also, they are generally used on a whole-field basis, and they are not easily adapted to use in precision agriculture. Remotely sensed imagery requires calibration and geographic correction, both of which can be difficult to do, particularly in a commercial farm setting. Furthermore, remote sensing has limitations in temporal frequency and timely delivery; i.e., images typically cannot be collected and/or delivered as often or as quickly as needed.

A solution to the problems posed by the independent use of remote sensing and crop-growth models is to combine them. Remote sensing can provide the spatial-variability information required to make inputs and outputs of crop-growth models site-specific, and models can be integrated with a GIS (geographic information system) to facilitate the use of site-specific inputs and outputs of the models. Moreover, models can be used often and thus can provide the high-temporal-frequency data that remote sensing often lacks. Remote sensing, or some other highly efficient data collection method, will be necessary to calibrate GIS-integrated crop-growth models so that they can be used to predict production site-specifically over large areas; the traditional procedures of field data collection are not feasible in this scenario. While incorporating remote sensing into a GIS-integrated crop-growth model has been considered in the past, a suitable operational system for commercial cotton farming has not as yet been developed.

Literature Review

Barnes et al. (1997) noted that remote sensing can be a valuable tool when crop-growth models are applied in a GIS environment. They stated that the remote-sensing data could serve three functions: (1) to aid in the definition of zones requiring independent simulations, (2) to provide validation data on crop development, canopy density, and evapotranspiration, and (3) to provide direct input to the crop-growth model. Moulin et al. (1995) reviewed studies that integrated remote sensing with crop growth models, and they reported that yield prediction was improved.

Objectives

The objectives of the research described herein were threefold:

1. to develop a GIS interface for the cotton growth model, Gossym
2. to develop an approach for estimating plant height in a given field with remote-sensing data
3. to enable within the GIS interface
   a. remote-sensing based zone delineation
   b. input of plant height estimates into Gossym

Materials and Methods

GIS Interface for Gossym

The Gossym cotton growth model was selected, because it calculates the level of photosynthesis occurring in a plant. To do this, it must estimate the size or volume of the plant. Whereas plant height is an indicator of plant size, plant-height measurements can be introduced into Gossym to provide real-world feedback to its estimates of size, photosynthesis, and eventual yield.

The principal task in developing a GIS interface for Gossym was to write the code required to link Gossym with Arcview, which was selected because of its widespread use. All interface code was written in Visual Basic, and the programming was structured such that Gossym would run from its own menu item within Arcview.

Estimating Plant Height with Remote-Sensing Data

Data regarding the relationship between remotely sensed images and cotton plant height were collected by two different research teams in two ways. First, as part of a separate study, a research team led by Dr. Raja Reddy (Professor, Department of Plant and Soil Science, Mississippi State University) collected data in controlled plot studies over two years. This paper will not include any details of their, as yet, unpublished work, but some general comments will be made about the methodology and results. Their remote-sensing data included high-resolution (0.5-m) aerial imagery of plots that had been subjected to various treatments in order to produce differences in plant height. In that study, the image resolution was high enough to produce multiple pixels per plot, so there was no question about which pixels corresponded to which plot. Second, data collection in the principal study covered in this report involved two large commercial farm fields in Mississippi's Delta region where images and plant height data had been collected over 5 years. In this study, some of the imagery was from an aerial platform (0.5-m resolution) and some was from a satellite platform (Landsat, 30-m resolution). Here, all the variation in plant height occurred naturally, so there were no defined plots. This situation made it difficult to tie individual pixels to specific locations in the field, particularly when using high-resolution images. The lower-resolution images presented less difficulty in assigning the correct pixel to a ground-measurement location, but they presented more difficulty in light of the natural variability occurring inside each 30-m pixel. In both studies, plant height was measured manually on each plot or sampling location at roughly the same time that images were acquired.

Image processing involved calculating the value of NDVI (normalized difference vegetation index) for every pixel in each image. Simple linear regression was used to determine the relationship between plant height and NDVI, and to establish generalized parameters for estimation of plant height based on NDVI.

Specific Capabilities within the GIS Interface

In addition to the computer code writing required for the GIS interface for Gossym, code was written also to allow automated remote-sensing-based zone delineation within agricultural fields. This feature was important because of the desirability of being able to run Gossym on several management zones within a field while not being required to run it at every pixel location within an image. Furthermore, code was written to allow remote-sensing based plant height estimates to be input directly into Gossym.

Results

GIS Interface for Gossym

The Arcview interface for Gossym has been successfully developed. Figures 1 through 6 demonstrate the various capabilities of the interface. Figure 1 exhibits the button menu for Gossym functions, the interface for remote-sensing data, and the ability to delineate field boundaries. Figure 2 exhibits the GUI (graphical user interface) for the PlantMap feature within Arcview. Figure 3 exhibits the ability to run Gossym within Arcview in conjunction with numerous data layers, such as data sampling locations within a field. Figure 4 exhibits the "Run Gossym" window, which allows the entry of data pertaining to the field in question. Figure 5 exhibits the ability to enter soils and other data from predetermined data files. Finally, Figure 6 exhibits a special feature that was incorporated into the interface: that of being able to download from the internet up-to-date weather information for use in Gossym calculations.

Estimating Plant Height with Remote-Sensing Data

It is well known that the height of cotton plants exhibits a sigmoidal pattern over the course of a growing season (Figure 7). It is also known that NDVI exhibits the same pattern, and data collected in Mississippi's Delta region in 2002 verify this fact (Figure 8). When NDVI data were compared to cotton plant height data over the course of a growing season, the data collected from small plots by Reddy exhibited high correlations, and the data collected on large commercial fields also exhibited fairly strong correlations, with R^2 values ranging from 0.49 to 0.69.

What would be more impressive is the ability to differentiate among plant heights within a given field with an image representing one date. When NDVI data were compared to cotton plant-height data on one date, the data collected from small plots by Reddy again exhibited fairly strong correlations, while the data collected on large commercial fields exhibited statistically significant, though not necessarily strong correlations (R^2 = 0.10 to 0.39). Correlations with NDVI based on satellite data were better than those with NDVI based on aerial data.

Beyond the desire to find correlations between remote-sensing and plant-height data, one would ideally wish to be able to use remote-sensing data to predict cotton plant height for input to Gossym. Along these lines, linear-regression analyses over all the sets of data indicated that equation parameters were fairly consistent for a particular sensor. Thus, it appears that it would be reasonable to use equations developed with a full-season of data to predict plant height during subsequent seasons, assuming that data were of high quality and consistent in terms of the sensor used, proper calibration, the same agricultural field, etc.

Enable within the GIS Interface

Since it appears that it may be possible to predict cotton plant height on a particular cotton field at a given date based on well-calibrated NDVI data, it would be advantageous to be able to use these predictions in a GIS-based cotton growth model. The results of the programming efforts in this study were successful and have made this possible. The GIS interface for Gossym has been developed such that a user can employ an automatic zone-delineation algorithm that will create management zones within a field based on available geospatial data including remotely sensed images. Second, and more important, the GIS interface for Gossym can evaluate, for each management zone, a representative plant height, and use that value as feedback to the Gossym model. This feedback will improve the yield predictions made by Gossym.

Conclusions

A GIS interface for Gossym has been developed, enabling Gossym to be run directly from with the Arcview GIS program. Reasonably good correlations were found between remote-sensing and cotton plant-height data. Furthermore, the relationships between NDVI and plant height were fairly consistent, so it is expected that NDVI can be used to provide a reasonable estimate of plant height to be used as input to Gossym. Care should be taken to ensure that remote-sensing data are consistent and of high quality. The GIS interface was developed with certain principal features that allow it to automatically delineate management zones within fields, and to calculate cotton plant-height estimates and input them into Gossym to improve its yield estimates.

Acknowledgements

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References

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Moulin, S., A. Fischer, G. Dedieu, and R. Delecolle. 1995. Temporal variations in satellite reflectances at field and regional scales compared with values simulated by linking crop growth and SAIL models. *Remote Sens. Environ.* 54(3):261-272.

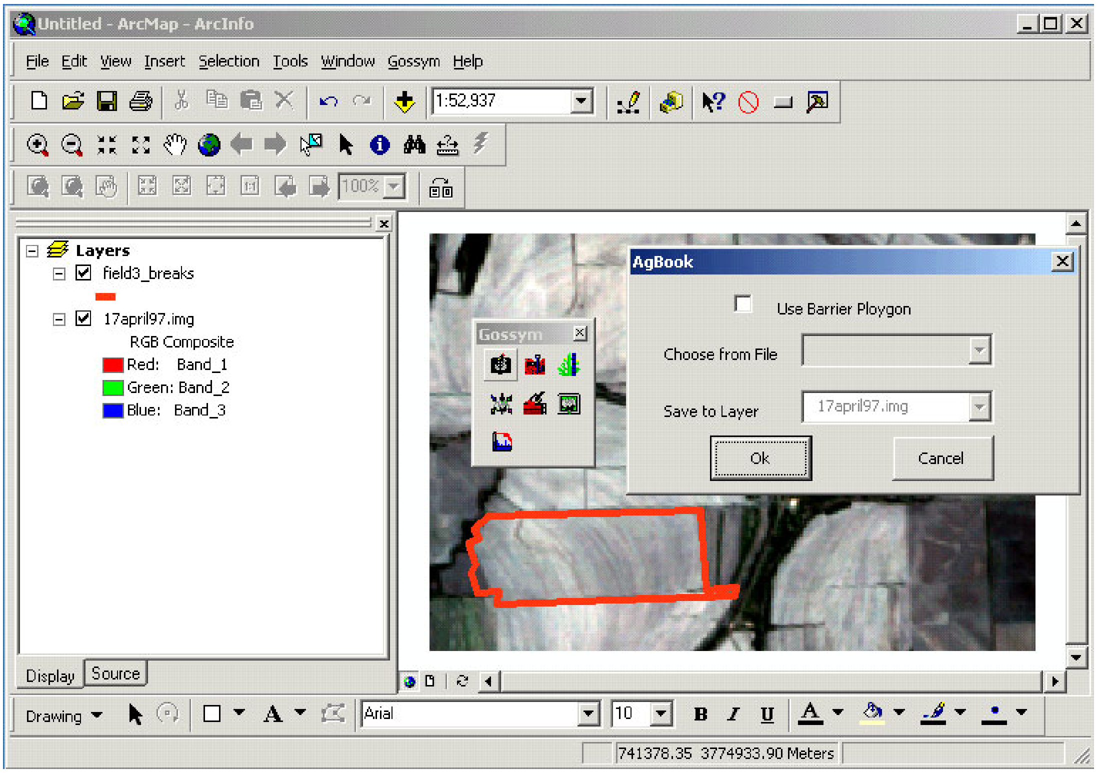

Figure 1. Arcview computer window exhibiting the Gossym interface.

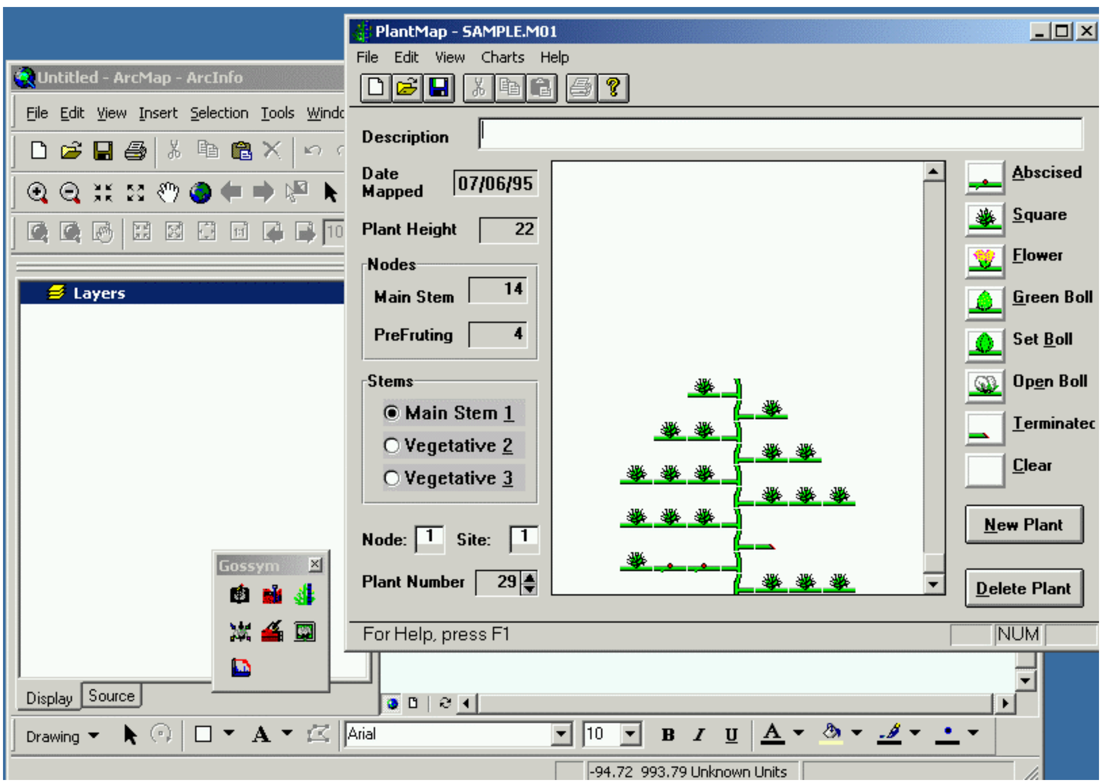

Figure 2. Gossym's PlantMap feature exhibited within Arcview.

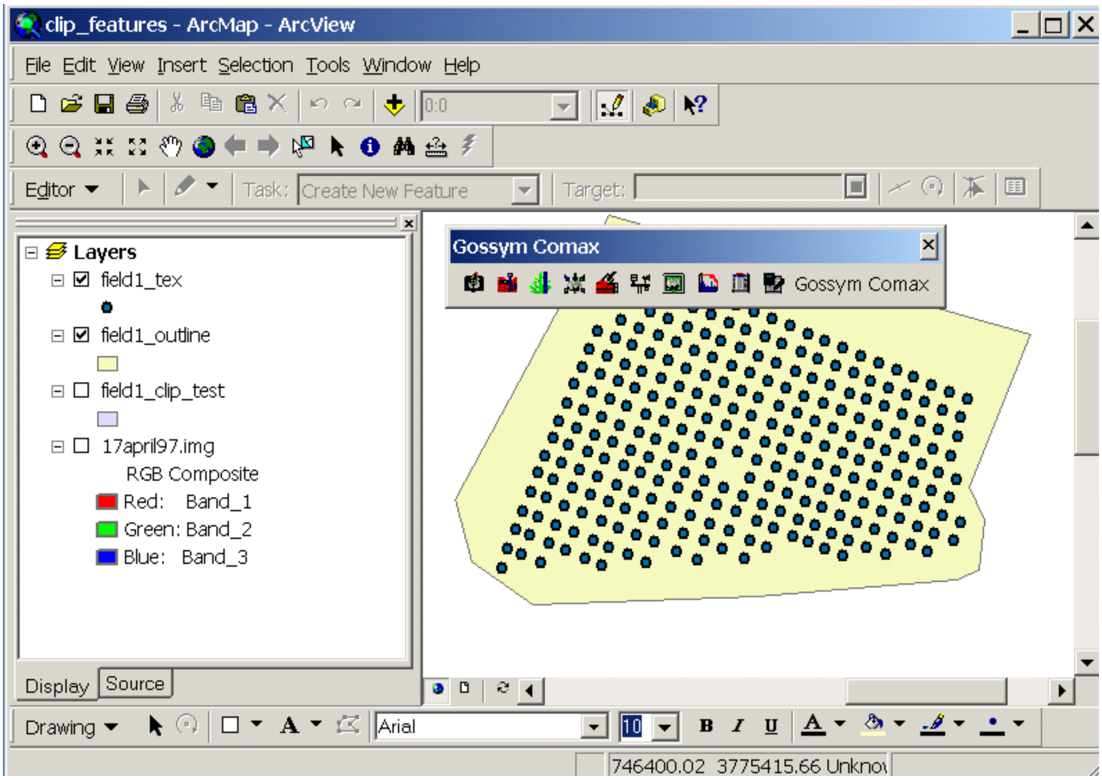

Figure 3. Gossym window within Arcview, exhibiting delineated field boundary and sampling locations.

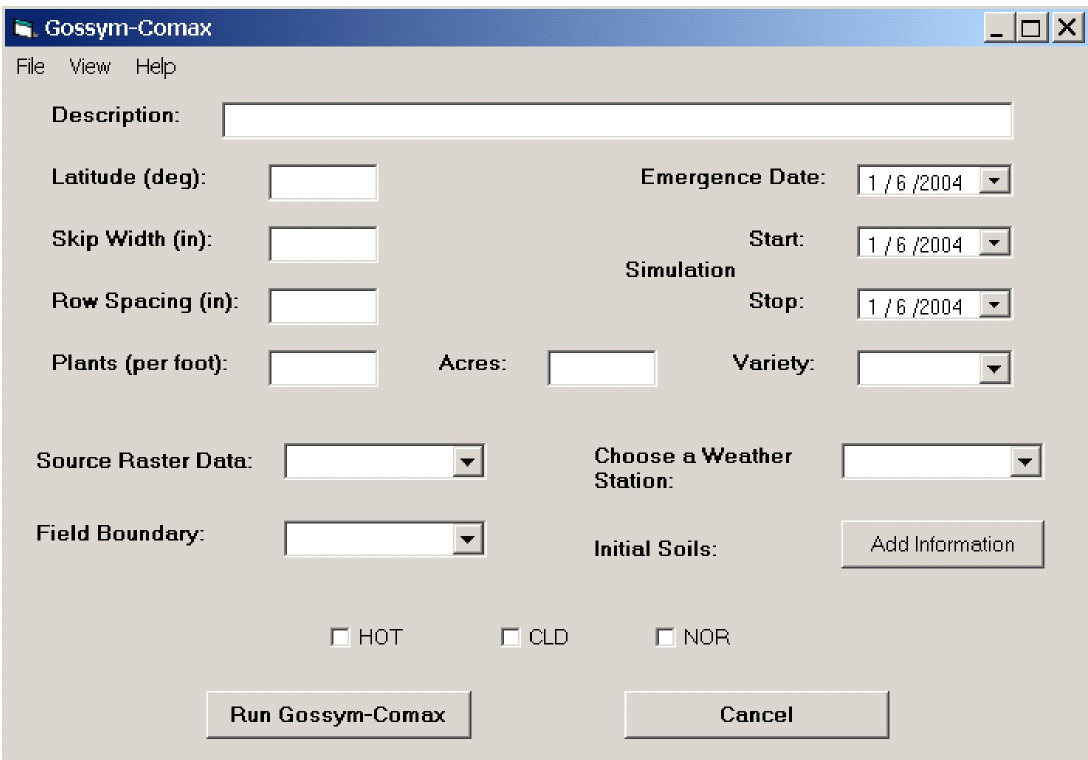

Figure 4. “Run Gossym” interface window.

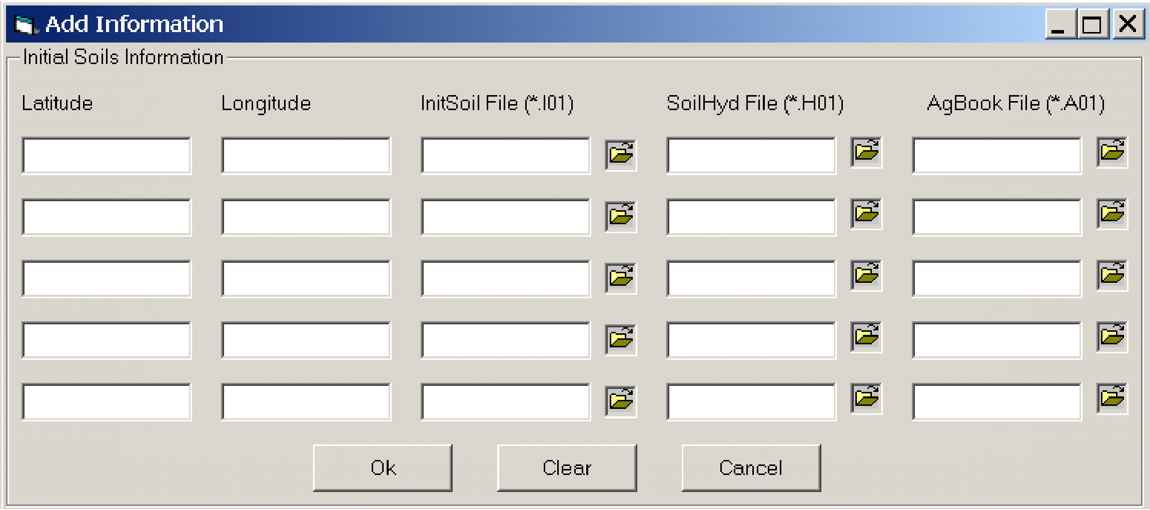

Figure 5. Data entry window for soils and other data.

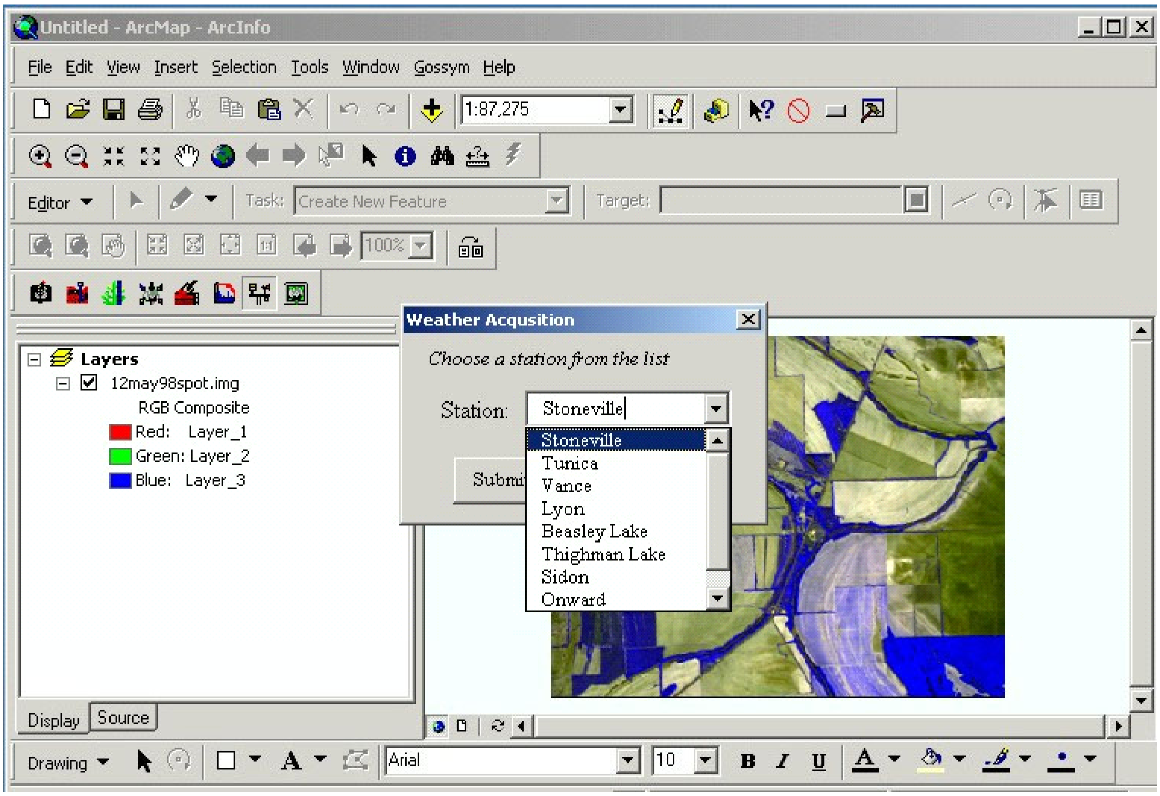

Figure 6. Gossym window exhibiting capability to download internet weather data.

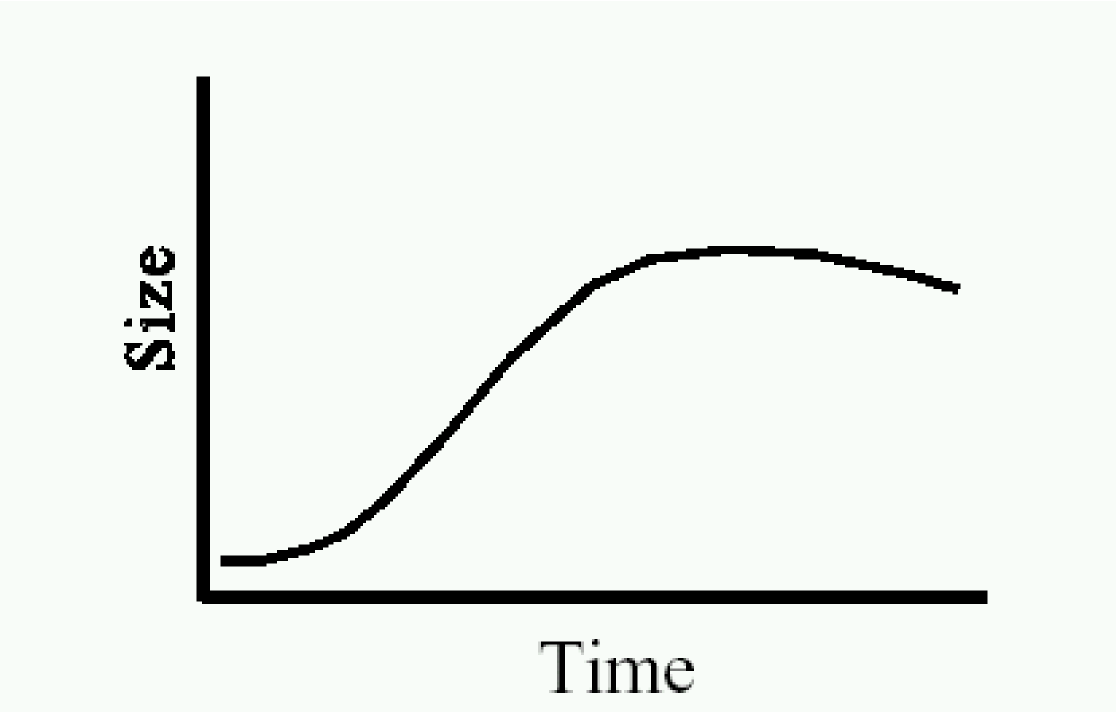

Figure 7. Standard empirical plot of changes in cotton plant height during the growing season.

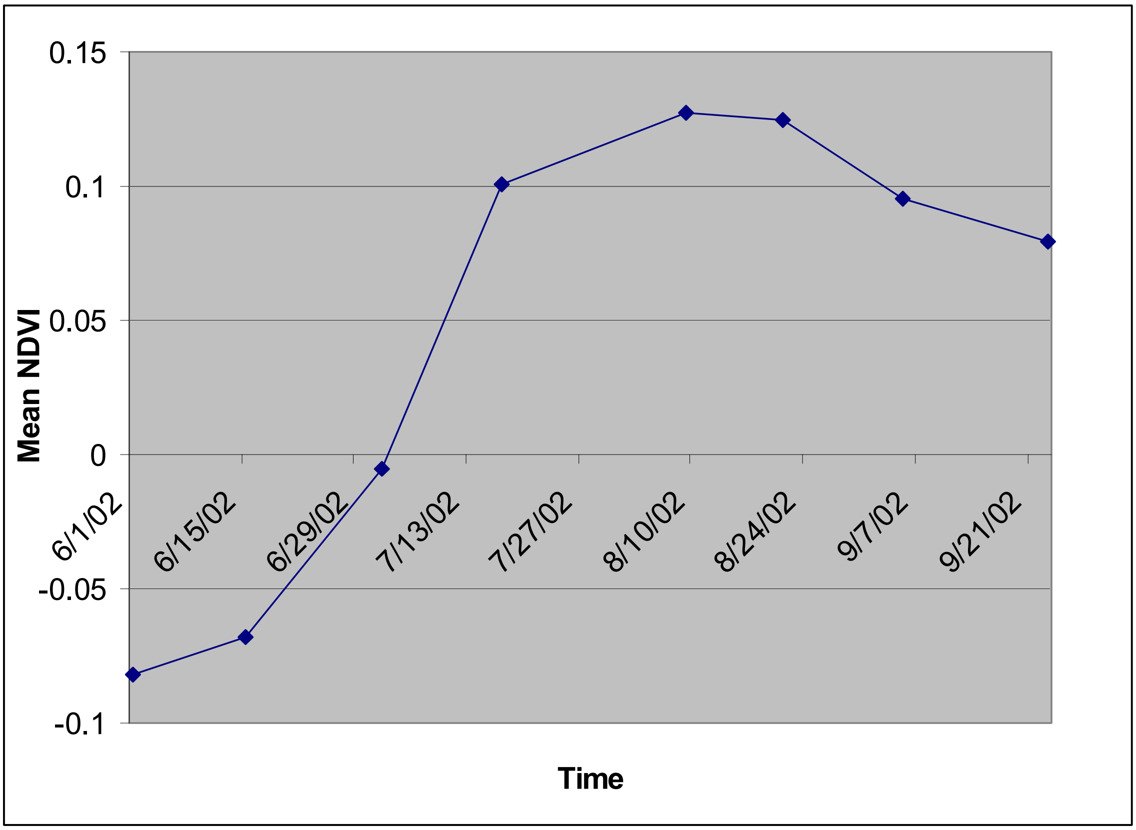

Figure 8. Plot of 2002 average NDVI data from cotton field in Mississippi's Delta region.