LOCATING TURFGRASS PRODUCTION SITES FOR REMOVAL OF PHOSPHORUS IN ERATH COUNTY, TEXAS

A Thesis

by

JEREMY EDWARD HANZLIK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2003

Major Subject: Biological and Agricultural Engineering

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Approved as to style and content by:

Clyde Munster (Chair of Committee)	Donald Vietor (Member)
Richard White (Member)	Gerald Riskowski (Head of Department)

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ABSTRACT

Locating Turfgrass Production Sites for Removal of Phosphorus in Erath County, Texas.

(May 2003)

Jeremy Edward Hanzlik, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Clyde Munster

The North Bosque River watershed of central Texas hosts a large portion of dairy production in the state. In recent years, the Texas Commission on Environmental Quality (TCEQ), formerly known as the Texas Natural Resource Conservation Commission (TNRCC), has applied a Total Maximum Daily Load Program for soluble phosphorus to the watershed. Best management practices (BMPs) are now necessary to remedy the issue of excess phosphorus.

This thesis explores the application of GIS as an agricultural planning tool in support of a BMP for the region. The suggested BMP calls for the production of turfgrass sod using composted dairy manure; this sod is then transported at a profit from the watershed and provides an economically sustainable means to reduce the nutrient loading in the watershed. Using GIS, a geospatial database was developed with available data from government and institutional sources. As part of the development process, these sites were verified by field technicians and the results were combined in the GIS to refine the database. This database demonstrates the suitability of GIS as a tool for large-scale planning in agriculture.

Dedicated to all those who supported me and made my experiences at Texas A&M University possible and worthwhile including some of the following people by name.

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CHAPTER I

INTRODUCTION

The North Bosque River has elevated levels of nitrogen (N) and phosphorus (P) (TNRCC, 2001). According to a Texas Institute for Applied Environmental Research (TIAER) study, 94 dairies, with a combined sum of approximately 34,000 cows, represents the major agricultural use of the watershed (McFarland, 1996). Waste runoff from these dairies combined with urban inputs has degraded water quality in the watershed. The North Bosque River watershed drains into Lake Waco, which is the primary source of public water for Waco, TX, as well as for the cities of Clifton and Meridian (TNRCC, 2002).

Due to the degradation of the water quality in the North Bosque River, there has been a large response in terms of research, monitoring, and planning for this watershed. The TNRCC (Texas Natural Resource Conservation Commission) developed TMDLs (Total Maximum Daily Loads) for phosphorus in the North Bosque River with the objective to "restore and maintain the beneficial uses of impaired or threatened water bodies." The "beneficial uses" clause is broadly interpreted to include such uses as drinking water, recreation, fishing and support of aquatic life (TNRCC, 2002).

In an effort to move excess manure nutrients out of the watershed, the State of Texas has begun subsidizing the hauling of dairy manure to composting facilities. In

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This thesis follows the style and format of the *Transactions of the American Society of Agricultural Engineers*.

addition, the Texas Department of Transportation (TxDOT), a large consumer of this composted dairy manure has been subsidized by the state to haul the compost out of the watershed to amend poor soils on construction projects. Due to the state subsidies for the composting of dairy manure, a composting infrastructure has developed in the region. In the coming years, these subsidies may no longer be available, but the composting infrastructure will remain in place. The emergence of this composting infrastructure has led researchers at Texas A&M University (TAMU) to investigate the possibility of using composted dairy manure to grow turfgrass sod. The transport of manure nutrients in turfgrass sod may prove to be a sustainable means to export composted diary manure from the North Bosque River watershed.

A current turfgrass sod research study at TAMU includes field-scale experimentation. The goal of the study is to improve water quality by the sustainable transport of manure nutrients out of the North Bosque River watershed in turfgrass sod grown with composted dairy manure. However, suitable sites for turfgrass operations must be identified before extensive turfgrass production can take place within the watershed.

Implementation of turfgrass sod production necessitates identification of acceptable land areas for this use. Such considerations for land use could include soil type, irrigation water availability, property values, topography, identification of urban areas, distance from composting facilities, highway networks and other factors. With these considerations in mind, geographical information system (GIS) software was used to identify suitable locations for turfgrass operations in or near the North Bosque River watershed.

Additionally, the implementation of turfgrass sod production to improve water quality requires the estimation of phosphorus removal. The estimation of phosphorus removal in sod allows for an understanding of what can be achieved in terms of phosphorus removal from the watershed, and thus allow for better land-use planning within the watershed.

With these aforementioned requirements in mind, this research focused on the following objectives:

1. Develop GIS methods and procedures to locate suitable turfgrass production sites in Erath County in the North Bosque River watershed to utilize composted dairy manure.
2. Validation of the production sites identified by the GIS methods.
3. Estimation of the potential phosphorus removal from the North Bosque River watershed in turfgrass sod.

The results of the water quality research are presented in the following chapters. The first two objectives are addressed in chapter 2 and the third objective is addressed in chapter 3.

CHAPTER II

LOCATION OF TURFGRASS PRODUCTION SITES FOR PHOSPHORUS REMOVAL FROM AN IMPARED WATERSHED

Synopsis

The North Bosque River watershed of central Texas hosts a large portion of dairy production in the state. In recent years, the Texas Commission on Environmental Quality (TCEQ), formerly known as the Texas Natural Resource Conservation Commission (TNRCC), has approved a Total Maximum Daily Load Program for soluble phosphorus for two segments of the North Bosque River. The TMDL program affects dairy producers in the region who contribute to the non-point source phosphorus loading in the watershed. Best management practices are now necessary to remedy the issue of excess phosphorus. One such management practice calls for the production of turfgrass sod using composted dairy manure; this sod could then be transported from the watershed to provide an economically sustainable means to reduce nutrient loading. In order to produce the turfgrass sod, appropriate production sites must be located. A geospatial database was developed with available data from government and institutional sources. As part of the development process, field technicians verified potential turfgrass production sites and the results were combined to refine the database. These sites can be used for watershed-scale modeling or furnished to potential producers as a starting point to acquire land for turfgrass production in the watershed.

Introduction

The North Bosque River (NBR) watershed (Fig. 2-1) covers approximately 3,200 square kilometers in north central Texas (Adams and McFarland, 2001). This watershed drains from a limestone plateau into Lake Waco, which provides flood control and drinking water for Waco, and surrounding municipalities with a combined population of more than 150,000 people (TNRCC, 2002). Dairy production and ranching became predominant practices beginning in 1945, marking a switch from cotton production. As urban demand in the Dallas-Ft. Worth region grew during the 1980s and 1990s, dairy production experienced exceptionally rapid growth (Erath County, 2002). As of October 2002, about 80 dairies were active in the North Bosque River watershed representing about 40,000 milking cows. Most of these dairies reside within Erath County, the number one milk producing county in Texas (USDA-ARS, 2003). In 1996, the TNRCC indicated that nonpoint source loadings of nutrients and fecal coliform associated with dairy operations were the most serious threat to meeting designated uses along the North Bosque River (TNRCC, 1996). Under most conditions, algal growth along the North Bosque River is limited by phosphorus (Kiesling et al., 2001). Within the Total Maximum Daily Load (TMDL) process, dairy waste application fields were identified as the major controllable nonpoint source of soluble P to the North Bosque River (TNRCC, 2001). Ultimately, confined dairy production emerged as a major source of nutrient loading during water quality testing in the North Bosque River watershed performed by the Texas Commission on Environmental Quality (TCEQ), formerly known as the Texas Natural Resource Conservation Commission (TNRCC). Nutrient-impaired segments in the North Bosque River watershed were included in a TMDL program adopted by the State of Texas and approved by the U.S. EPA. The TMDL goal was "an average overall reduction of approximately 50% in soluble phosphorus (P) average total-annual loading," (TNRCC, 2001). In meeting the TMDL goal, an annual reduction of this magnitude should reduce the potential for problematic algal growth in river segments as P is the limiting nutrient in this watershed (McFarland et al., 2000).

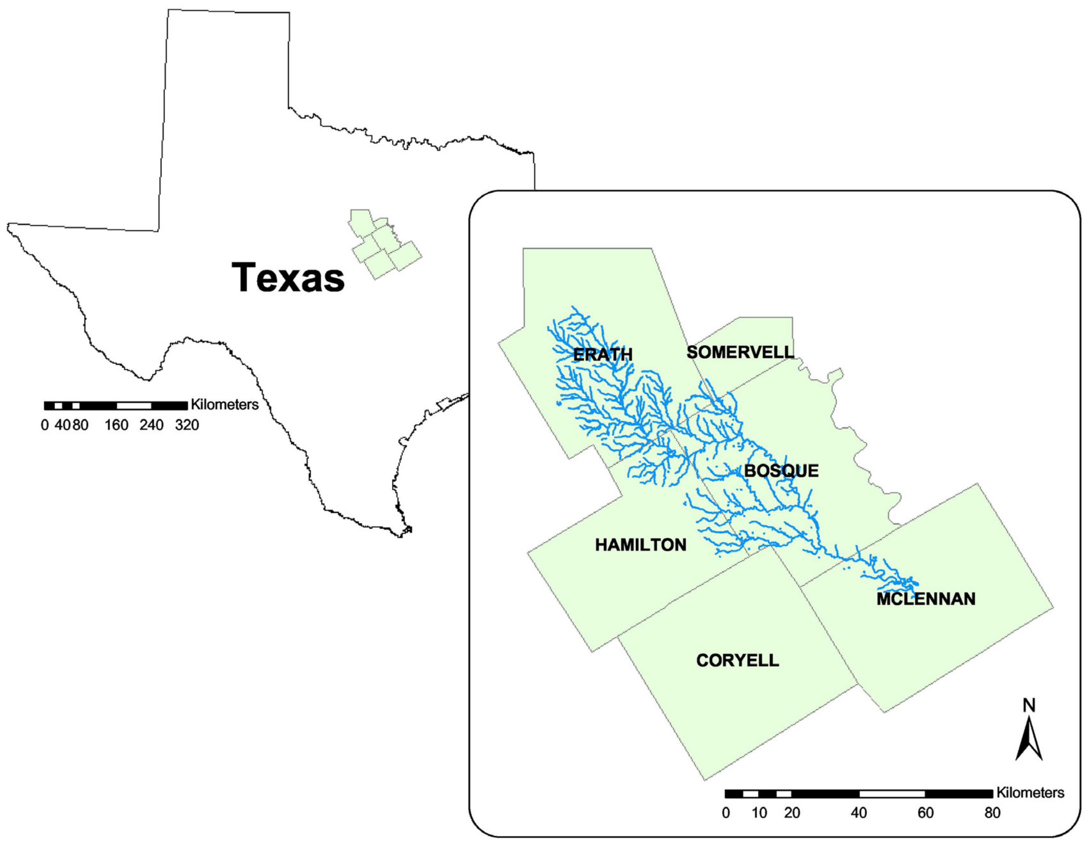


Figure 2-1. Location and extent of the North Bosque River watershed in central Texas with county boundaries shown.

With the implementation of the TMDL program, new technologies and practices will need to be adopted by the dairy industry in order to achieve the goal of restoring designated uses to the impaired waters of the North Bosque River. As observed by McFarland and Hauck (1996), there exists a need to develop and promote best management practices (BMPs) for control of P.

One suggested BMP is the export of P from the impaired watershed through turfgrass sod production (Vietor et al., 2002b). This BMP offers dairies and other concentrated animal feeding operations (CAFOs) the potential of producing a high-value commodity, turfgrass, using P from the CAFOs in the form of composted dairy manure (Vietor et al., 2002a). Beyond benefiting the watershed and CAFOs, value is added for the consumer in the urban sector. Import of manure P with sod negates the need for P fertilizer application on the consumer's property and avoids loss of fertilizer P in urban surface runoff (Vietor et al., 2002b).

In the NBR watershed, and Erath County in particular, a dairy manure composting infrastructure has already been established. The infrastructure has resulted from a state subsidy program to transport manure from dairies to composting facilities. As part of this subsidy program, the Texas Department of Transportation (TxDOT) purchases a portion of the compost for application on construction projects and is the largest single consumer of the compost (Moffitt, 2001). If implemented, turfgrass production with compost could sustainably export manure P from the watershed without subsidies.

In order to implement turfgrass sod production as a BMP in the NBR watershed, suitable locations must be identified. Erath County was chosen as the location for this study due to the large concentration of dairies and composters already established. Geographic Information Systems (GIS) provided a capability for processing digital data in a spatial context, which could be applied to this county-scale problem. In this instance, GIS was used to analyze data and develop a geospatial database of suitable locations for turfgrass production. In addition, GIS provided the option of future digital modeling with the geospatial database developed by this project. Many software models are beginning to interface with GIS packages including the EPA's BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) package which incorporates the USDA's SWAT (Soil and Water Assessment Tool) model and other hydrology models.

Materials and Methods

Software

For this project, the most recent GIS platform, ArcGIS 8 by ESRI (Environmental Systems Research Institute) was selected because much of the existing GIS data were readily available in a form that is usable by ArcGIS without significant and resource-intensive modification. ArcGIS 8 is also a readily available GIS package for the desktop PC and works well with other Microsoft Windows software packages. As such, these methods pertain to the ArcGIS 8 software specifically, but may be applied to other GIS packages, although terminology and data storage may differ. In addition, remote sensing software was used to preprocess some large grids for ArcGIS.

Ecological Parameters and Data Sets

Implementation of turfgrass sod production necessitates identification of acceptable land areas for use. To identify these acceptable lands, the requirements for turf production were developed to specify the digital data needed for the GIS database and analysis. Clemson University Cooperative Extension has produced a detailed publication on the subject of sod production in the southern United States, which discusses production factors including farm size, distance to markets, soil characteristics, and other site selection requirements (McCarty et al., 1999). Additional data sets were also selected to incorporate not only the market and production requirements of the turf, but environmental factors. The data selections include a soils database, aerial photographs, land use and cover, political and administrative boundaries, and hydrologic data. Internet addresses for acquisition of these data sets as well as storage requirements are provided in Table 2-1.

Table 2-1. GIS digital data types, supplying agencies, scale, and storage requirements required to determine suitable turfgrass sod production sites in Erath County, Texas.

Data Type	Source	Scale	Size
Cities	EPA www.epa.gov/waterscience/basins/b3webdwn.htm	1:24,000	3.6 MB
Counties	Texas GLO www.glo.state.tx.us	1:24,000	36 KB
Dairy and Composting Facility Location	TIAER tiaer.tarleton.edu	N/A	176 KB
DOQ Digital Orthophoto Quadrangle	TNRIS www.trnis.state.tx.us	1m	1.8 GB
Land Use and Land Cover	TNRIS www.trnis.state.tx.us	30m	142 MB
NED files	USDA www.lighthouse.nrcs.usda.gov/gateway	1:24,000	239 MB
Rail Roads	Texas GLO www.glo.state.tx.us	1:24,000	5.2 MB
RF3 River Reach Files	EPA www.epa.gov/waterscience/basins/b3webdwn.htm	1:100,000	1.9 MB
State Boundary	USGS www.usgs.gov	1:2,000,000	6.7 MB
State Parks and Natural Areas	Texas GLO www.glo.state.tx.us	1:24,000	0.9 MB
SSURGO Soils Data	USDA NRCS NSSC www.ftw.nrcs.usda.gov/ssur_data.html	1:24,000	171 MB
Wildlife Refuge Locations	Texas GLO www.glo.state.tx.us	1:24,000	280 KB
Working Files	Shapes and Grids generated from above data for analysis	N/A	3.2 GB

Soils Database

The USDA-NRCS-NSSC (United Stated Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center) provides three geographic soil databases differing in resolution: 1) Soil Survey Geographic (SSURGO) data base, 2) State Soil Geographic (STATSGO) data base, and 3) National Soil Geographic (NATSGO) database. The SSURGO database includes variables such as bulk density, drainage class, depth of topsoil, rockiness, soil taxonomy, and many other features. For the purposes of this study, the SSURGO data base was most appropriate. It was developed at a scale ranging from 1:12,000 to 1:24,000 and designated for use with farm/ranch, township, or county natural resource planning and management (USDA-NRCS-NSSC, 1995).

Aerial Photography

The Texas Natural Resource Information System (TNRIS) provides complete coverage of Texas with 1-m resolution digital orthophoto quadrangles (DOQ). These images have been scanned and corrected for distortions. As specified by USGS standards, DOQs are provided in the Universal Transverse Mercator (UTM) coordinate system (USGS-NMD, 1996). DOQs are useful both as a background to visually interpret the various digital data sets and as a means to visually check against possible error in processing of digital data. Since these photographs are recent (late 1990s), they were used to verify land use and coverage.

Land Use and Cover

TNRIS provides land use and land cover data which has been classified according to the Anderson Level II system of the USGS. Anderson Level II data are obtained through use of high-altitude, color-infrared photography and provides datasets that include classifications as cropland/pasture, rangeland, and forested land. Detailed descriptors of these classifications are available in USGS publications (Anderson et al., 1976). The land use and cover data are subject to more frequent change than other types of data. Verification of digital land-use data was necessary after processing to determine suitable locations for production.

Political and Administrative Boundaries

Boundaries of political and administrative nature include cities, state parks, federal preserves, and other natural areas. The USGS supports a program known as the National Atlas which provides some of these data including state and county boundaries. In addition, the Texas General Land Office provides Texas-specific data regarding parks and wildlife areas. These data sets are used to exclude certain restricted land areas from the selection process including wildlife preservation areas and other governmental lands.

Hydrological Data

The EPA provides RF3 files, known as River Reach Files, through the EPA-BASINS website. These files are a result of the efforts by the EPA Office of Wetlands, Oceans, and Watersheds (EPA-OWOW) to provide higher resolution digital data for GIS, modeling, and water quality reporting efforts under section 305(b) of the Federal Clean Water Act. RF3 files provide a standardized labeling system for stream segments that is recognized by state and federal agencies (Dulaney, 2001).

Procedure

Data Determination

Positive and negative paradigms were developed after production, environmental, and market parameters were defined for selection of digital data and for decision-making procedures for locating turfgrass production sites. In the positive paradigm, all ideal situations exist for the production of turfgrass on a given site. In contrast, the negative paradigm represents a totally unacceptable site for turfgrass production. This process yielded a decision matrix (Fig. 2-2) which provided a basis of context from which to develop computer queries and dictated which data sets should be sought for analysis. Inherently, as depicted in the decision matrix, actual production locations exist between the extreme paradigms and the number of sites decreases as characteristics of the ideal paradigm are approached.

Obtaining and Projecting Data

Obtaining and organizing digital data in a usable form was paramount. Management of nearly six gigabytes of data required a file structure that clearly defined parameters for organization of data. Data were sorted by county name, data type, and data set. In addition, backups of all original files were maintained in the same structure for reference should discrepancies occur or in case data were inadvertently altered by the GIS through the normal course of viewing and analyzing.

Because the data were obtained from different agencies with different internal uses, data were published in a wide variety of projections. It was, thus, necessary to project the data into a standard, usable coordinate system. Since aerial photography in the form of DOQs cannot be readily projected into a different coordinate system, the native DOQ projection of UTM 14 North American Datum 1983 was selected for the working projection.

Turfgrass Production Site Decision Matrix

Category	Feature	Ideal Paradigm	Applied Value	Negative Paradigm
Production	Irrigation Water Availability	Readily Available and in Ample Supply	NT[1]	Must Install Expensive System
	Irrigation Water Quality	Low P Content, Total Dissolved Salts < 800 ppm	NT[1]	High P Content, Total Dissolved Salts > 800 ppm
	Proximity to Roads	Near Paved Road	NI[2]	Must Install Road
	Proximity to Compost Facilities	Near Composting Facility	NI[2]	Long Distance for Compost to be Moved from Facility to Plot
	Previous Land Use	No Resistant Weeds, Little Land Preparation Required	cropland, pasture, rangeland, herbaceous rangeland, & agricultural rangeland[3]	Presence of Resistant Weeds, Extensive Land Preparation Required
	Land Value	Inexpensive	NT[1]	Costly
	Size of Plot	Large Scale	40 ha & 80 ha	Small Scale (<40 ha)
Env & Prod	Rockiness	No Rocks	<=3%	Highly Rocky
	Available Water Capacity	High (>7.62 mm/mm)	>= 2.54 mm/mm	Low (< 1.27 mm/mm)
	Drainage	Well Drained	Moderately Well	Poor
	Topsoil Thickness	Thick (>0.3 m)	>= 0.2 m	Thin (< 0.1m)
	Erodability	None	Moderate	Highly Eroded
	Land Slope	Shallow Slope (1-2%)	slope <=8%	Steep Slope (> 8%)
Environmental	Proximity to Streams	Far from Stream	Distance Buffer of 250m	Near Stream
	Proximity to Residential Zone	Rural	All soils within city limits were eliminated	Urban
	Groundwater Depth	Deep Watertable	NT[1]	Shallow Watertable
	State/Federal Lands/Parks	Unrestricted Lands	Unrestricted	Restricted Lands
	Flood Plain	Not in a Flood Plain	Rare (0-5% chance)	In annual Flood Plain
Market	Distance from Market	Near (< 200 km)	NT[1]	Far (> 200 km)
	Stability of Market	Highly Stable	NT[1]	Severe Fluctuations
	Market Demand	Demand Exceeds Supply	NT[1]	Supply Exceeds Demand

1. Not tested since data was unavailable, incomplete, or non-spatially oriented.
2. Although originally considered, it was not important to the GIS after verification.
3. Cropland was found to be the only suitable value for consideration in after verification.

Figure 2-2. Decision matrix used to determine suitable turfgrass production sites.

Analysis of Soils Database

After standardizing the projection and storage of data files, the data sets were prepared for analysis in the context of the decision matrix. The SSURGO database manual, which includes units and definitions of variables along with "Landscape Spatial Data on the Web" by Mueller and Isukapalli (2002) and a detailed example by Parmenter (2001), provided a basis for interpretation of the SSURGO database. The SSURGO data provided by the USDA-NRCS-NSSC does not contain the links necessary for analysis; therefore it was necessary to develop a clear visual picture of the relationships between database tables. This process was based upon a join and relate tree that was constructed and applied to ArcGIS (Fig. 2-3). In order to implement the figure, links were created in the form of "joins" and "relates" in specific order through the ArcGIS interface. Database joins were performed first, and the data relates were performed from branches of the tree inwards.

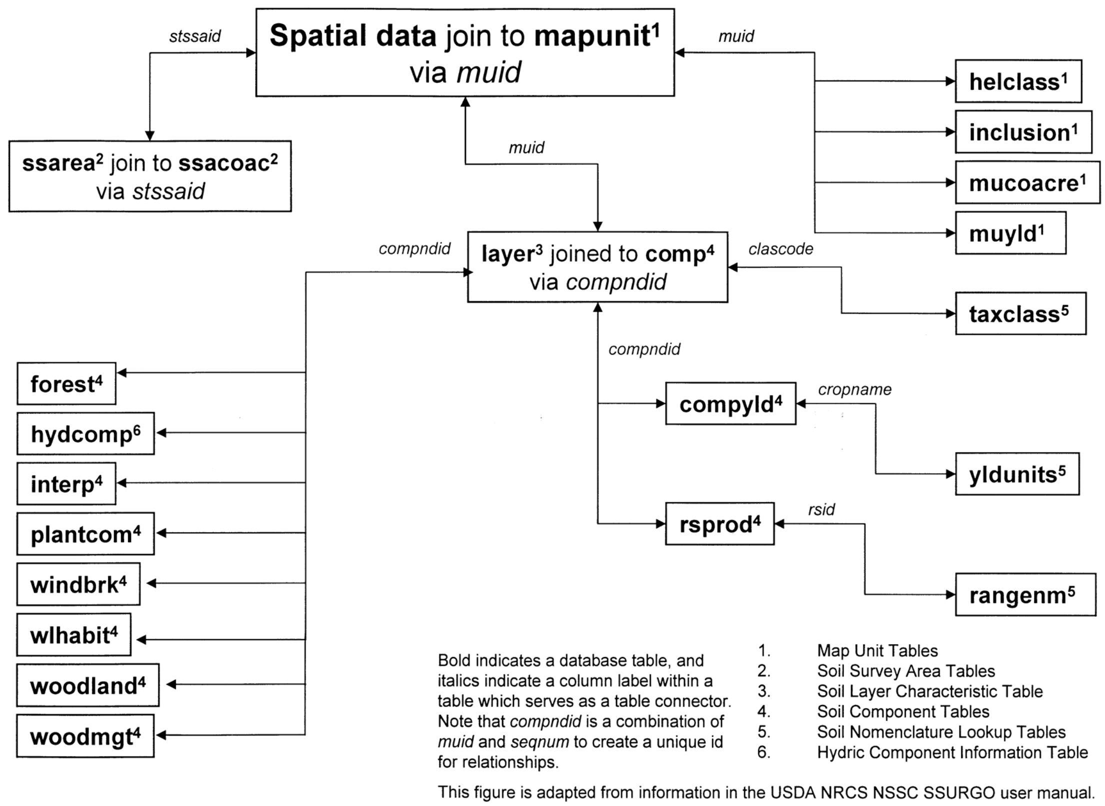


Figure 2-3. SSURGO database table relationships which were applied in the GIS analysis.

After organizing the SSURGO data tables for use in the GIS, a method was implemented to sort and identify appropriate soils for use in turfgrass production. ArcGIS uses the Structured Query Language (SQL) common to many large database software packages. ArcGIS does not require an extensive program in SQL, but rather, user-built query functions. These compound SQL functions based on the decision matrix were created to select soils according to a variety of parameters. Locations were selected based on the most important characteristics first (i.e. removing those locations which flood or are too rocky) and saved as a shapefile so that this new set could be queried further without the overhead of extraneous soils that were unacceptable for turfgrass production. Through further queries of this soils subset, the search was refined with respect to decision matrix features including available water capacity, drainage, slope, erodability, and topsoil thickness (Fig. 2-2). The land areas identified by this sort were compared to the original subset of acceptable locations from the SSURGO database.

Analysis of Urban and Governmental Lands

A critical sort criteria from the decision matrix included urban areas and state or federal lands. These locations are unacceptable for turfgrass production due to governmental laws and/or improvements that prohibited such uses. Because Erath County is primarily a rural county, only two cities (Dublin and Stephenville) required removal. No sizeable state or federal lands were found in Erath County. The urban and government lands were saved as a shapefile and then subtracted from the soils database.

Analysis of Land Use and Remaining Factors

After acceptable soils from the SSURGO database were identified and urban and governmental lands were removed, the search for suitable turfgrass production locations was further refined by eliminating areas based on the land usage and cover, as per decision matrix requirements. This was accomplished through the application of GIS spatial functions. In ArcGIS, the Spatial Analyst Extension was used to subtract those areas of unacceptable land use. Subtraction was accomplished by identifying those areas with acceptable land use characteristics and the intersection with acceptable lands in the

SSURGO database. The acceptable characteristics from the Anderson Level II data included types such as cropland and pasture, rangeland, herbaceous rangeland, and agricultural land. The result of this sort was a new data file of locations with appropriate land use and appropriate soil characteristics. Next, ArcGIS distance buffers were generated around streams, roads, and compost facilities. Distance buffers, a feature of ArcGIS, allow inclusion or exclusion of an area within a specified radius of a point or line. These buffers refined the set of potential locations.

As shown in the decision matrix, two thresholds of contiguous acreage were implemented in the GIS and used for analysis. The lower threshold, 40 ha, was a suggested economic breakpoint for turfgrass production (2-2). The higher threshold, 80 ha, was selected as a clear breakpoint in size of contiguous plots after inspecting the data for Erath County. These breakpoints were based upon an analysis of turfgrass producers within Texas (R.H. White, unpublished data).

Verification Process

The verification process included an initial ground-truthing of the selected production sites. Results of the initial survey were applied to refine database development before a final ground-truthing. Ground-truthing comprised a visual inspection of the selected sites by a field technician. The technician recorded land features, including current land use, rockiness, and slope for each accessible GIS-identified location for turfgrass sod production. The initial ground-truthing process revealed three major issues that were addressed during the verification process. These issues included 1) a need to refine the land use criteria, 2) a need to evaluate the slope of sites, and 3) a need to re-evaluate portions of the SSURGO soils data.

Existing selection processes were modified to account for trends in the verified data and address the needs identified during the verification process. Because ground-truthed data demonstrated that only one type of land use was verified acceptable for turfgrass production, all landuses other than cropland were eliminated from consideration. In addition, the ground-truthed data revealed slope was not adequately considered during the initial phase of the selection process. The National Elevation Dataset (NED) was applied during subsequent rounds of the selection process at a 1:24,000 scale and all lands with slope greater than eight percent were discarded. Shortcomings of the SSURGO data were visually evident during the initial ground-truthing. For example, SSURGO data indicated a Houston Black Clay soil series in the county, but ground-truthing revealed that these soils were rocky and did not exhibit favorable characteristics of a clay soil type. In addition, the Purves and a few minor soil series that were questionable prior to verification were too rocky for turfgrass production. Ground-truthing eliminated these sites from consideration. A second round of ground-truthing produced the final map and geospatial database that emerged from the verification process.

Results and Discussion

Constrained by the plan to use composted dairy manure, the GIS analyses resulted in a geospatial database containing locations of tracts of land suitable for turfgrass production on 40 and 80-ha tracts. The verification process, including ground-truthing, produced a final, verified geospatial database of suitable locations.

Identified Sites

As criteria were refined, and the verification process applied, the nature of identified sites for turfgrass production evolved (Table 2-2). The largely rural status of Erath County provided a presumable large land resource for agricultural production. As the GIS was applied to SSURGO soils data at the 40 ha minimum threshold for contiguous land area, 29% of the county appeared suitable for production. After applying the additional criteria including landuse, only 7.4% or the county appeared suitable (Table 2-2). Due to man-hour constraints, the 100 ac minimum threshold for contiguous area of suitable land was not ground-truthed.

At the 80 ha minimum threshold for contiguous land, results were obtained with an initial availability of 20.8% before consideration of landuse and 3.9% after inclusion of landuse in the GIS-identification criteria. This 80 ha threshold size was verified by ground-truthing and revealed only 0.7% of the county was suitable (Table 2-2). This is an 82% reject rate between the initial GIS-selected sites and the validated, ground-truthed sites.

Applying the information from the verification process, another iteration of GIS analysis was performed to identify suitable turfgrass production sites. This second iteration at the 80 ha threshold identified 102 sites totaling 6,616 ha or 2.3 % of Erath County suitable for production. After ground-truthing, 71 sites were verified totaling 5,219 ha and 1.8% of Erath County (Table 2-2). Only three sites were visually inspected and rejected as unsuitable for turfgrass sod production comprising a 3% reject rate, however, 28 sites were inaccessible by public roads and could not be visually verified. In all likelihood these sites should be consistent with the verified, ground-truthed results and be suitable for turfgrass sod production. This would amount to 6,477 ha suitable for turfgrass production comprising 2.3% of Erath County.

Table 2-2. Results of the GIS analysis for suitable turfgrass production sites under different evaluation criteria in Erath County, Texas.

Evaluation Criteria and Minimum Area	Number of Locations	Total Area (ha)	County Remaining (%)
Removal of cities, state, and federal lands	N/A	282,171	99.0
40 ha, soil data	705	82,648	29.0
40 ha, soil data and landuse	246	21,138	7.4
80 ha, soil data	289	59,378	20.8
80 ha, soil data, and landuse	71	11,065	3.9
80 ha, soil data, landuse and verified	13	1,884	0.7
Final GIS selection	102	6,616	2.3
Final GIS selection including inaccessable sites[1]	99	6,477	2.3
Final GIS selection and verified	71	5,219	1.8
Total area of Erath County[2]	N/A	285,099	100.0

1. Several sites were not accessable by public roads and were unavailable to be ground-truthed
2. This area is greater than the USDA SCS soil survey by 1.4% due to the UTM 14 projection

Distribution and Ground-Truthing

Figure 2-4 depicts the geographical distribution of selected sites for turfgrass production and the difference between maps before and after ground-truthing of GIS-identified sites. As shown at the 80 ha threshold (Fig. 2-4a), the quantity and distribution of sites were seriously impacted during the ground-truthing (Fig. 2-4b). The disparity between GIS-identified sites and verified sites lead to the procedures outlined in the verification process by which the results were analyzed and the GIS selection criteria were refined in terms of land use criteria, slope evaluation, and soils data. Upon applying the changes from the verification process, the second iteration of the GIS analysis determined the location of suitable turfgrass production sites as shown in Figure 2-4c. During the ground-truthing, only three potential sites were eliminated, although 28 sites were not ground-truthed due to man-hour constraints and inaccessible private roads. The resulting 71 verified sites, comprising 1.8% or Erath County, are presented in Figure 2-4d.

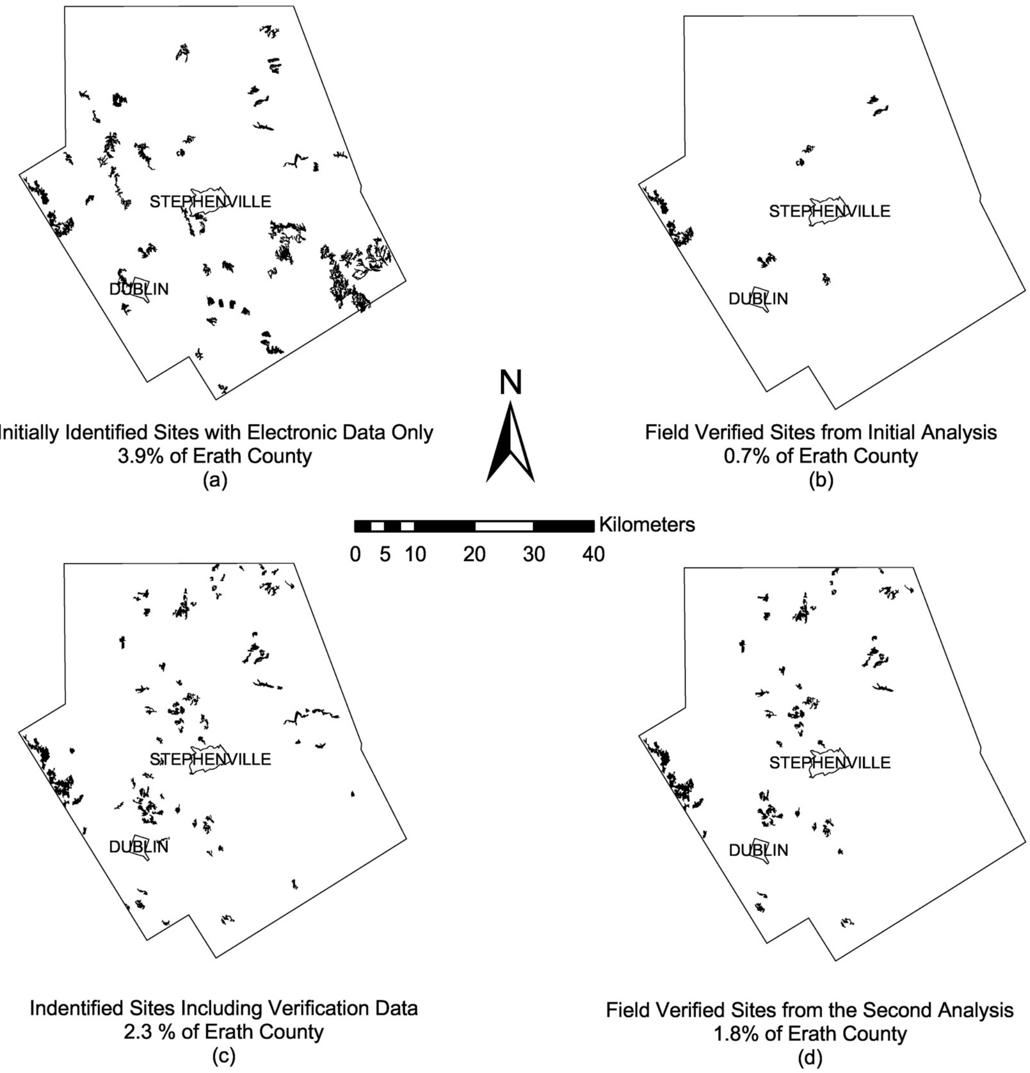


Figure 2-4. GIS-selected and field verified locations of potential turfgrass production sites in Erath County, Texas using an 80 ha threshold.

Predominant Soils

Since the selection of acceptable sites was initially based on soil characteristics, not soil taxonomy, the soil series for each GIS-selected site and the corresponding percent coverage in Erath County are presented in Table 2-3. Although the 40 and 80 ha thresholds share most of the same abundant soil series, the 40 ha threshold includes additional series which were not present in a large enough area to comprise many 80 ha sites.

Table 2-3. Percentage of GIS selected lands by major soil series for turf production in Erath County, Texas.

Soil Series	Initial GIS-Selected Sites (%)	Initial Verified GIS-Selected Sites (%)	Final GIS-Selected Sites (%)	Verified Final GIS-Selected Sites (%)
Blanket	1.0	5.7	5.8	3.9
Bolar	0.8	0.0	0.0	0.0
Duffau	0.9	5.2	5.1	13.2
Houston Black	35.9	0.0	0.0	0.0
Lewisville	6.3	6.5	6.5	13.4
Nimrod	10	53.7	53.7	27.3
Purves	32.2	0.0	0.0	0.0
Windthorst	6.8	28.9	28.9	26.7
Other	6.1[1]	0.0	0.0	15.5[2]

1. Other soils of low occurrence include: Denton, May, Venus, and Waurika
2. Other soils of low occurrence include: Chaney, Demona, Selden, Thurber, Truce, and Venus

Several of these soil series are more suitable turfgrass production than others such as Windthorst. Windthorst tends to have a low rockiness compared to the Purves series which appeared rocky during ground-truthing. Each have suitable properties for turfgrass sod production such as low rockiness, and ample topsoil depth (> 0.2 m) that were identified by the USDA Soil Conservation Service in cooperation with the Texas

Agricultural Experiment Station (USDA SCS, 1973). Most of the identified soils tend to have high percentages of sand and loam and less than eight percent slope.

Additional Consideration

In Erath County, data unavailable for analysis included digitized property boundaries (as opposed to paper records) from the county tax assessor office, the area of CAFO lagoon waste application fields, and the size of CAFO waste lagoons available for irrigation. At the time of this study, the property boundaries were not accessible in a digital format, and to make these data available in a digital format would have required a significant investment of time and resources. However, if these data were available, ownership boundaries of specific properties could have been identified along with the addresses. Sites identified through application of current criteria cross multiple parcels of land and boundaries of different owners. To have specific, singly-owned properties identified could ease land acquisition for purposes of sod production. Also, had delineated waste application field and lagoon data been available, a subset of highly usable turfgrass production sites could have been developed because most dairy wastes are currently applied to Coastal bermudagrass fields(*Cynodon dactylon*), which would generally indicate the land would be suitable for turfgrass production. In addition, land application sites with high nutrient levels in the soil could be remediated by topsoil removal with the turfgrass sod. Lagoons would also make a readily available source of irrigation water that would be high in nitrogen, thus, potentially reducing the need to apply commercial nitrogen with the manure compost. In all likelihood, many of these sites are contained within the selected output from this study, although they could not be identified specifically. Even though these data were not spatially available for analysis, a summary of waste application fields for the entire NBR watershed was obtained from TIAER (A. McFarland, unpublished data) and is provided in Table 2-4.

Table 2-4. Waste disposal fields within the North Bosque River watershed as of May 1999.

Application Type	Number of Fields	ha Mean	Total	Minimum	Maximum
Liquid	146	46	273	1	162
Solid	323	50	6596	1	577

Conclusion

The GIS mapping and analyses of diverse information sources were effective methods for identifying sites suitable for turfgrass sod production in Erath County. The verification process including ground-truthing of potential sites was essential in evaluation of GIS results and improvement of databases and GIS analyses. The ground-truthed data were used to identify weaknesses and develop refinements. These included the need to refine the land use criteria, to evaluate the slope of sites at a 1:24,000 scale, and to evaluate the SSURGO soils data to remove Houston Black Clay soil series from consideration.

After ground-truthing and a re-evaluation of the GIS analysis procedures, it became apparent that current land use and slope were more critical to identifying suitable locations for turfgrass production than the SSURGO soils data. As such, landuse and cover combined with an evaluation of slope and contiguous acreage were the most important factors in selection of sites for turfgrass production. SSURGO data does fulfill an important secondary role in decision-making for site selection after the aforementioned criteria. The SSURGO data provides general information regarding the soil series for sites under consideration, and this information is useful in further refining the site selections in the geospatial database. However, ground-truthing revealed several inaccuracies in the SSURGO data for Erath County such as the SSURGO-identified Houston Black Clay series which was not found to be present in the ground-truthed fields. These inaccuracies further emphasize the necessity of ground-truthing in development of the geospatial database. The selected and visually verified sites from this study comprise a geospatial database which forms a basis from which to pursue watershed-scale modeling to evaluate the potential water quality impacts of this suggested BMP in Erath County.

The sites identified within the geospatial database are suitable for potential turfgrass producers. These identified lands provide potential producers with a starting point from which to evaluate potential sites for turfgrass production. While not all parameters defined in the decision matrix were available for evaluation in this study, these features could be accessed and used for further evaluation by producers. With the 71 visually verified sites comprising 5,219 ha of Erath County, an ample supply of land has been identified for turfgrass sod production using composted dairy manure.

CHAPTER III

GIS AS AN AGRUCULTURAL PLANNING TOOL TO ESTIMATE P EXPORT THROUGH TURFGRASS SOD PRODUCTION

Synopsis

The North Bosque River watershed hosts a large portion of dairy production in Texas. In recent years, the Texas Commission on Environmental Quality (TCEQ), formerly known as the Texas Natural Resource Conservation Commission (TNRCC), has applied a Total Maximum Daily Load (TMDL) program for P in the watershed. This program directly affects dairy producers in the region. A best management practice (BMP) to help remedy the issue of excess manure P is the production of turfgrass sod using composted dairy manure. This BMP uses sod grown with composted dairy manure to transport manure P from the watershed in an economically sustainable means to reduce the nutrient loading within the watershed. Using a Geographic Information System (GIS) as a planning tool, a geospatial database of suitable turfgrass production sites was generated for Erath County, which encompasses a large portion of the watershed affected by the TMDL. Data provided through plot and field-scale studies of the recommended BMP contributed to development of this geospatial database in Erath County and to estimates of export values of manure P. Applying GIS as an agricultural planning tool yielded predictions for export of P from the county and a database to provide a method for locating turfgrass production sites. The suitability of GIS as a tool for large-scale planning in agriculture rather than the traditional role as software for precision agriculture was demonstrated.

Introduction

The North Bosque River watershed (Fig. 2-1) drains from a limestone plateau into Lake Waco, which provides flood control and drinking water for cities of Waco, Clifton, and several smaller municipalities with a combined population of more than 200,000 people (TNRCC, 2002). It covers approximately 32,000 ha in north central Texas (Adams and McFarland, 2001). The upstream portion of this watershed is located in Erath County, Texas, which contains nearly 85,000 of the estimated 100,000 milk cows within the North Bosque River watershed (Norvell, 1998). Water quality testing performed by the Texas Commission on Environmental Quality (TCEQ), formerly the Texas Natural Resource Conservation Commission (TNRCC), identified river segments within the upper North Bosque River watershed impaired by loading of soluble reactive P. A total maximum daily load (TMDL) program for P has been implemented to achieve "an average overall reduction of approximately 50% in soluble P average total-annual loading," (TNRCC, 2001).

Best management practices (BMPs) are needed to implement and achieve the P TMDL on a watershed scale (McFarland and Hauck, 1996). One suggested BMP is a system for export of manure P from an impaired watershed through turfgrass sod (Vietor et al., 2002b). This BMP offers dairies and other confined animal feeding operations (CAFOs) an opportunity for using and exporting P in composted dairy manure through production, harvest, and transplanting of a high-value commodity, turfgrass sod (Vietor et al., 2002a). This BMP benefits not only turfgrass producers and CAFO operators, but also urban consumers of sod produced with manure. Import of manure P with sod eliminates import and application of P fertilizer on a consumer's property within urban landscapes due to the slow release of P from composted manure. In addition, import of P in manure residue minimizes runoff from transplanted sod (Vietor et al., 2002b).

Acquiring compost will not be a challenge in this region. In Erath County, the headwater of the North Bosque River watershed (Fig. 2-1), a dairy manure composting infrastructure is available to supply potential demands of turfgrass producers. The infrastructure developed rapidly in response to a federal subsidy program for transporting manure from the dairies to composting facilities. Currently, the Texas Department of Transportation (TxDOT), the single largest consumer, purchases a portion of the compost in another subsidy program for application on construction projects (Moffitt, 2001).

Implementation of a BMP for exporting manure P through sod necessitates identification of suitable locations for turfgrass production within the North Bosque River watershed. In addition, potential exports of manure P through turfgrass sod needs to be quantified on a watershed scale to assess TMDL compliance. In this project, a Geographic Information System (GIS) was used as a planning tool to develop a geospatial database of suitable turfgrass production locations within Erath County. Erath County was selected because of its existing infrastructure for composting manure and predominance of dairy production in the North Bosque River watershed. In addition to mapping areas of available sites, field experiments were conducted to quantify the potential for P export per area unit of manure-produced sod.

Entry and integration of site-specific information and the experimental data through a GIS database provided a county-wide estimate of P export through the sod production system under optimal conditions. Application of GIS for watershed scale evaluation of BMPs is a departure from the traditional agricultural use of GIS for small, field scale, precision agriculture tool. The GIS application on a watershed scale for both policy and management decisions expands the scope of data used and adapted for this planning. Although watershed-scale models of water and nutrient transport practices are available, the utility of the models for support of producer decision has been limited (McCown, 2002). As watershed scale applications of GIS expand, new data searching and processing techniques and more advanced computing hardware will be required. This paper demonstrates through example of the turfgrass grown with composted manure BMP, the suitability of GIS as a planning tool for agriculture.

Materials and Methods

Computing Hardware and Software

Since GIS was applied in this case as a large scale planning tool for an entire county, computing hardware must be capable of processing large amounts of digital data. In typical cases of precision agriculture, computing needs are reduced for field-scale data sets compared to an entire county in this example. The computer system used in this case of countywide agricultural planning comprised of dual monitors, 78 GB of 10,000 RPM high speed SCSI storage, 1 GB of RAM, and a 2.2 GHz CPU. Dual monitors were necessary because of the large amount of data viewed simultaneously both graphically and in tabular form during evaluations of countywide databases. In addition, dual monitors allow display of GIS tools needed for calculations of slope and other variables.

The large size of countywide databases necessitated large amounts of RAM and high speed processing to access the stored databases and to perform calculations in a reasonable time-frame. High speed, large storage devices were necessary to support and maintain the databases on this large scale. Table 2-1 shows datasets used to produce the geospatial database, including associated storage requirements. The storage requirements represent only the amount required to keep and access the data. Processing of data files requires additional temporary storage and GIS and related software packages further increase space requirements. For example, depending upon data resolution, some calculations required up to 72 hours of computing time on this system. Such calculations included instances of intersecting and dissolving polygons to produce a new data layer, including slope calculations to produce the corresponding polygons.

For this project, the most recent commercial GIS platform, ArcGIS 8 by ESRI was selected because it was compatible with existing GIS data. Additionally, ArcGIS 8 is readily available as a GIS package for the desktop Personal Computer and works well with other Microsoft Windows software packages including spreadsheets and remote sensing software.

GIS Database Development

Although precision agriculture uses field-scale environmental and yield data, the GIS software packages can employ much larger data sets comprising land use, soil maps, networks of roads and streams. The county-wide GIS data files can be created through modification of existing digital databases, global positioning data, digitizing of existing maps, or capture of data from other software packages.

In the case of a system for the export of manure P through sod, GIS was used to develop a geospatial database of suitable turfgrass production locations within Erath County. This database was based on various environmental and production features including data for soil, land use and land coverage (LULC), surface hydrology, political and administrative boundaries, national elevation maps (NED), and aerial photography in the form of digital orthophoto quadrangles (DOQs). These data sets were obtained from government agencies including the US EPA, USDA, Texas Institute for Applied Environmental Research, Texas General Land Office, and Texas Natural Resources Information Service (Table 2-1).

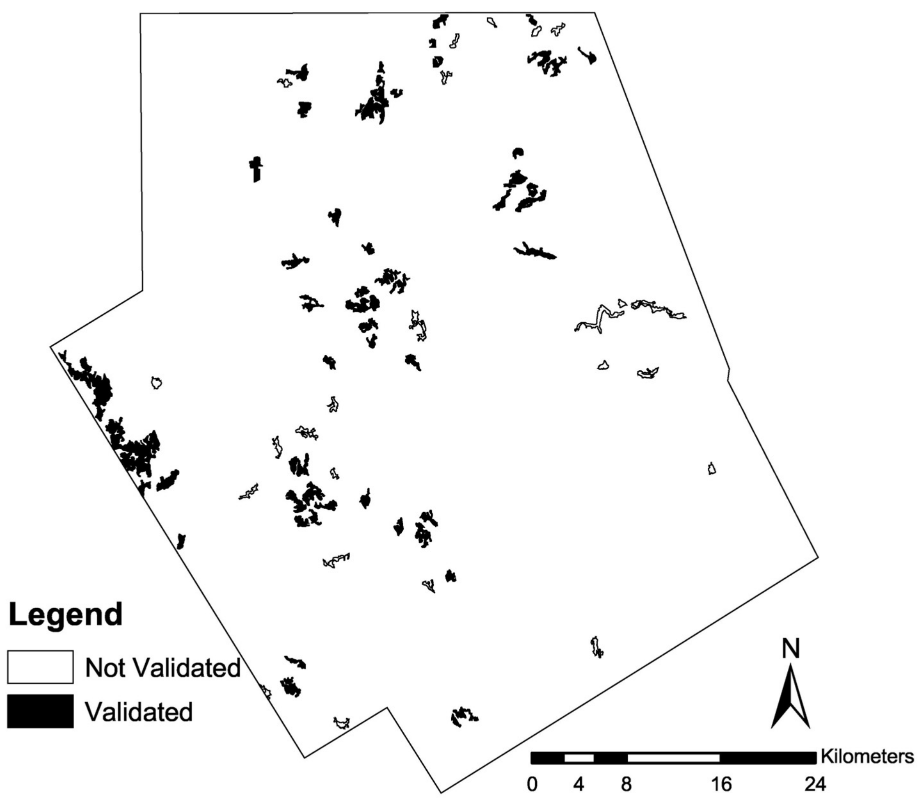
Development of the geospatial database was a multi-stage process requiring collection, processing, ground-truthing, and refinement of the aforementioned data as described by Hanzlik et al. (2003). Data was initially re-projected into a uniform Universal Transmercatur (UTM) Zone 14 projection for overlay on DOQs, which were produced in UTM 14 North American Datum 1983. The soils database was constructed from SSURGO soil survey data provided by the United States Department of Agriculture Natural Resources Conservation Service National Soil Survey Center (USDA NRCS NSSC). This soil data is available for natural resource planning at a scale from 1:12,000 to 1:24,000 (USDA NRCS NSSC, 1995). After suitable soils from the SSURGO database were identified, the search was further refined through elimination of urban and governmental lands, and application of land usage and cover data.

After development of the initial database, it was verified with DOQs and ground-truthed through visual surveys of desirable production sites. The feedback from ground-truthing identified needs for additional data which were addressed during the refinement process. For example, the NED was applied to calculate slope at a higher resolution. These slope data were intersected with LULC data to remove all locations classified as cropland except those with a slope less than or equal to eight percent.

The refined geospatial database identified suitable locations for turfgrass production based on combined subsets of data from the USDA NRCS SSURGO database, USGS Anderson Level II land classification data, NED calculated slope data, and distances to roads, streams, urban areas, composting facilities and dairies for Erath County. This allowed queries to determine total acreages based on characteristics including location, soil type, plot size, and any other database feature necessary for planning.

In addition to site locations based on the geospatial database, the total area available for sod production was quantified. A total of 6,615 ha were suitable for turfgrass production in Erath County (Hanzlik et al., 2003). Of these suitable sites, 2,643 ha met a minimum contiguous size of 80 ha, a suggested economic threshold for a turfgrass enterprise (R.H. White, unpublished data). A map revealed the geographic distribution of these suitable sites (Fig. 3-1). The sites in Figure 3-1 which were validated through ground-truthing by a technician are shown in black, while the sites that were inaccessible for on-site validation are shown in white. The close proximity of suitable sites is desirable for turfgrass sod production. An interested sod producer will be able to select geographical regions of the county in which several turfgrass fields could be located. The search to acquire land for production could be optimized to accommodate both short and long-term land requirements. In addition, a researcher can use the graphic representation to evaluate impacts of turfgrass sod produced with composted manure on P loading on the watershed. Specifically, potential sod acreages can be used to estimate P amounts exported through sod to evaluate the system for exporting manure P through sod on the scale of a watershed or county.

Figure 3-1. Suitable sites for turfgrass sod production in Erath County, Texas.



Runoff Plot and Turf Field Data

The GIS database and analysis were integrated with replicated field studies for countywide estimates of manure P export through sod (Vietor et al., 2002a). The field research compared turfgrass responses and P export through sod among different rates of composted dairy manure and supplemental N applied to Tifway bermudagrass (*Cynodon dactylon* L. X C. *transvaalenis* Burtt-Davey), 609 Buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.), and Reveille bluegrass (*Poa arachnifera* Torr. X *P. pratensis* L). Two manure rates (100 and 200 kg P/ha-yr) with and without supplemental inorganic N fertilizer were compared to recommend rates of inorganic fertilizer sources of P and N. The bermudagrass and buffalograss were established on a Boonville fine sandy loam in College Station, Texas. The bluegrass was established on a Windthorst fine sandy loam in Erath County, Texas. The results of the first sod harvest from turfgrass amended with manure were used to estimate P removal under the suggested BMP (Vietor et al., 2002a). A single sod harvest removed 50% of the manure P applied during production of bermudagrass sod with supplemental N. Current field studies are evaluating production practices that optimize turfgrass regrowth and minimize the duration between sod harvests.

Although manure P is exported through sod, the production sites are potential nonpoint sources of P in the watershed. Additional replicated studies evaluated potential runoff losses of manure P applied during turf establishment and production (Gaudreau et al., 2002, Vietor et al., 2002b). The replicated observations indicated concentrations of total dissolved P in runoff were up to five times larger for inorganic fertilizer than for manure P during runoff events shortly after P application on bermudagrass turf. Total runoff losses of P during bermudagrass sod establishment and production were comparable between surface applications of manure and inorganic fertilizer P. Therefore, the system for turfgrass production with composted dairy manure will contribute no more dissolved P to runoff than turfgrass produced with a traditional inorganic source of P (Gaudreau et al., 2002). In addition, use of manure P sources from within a watershed eliminates import of soluble P fertilizer to the watershed for turfgrass sod production.

The conservative estimate of manure P export comprises 50% removal of applied manure P in one sod crop per year (Vietor et al., 2002a). The percent export was estimated from sod grown with composted dairy manure rates of 200 kg P/ha-harvest and 400 kg P/ha-harvest (Vietor et al., 2002a). This estimated export of P is conservative compared to another study where 81% of the manure P was recovered from an application of 277 kg P/ha of manure P during bermudagrass sod production on a clay soil (Vietor et al., 2002b). The export per hectare can be combined with the geospatial database to estimate P removal from the Erath County portion of the North Bosque River watershed.

Expected Production Practices

The replicated field studies of composted manure use and export through sod provided examples of manure rates and turfgrass production practices. These examples were used to demonstrate GIS as a planning tool for estimating export of P from the county and watershed. Calculations assume the market for high-value turfgrass sod is sufficient to consume an increase in production from Erath County. The simplifying assumption is that all identified sites larger than 80 ha (totaling 2,643 ha) will be placed into production. According to a 1993 survey of the Texas turfgrass industry, 156 sod producers produced 8,707 ha of turfgrass sod (Lard et al., 1996). The estimated increase in Erath County would represent a 30% increase in turfgrass production within the state.

Tifway bermudagrass was chosen for the new sod production areas. The Tifway hybrid grows rapidly, is well suited to the climate, and is expected to provide three harvests during a two-year period under Texas conditions (R.H. White, unpublished data). While St. Augustine grass is popular in the homeowner market, the turf must be produced in southern Texas near the Gulf Coast to avoid low-temperature stresses during winter. The hybrid bermudagrass, which is used for sports fields, golf courses, and in some home markets, can be produced in Erath County's climate.

For the GIS analysis, the suggested application rates (100 kg P/ha-harvest and 200 kg P/ha-harvest) of composted manure are topdressed after each harvest and provide an excess of P for turfgrass production. In addition to the composted manure, supplemental fertilizer N must be applied monthly to turfgrass at a rate of 50 kg N/ha to promote optimal growth (R.H. White, unpublished data).

Results and Discussion

GIS Analysis of Manure P Export

The GIS-derived geospatial database was combined with experimental and production parameters for turfgrass sod in Erath County to estimate P export from the county. This estimate represents an upper potential for P removal through export of one sod crop from Erath County under optimal conditions. It is important to note that constraints of market demand have not been imposed on computations of potential sod and manure P exports.

Export was estimated for low (100 kg P/ha-harvest) and recommended (200 kg P/ha-harvest) manure rates for the dual purposes of sod production and P export. Export estimates can be interpreted in relation to manure P output of livestock. If a lactating dairy cow excretes 54 g of P daily, the annual cow equivalent for P in manure and urine is 19.7 kg (Van Horn et al., 1994). Under conditions of low application rate, 50% removal in each crop, 1.5 harvests per year, and supplemental N, 75 kg P/ha-yr would be exported. The turfgrass sod production would use composted diary manure from 7.6 cow/ha-yr and P export in sod would be equivalent to the P excreted by 3.8 cow/ha-yr. At the recommended application rate assuming 50% removal, 1.5 harvests per year, and supplemental N, 150 kg P/ha-yr would be exported in sod. Turfgrass sod production would consume manure from 15.2 cow/ha-yr and export P equivalent to 7.6 cow/ha-yr. If the proposed rates of manure P were applied to sites identified through GIS and verified visually as shown in Figure 3-1, total export from the county for each rate and set of production conditions can be calculated (Table 3-1). Under the recommended application rate, 528,000 kg P/ha representing 40,249 cows would be applied annually and 20,124 cow equivalents would be would be exported from Erath County.

Table 3-1. Calculated manure consumption under high and low manure application rates.

	Units	Low Manure Rate	Recommended Manure Rate
Application Rate	(kg P/ha-harvest)	100	200
Removal Rate	(%)	50	50
Harvests	(harvest/yr)	1.5	1.5
Annual Removal	(kg P/ha-yr)	75	150
Van Horn et al.	(kg P/cow)	19.7	19.7
Manure Applied	(cow equiv/ha-yr)	7.6	15.2
Manure Exported	(cow equiv/ha-yr)	3.8	7.6
Application Area	(ha)	2,643.0	2,643.0
Manure Applied	(cow equiv/yr)	20,124.4	40,248.7
Manure Exported	(cow equiv/yr)	10,062.2	20,124.4

Manure P losses in runoff and contributions to nonpoint source P loading can be computed similar to potential exports from the turfgrass production fields. For example, under worst case conditions for sod production (an 8.5% slope), 3.0 kg P/ha was lost in runoff during eight rain events. The runoff losses occurred after 100 kg P/ha was applied as composted dairy manure on bermudagrass turf (Gaudreau et al., 2002). Yet these losses contribute to P loading of stream and rivers only if the dissolved P is transported to a water body. Inclusion of another defining parameter, e.g. distance to streams or surface water, would quantify the area used to calculate potential P loading of water bodies in the county and surrounding watershed. At this rate of loss (3%) 6 kg P/ha could be lost due to runoff at the recommended application rate (200 kg P/ha).

Concluding Discussion

The hardware and software requirements of GIS for use in decision-making on a watershed scale will likely preclude use by individual turfgrass producers. It is expected that GIS will serve as a tool for consultants who advise turfgrass producers, policy-makers, and regulators who evaluate potential impacts of this BMP on nutrient loading and water quality of watersheds. In addition, the transparency of the GIS processes for integrating and analyzing spatial information contributes to improved communication and mutual understanding between the scientist/consultant and managers (McCown, 2002).

The GIS software and analysis allows researchers and agricultural and environmental planners to process data for entire counties (285,100 ha in the case of Erath County, TX) and allows producers a method of decision support to identify suitable sites for turfgrass sod production. Traditionally, producers have had few tools available other than real-estate infrastructure and ground-level exploration for identifying sites for turfgrass production. Through application of GIS as a planning tool, producers can view potential locations on a map and immediately refine their search for suitable lands. This can reduce the time and financial investment in searching for new land to produce on.

From the standpoint of environmental planning, GIS allows researchers, regulators, and concerned parties the ability to analyze agriculture on a large scale. In this case, estimates of P reduction could be calculated for Erath County based on existing studies and knowledge of production practices in conjunction with a geospatial database that identifies suitable sites for turfgrass production. As observed under optimal production conditions (Table 3-2), 20,124 cow-equivalents could be exported from Erath County through implementation of a system for exporting manure P through sod.

CHAPTER IV

CONCLUSIONS

The GIS mapping and analyses of diverse information sources were effective methods for identifying sites suitable for turfgrass sod production in Erath County. It is expected that GIS will serve as a tool for consultants to advise turfgrass producers, policy-makers, and regulators who evaluate potential impacts of this BMP on nutrient loading and water quality. As demonstrated through providing decision support to identify suitable sites for turfgrass sod production, the GIS software allows researchers and agricultural and environmental planners to process data on the countywide scale.

In the applied case of Erath County, using the initial ground-truthed data, weaknesses were identified and refinements to the process were implemented to produce a final geospatial database. This final geospatial database was based on refinements to the slope criteria and a re-evaluation of the SSURGO soils data. The sites from the final geospatial database were visually verified and are suitable for turfgrass production. These identified lands provide potential producers with a starting point from which to evaluate potential sites for turfgrass production. While not all parameters defined in the decision matrix were applied in the evaluation process of this study, these features could be accessed and used for further evaluation by individual producers. With 71 visually verified sites totaling 5,219 ha of Erath County, an ample supply of land was identified for turfgrass sod production using composted dairy manure.

Estimates of manure-P removed from the watershed were also calculated. These calculations demonstrate the ability of the suggested BMP to export large amounts of manure-P from the NBR watershed in Erath County. As observed under optimal production conditions, 20,124 cow-equivalents could be exported from the county through implementation of the system for exporting manure P through turfgrass sod.

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Hanzlik J.E., C.L. Munster, D.M. Vietor, and R.H. White. Application of GIS to Meet Phosphorus TMDL in North Bosque River, 2002 *ASAE TMDL Environmental Regulations Conf. Proc.*, Ft. Worth, TX, March 11-13, 2002.

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Additional publications in review

Selected Memberships
Alpha Zeta
ASAE – The Society for Engineering in Agricultural, Food, and Biological Systems
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