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A multi-model approach for sustainable agriculture in the US corn belt

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Abstract. *The goal of this three-year project is to identify, promote, and assist farmers in adopting integrated crop and livestock farming systems that reduce costs, minimize negative environmental impacts, increase market opportunities and increase profits for small and mid-size family farms. The project uses a holistic systems approach that evaluates six inter-related elements: economic impact, marketing opportunities, community impact, ecosystem impact, farmer adoption, and information transfer. This paper deals with ecosystem impacts of changes in land-use, crop rotations, and farm management. A number of existing simulation models for crop growth, livestock performance, soil erosion, nitrogen dynamics, tillage and manure management, and energy consumption are being used to evaluate impacts of alternative management strategies on indicators of ecosystem sustainability. Databases on soil and weather needed for these models are clustered and inter-connected by means of web-based interfaces. This paper describes the models to be integrated,*

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initial scenarios for future land-use, our approach to defining representative farms, the current status of the web based model development, and some results.

Keywords. crop models, soil conservation, livestock farming, sustainable agriculture, ecosystem, erosion control, simulation models, nutrients, landscape.

Introduction

Science-based mathematical models and computer simulation provide useful tools with which to determine biophysical consequences of resource management options at field, farm and regional scales. For a true systems analysis, such biophysical assessments need to be complemented by socio-economic analyses before they can define system benefits at any scale (Kropff et al., 2001). Kropff et al. (2001) describe three system approaches for designing more sustainable agricultural systems at farm and regional levels. Their first approach is to predict future land use by extrapolating current trends; second, hypothetical scenarios can be explored that might fit local or regional circumstances use options; and third is an evaluation of policies and their instruments that may encourage (or discourage) particular land use planning and decision-making. The approach described in this paper focuses on the second option, which explores possible future scenarios. We try to avoid the possible criticism that agro-ecological opportunities might be unrealistic by addressing socio-economic factors as well. Several studies have demonstrated the usefulness of this approach for policy-making (van Ittersum et al., 1998).

This modeling effort is part of a larger project whose goals are to identify, promote, and assist farmers in adopting integrated crop and livestock farming systems that may reduce costs, minimize negative environmental impacts, increase market opportunities and increase profits for small and mid-size family farms. The project uses a holistic systems approach that evaluates six interrelated elements: economic impact, marketing opportunities, community impact, ecosystem impact, farmer adoption, and information transfer. The ecosystem element focuses on land-use issues, potential soil erosion, and nutrient flows and emissions in two west-central Iowa counties (Crawford and Shelby) that lie within the Missouri River watershed. Erosion potential in both counties is high due to the prevalence of loess-derived soils and steep slopes. A key part of the project is to develop software that describes the particular interrelated processes, which have an effect on the entire ecosystem. This software will be used to evaluate a number of alternative land-use options including rotations containing perennial crops, including forages, and other perennial vegetation allocations, based on slope classification and proximity to surface water.

Many of the processes in crop and livestock production have been modeled already. Most of the models describe individual processes, limited system relationships, or are narrowly targeted as decision support systems. The importance of integrated system modeling has been addressed (Ahuja et al., 2002), and examples of integrated models for specific purposes exist, such as DAFOSYM (Rotz et al., 1989) and GPFARM (Ascough, 1995). However, no single existing model encompasses the broad constellation of sustainability indicators and measures defined for this study. We therefore decided to integrate several existing models in what may be referred to as a meta-model or model cluster. A major challenge to such an effort is the wide diversity of computer languages and the input/output structures used in such models. Most designers of model clusters use executable versions of the various models designed by others and let them interact using an ASCII-based interface. We have chosen instead to reprogram models from the source code and interconnect them in a web-based application that uses a formal database management system (DBMS) for data storage and as an input/output medium. This approach requires a more extensive programming effort, but once complete it will be scientifically and practically more flexible. An application running at a server over the internet has the advantage of easy access by users, such as farmers, natural resource and conservation specialists, fellow researchers, policy makers, teachers, and students. One concern with any cluster or secondary modeling approach is that improvements to the primary models must be incorporated. In our approach this will be done through reprogramming based on communication with the primary model developers, which will require ongoing vigilance and cooperation among all modeling groups.

This paper describes the models to be integrated, scenarios for future land-use, the current status of the project, and some initial results.

Materials and Methods

Our approach is four-fold.

1. Developing a web based model application, which we call I-FARM (http://evo.ae.iastate.edu/), that runs at the farm level, and that includes a number of existing models, as described below.
2. Defining a number of future land-use/farm management scenarios.
3. Defining a number of representative farms for northern states, with special consideration of the Loess Hills region of western Iowa.
4. Running the models for a number of scenarios applied to these representative farms and assessing possible implications for agricultural and community sustainability.

Models

Existing models use various databases or data file clusters on topography, soil, and weather. Data handling is not standardized. Therefore, we have chosen to use Microsoft SQL Server 2000 RDBMS to support the web application for both data storage for input, temporary storage during execution, and output. Display of graphical output will be designed using Microsoft Office XP Web Applications. The web interface at the client side is HTML, while the server calculations are being designed using ASP-VBScript. Large subroutines will be translated into .NET application for effective run-time processing.

The following models are currently being investigated for inclusion into the new application.

Crop growth models

Major development of mechanistic crop growth models is taking place in the United States, Australia, and The Netherlands. Jones et al. (2001) describe the history of the modeling work in the three groups. Most models developed by each group have been influenced by approaches developed by one or both of the other groups. Most have used the Fortran Simulation Translator, developed at the Wageningen Agricultural University in The Netherlands (Rappoldt and van Kraalingen, 1996). For our project we focus on the latest versions of the models that have been developed in the United States, knowing that a considerable part of the scientific content is in line with models developed in the two other ‘schools’.

CERES (Crop Environment Resource Synthesis, Ritchie et al., 1986) is a group of models that has a series of modules for growth simulation of various crops, with CERES-Maize of particular importance in our study. CROPGRO (Crop Growth, Boote et al., 1998; Hoogenboom et al., 1992) is a group of models that has a series of modules for the growth simulation of various legumes, with CROPGRO-SOYBEAN of particular relevance to our region. CERES and CROPGRO-models have been combined in the DSSAT (Decision Support System for Agrotechnology Transfer) framework (Tsuji et al., 1994) during the last decade. For the soil-water balance and plant water stress, one module has been incorporated to serve all crops within the DSSAT framework (Ritchie, 1998). DSSAT uses pre-processing software to generate input ASCII files for soil and weather data selection and farm management, and has Windows-based graphical output software. A stripped-down version of DSSAT is available as a web application. DSSAT uses a weather data generator called Weatherman. The soil data that come with the software are limited, but there are utilities to enter specific soil data related to specific experiment evaluations.

Erosion models

Three erosion models are being evaluated for inclusion in the model cluster. WEPP (Water Erosion Prediction Project, Alberts et al., 1987) is a widely accepted erosion model, available under Windows, and written in Fortran and C++. WEPP can be used for soil loss calculations on multiple hill slopes and small watersheds. WEPP uses a weather data generator, called Cligen (available at: http://horizon.nserl.purdue.edu/Cligen/).

We will also examine the use of EPIC (Environmental Policy Integrated Climate, Williams and Renard, 1985), an erosion model that has been widely implemented in other software packages. The model itself is known as a DOS program.

RUSLE2 (Revised Universal Soil Loss Equation) has mainly been developed by the University of Tennessee, and is a Windows based software package for hill slope erosion simulation.

Soil organic matter model

CENTURY (Soil Organic Matter Model, Parton et al., 1987) simulates carbon, nitrogen, phosphorus, and sulfur dynamics through an annual cycle over time scales of centuries. A producer sub-model provides the flexibility of specifying potential primary production curves representing the site-specific plant community. CENTURY was developed to deal with a wide range of cropping systems and tillage practices, and allows for systematic analysis of the effects of management and global change on productivity and sustainability of agro-ecosystems. The interface for the latest version is written in C++. The database management uses the netCDF library. A considerable part of the CENTURY model has been incorporated in DSSAT recently.

Livestock and manure models

Several models have been developed that generate livestock production predictions (and sometimes other impacts like nutrient flows, losses, etc.) that can have impact on the environment. ANIPRO (Animal Production) is a software package developed in The Netherlands. The model allows for indoor climate and energy consumption simulation for livestock facilities. ANIPRO has several modules being written in Delphi (Borland, 2002). ANIPRO-BEZOVA (Pigs Comfort Module, van Ouwerkerk, 1992) is a heat balance model at the animal level, which predicts the comfort zone of housed pigs. The model thus gives set points for climate control (heating, cooling, and ventilation). ANIPRO-MESPRO (Pigs Manure Module, Aarnink et al., 1992) is a manure production model that predicts the volume flow and composition of feces and urine excreted by fattening pigs, depending on their diet and thermal conditions. ANIPRO-GASPRO (Pigs Gas Production Module, van Ouwerkerk and Aarnink, 1992) is a model that estimates the gaseous release of fattening pig compartments with respect to manure storing conditions (time and temperature).

For the pigs' performance depending on feed uptake we will include the Life Cycle Swine Nutrition model, developed at Iowa State University (Holden et al., 1996).

For dairy cattle we will explore the DAFOSYM model described below. Diet modeling for dairy cattle has been done by various institutions. Kohn et al. (1998) describe three protein requirement balance models for dairy cows: (1) the model developed by the National Research Council (NRC), (2) the Cornell Net Carbohydrate and Protein System (CNCPS), and (3) Molly (Baldwin et al., 1977).

Water quality models
RZWQM (Root Zone Water Quality Model, Ahuja et al., 2000) simulates major physical, chemical, and biological processes in an agricultural crop production system. It is a one-dimensional (vertical in the soil profile) process-based model that simulates the growth of the plant and the movement of water, nutrients and agro-chemicals over, within and below the crop root zone of a unit area of an agricultural cropping system under a range of common management practices. The model includes simulation of a tile drainage system.

SWAT (Soil & Water Assessment Tool, http://www.brc.tamus.edu/swat/, Shanthi et al., 2001) is a river basin scale model, developed in Texas, to quantify the impact of land management practices in large, complex watersheds. Another model is AGNAPS (Agricultural Non-point Source Pollution Model, Young et al., 1987) that describes soil movement in most forest-dominated watersheds. We do not know yet if we need to explore these two models for our purposes.

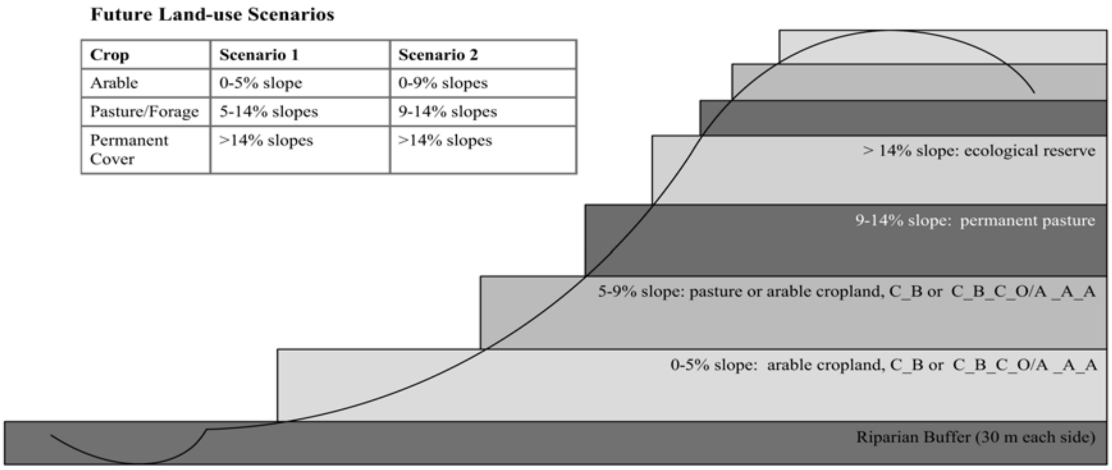
Whole farm/ranch management support systems
GPFARM (Great Plains Framework for Agricultural Resource Management, Ascough, 1995), developed by the Great Plains System Research Unit (USDA-ARS) and the Colorado State University, is a farm/ranch simulation model that produces output for various agricultural production systems and management options with respect to economics, environmental impact and sustainability.

DAFOSYM (Dairy Forage System Model, Rotz et al., 1989), developed by the Pasture Systems and Watershed Management Research Unit, a USDA-ARS institution in Pennsylvania, simulates the performance and economics of a dairy farm over multiple years of weather. The simulation includes the growth, harvest, handling and storage of alfalfa, grass, corn, small grain and soybean crops. Farm produced feeds are supplemented with purchased feeds to meet a given level of production for a dairy herd. Manure is returned back to the land where nutrients are lost, accumulated in the soil or used in crop production.

Future land-use and farm management scenarios

Crawford and Shelby counties are found in the Loess Hills region of west-central Iowa, where most of the soils are highly erodible. Long fallow field periods (winters) and tillage practices associated with annual crop production cause considerable soil loss on sloped fields. Analysis of crop data layer information (NASS, 2002) indicates that more than two-thirds of the land area in each county is in arable crops, with the vast majority (95%) of that area occupied by corn and soybean. Very small amounts of the arable land are used for oat, wheat, and alfalfa production. The NASS crop data, combined with the National Elevation Dataset (USGS, 1999), reveals that approximately 55% (135,000 ha) of the row crops grown in Crawford and Shelby counties are produced on slopes >6% and about 35% (78,000 ha) of the row crops are grown on slopes >9%. About a tenth of the land area in each county is in cool season grasslands used for pasture and hay and another tenth is in warm season grasses and perennial forbs. The counties also contain about 300,000 hogs and 150,000 cattle.

We are currently developing simulation models to examine how several alternative land-use scenarios would affect vegetation, erosion rates, and nutrient dynamics in Crawford and Shelby counties. Figure 1 depicts two examples of these scenarios which explore what happens if (1) surface waters are buffered by 30-m-wide strips of perennial vegetation; (2) arable crop rotations for areas with 0-5% slopes are extended beyond the typical two-year corn-soybean sequence (C_B) to a six-year corn-soybean-corn-oat/alfalfa-alfalfa-alfalfa sequence (C_B_C_O/A_A_A); (3) areas with 5-9% slope are covered with a mixture of pastures and arable crops; (4) areas with 9-14% slopes are used for pasture, hay, or biomass energy crops; and (5) areas with slopes >14% are placed in ecological reserves used for sustainable wood and other tree crop production, biomass production, recreation, and other activities with minimal potential for environmental damage.



Future Land-use Scenarios

Crop	Scenario 1	Scenario 2
Arable	0-5% slope	0-9% slopes
Pasture/Forage	5-14% slopes	9-14% slopes
Permanent Cover	>14% slopes	>14% slopes

Figure 1 Slope-based cropping scenarios

Table 1 shows the potential distribution of land use from two alternative scenarios; 1) fields with 0 – 5% hill slopes used as arable land, and 2) fields with 0 – 9% hill slopes used as arable land.

Table 1. Changes in land use in Crawford and Shelby County in alternative cropping scenarios (ha)

	Current land use (2001)	Scenario 1 0 – 5% slopes as arable land		Scenario 2 0 – 9% slope as arable land	
			Change		Change
Arable	270,276	73,630	-196,646 (-72%)	176,096	-94,180 (-35%)
Pasture/Forage	33,851	191,538	+157,687 (+565%)	95,585	+61,734 (+280%)
Permanent Cover	8,854	8,854	0	8,854	0
Artificial (roads and buildings)	25,349	25,349	0	25,349	0
Ecological reserve		32,489	+32,489	32,489	+32,489

For Scenario 1, 70% of the current arable land would be converted to pasture and ecological reserve and for Scenario 2, 35% of the current arable land becomes pasture and ecological reserve.

Effects of changing land use on livestock numbers and associated fertilizer replacement

We are also exploring relationships between crop and pasture productivity, swine and cattle numbers, manure production, and nutrient cycling through manure application. We are particularly interested in defining the characteristics of integrated crop and livestock systems that have minimal requirements for imported, purchased nutrients and maximal ability for nutrient and soil retention. The current number of farm animals kept in the two counties is given in Table 2.

Table 2. Number of farm animals in two west-central Iowa counties in 1992 and 1997 (USDC, 2000)

	Crawford		Shelby	
	1992	1997	1992	1997
Beef cows	19272	20667	10986	12117
Milk cows	668	1031	324	401
Cattle and calves (sold)	47748	48535	36781	37856
Hogs and pigs (inventory)	179383	181594	119133	194906
Sheep and lambs (inventory)	3002	4767	2109	5050

Swine production is typically dependent on abundant supplies of annual grains, especially corn and soybeans, whereas ruminants can be raised on varying ratios of grain or pasture/forages. The number of grazing livestock (beef and/or dairy) that can be raised on a larger area of pasture will increase if arable land were converted to pasture. Most of the current beef cattle are grain finished in feedlots to achieve US market criteria, although new breeding programs show promise for high quality grass-finished beef. Potential changes in land use and thus feed availabilities could therefore affect the species distribution of livestock, the number if individuals of each species, and the ratio of grass-fed versus grain-fed beef cattle. Such changes would have significant impact on local economic development and, should these scenarios be widely adopted, on national markets and prices. These additional impacts will be evaluated through complementary socioeconomic models and policy analysis.

Nitrogen balance at the county level

Information as to exactly where manure is applied, on which soils, and for which crops, is not available and must be estimated based on knowledge of existing agricultural practices. We assume that most of the livestock manure is being applied within the county of origin. Table 3 estimates the sources of nitrogen applied in two Counties in 1997.

Table 3. Nitrogen available in two counties in 1997 (kg)

	Crawford	Shelby
Fertilizer N (Lorentz, 1997)	12601205	11940801
Manure N (ISU, 1999; Lander et al., 1998; USDC, 2000)	1595467	1094590

Future modeling work should be able to simulate the long-term dynamics of the nitrogen balance for the whole farm system, including dinitrogen fixation by legumes (especially forage species such as alfalfa and clovers), the possible nitrogen release to air (volatilization) from livestock facilities and cropland, and leaching into deeper soil layers and ground water.

Representative farms

Modeling alternative agricultural landscapes from a farm perspective will be useful for individual farm owners and operators. In order to extend this research to larger areas, it may be useful to examine groups of farms. Our strategy for farm scale analysis includes (1) creating maps at county scale based on ownership boundaries and including that information in assessments of current and 'future' land-use, and (2) defining a number of farm types that represent the current agricultural activity in the region, and (3) using those representative farm types as input for modeling with I-FARM, grouping and scaling the results appropriately. Each farm type should have the following entities:

- number of distinctive fields
- field soil type
- field surface area
- field slope category

Results

Current status of I-FARM

The web application I-FARM (http://evo.ae.iastate.edu/) is still in the early stages of development. The linked database includes the observed and generated weather data for 100 years of about 90 weather stations throughout Iowa and a soil database containing 2,200 soils that can be found in Iowa.

The specific soils in Crawford and Shelby County are given in Table 4.

Table 4. Soils in Crawford and Shelby

Soil Series Name	Present in			Composition of top layer (%)			
	Crawford	Shelby		Clay	Sand	Silt	Organic matter
Dow	X			21.5	28.2	50.3	2.5
Ida	X	X		21.5	28.2	50.3	1.5
Judson	X	X		25.5	26.8	47.7	4.5
Kennebec	X			24.5	28.5	47.0	5.5
Marshall	X	X		26.0	26.7	47.3	3.5
Minden		X		25.5	26.8	47.7	4.5
Monona	X	X		23.5	27.5	49.0	1.5
Napier	X			23.5	27.5	49.0	3.5
Nodaway	X			22.5	27.2	50.3	2.5
Salida	X			10.0	80.7	9.3	0.8
Shelby	X	X		31.0	43.7	25.3	1.5
Sparta	X			6.5	74.6	18.9	1.5

The ANIPRO modules on comfort zones, manure production, gaseous releases, and energy consumption for heating for fattening pig facilities have been incorporated.

Shown below are results of a simulation example for a unit with 240 fattening pigs over a year. The excreted manure nitrogen per animal over time is shown in Figure 2, while Table 5 indicates the mass balance of the pig unit.

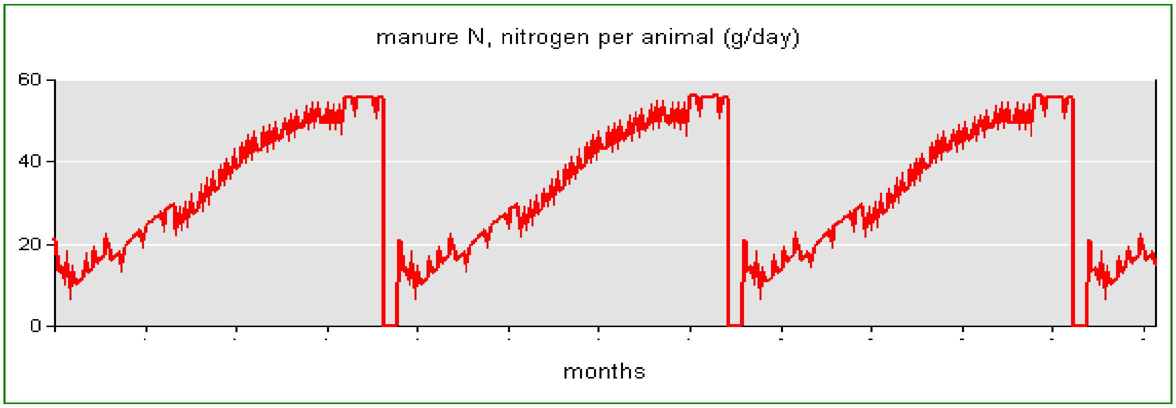


Figure 2 Simulated manure nitrogen excretions for fattening pigs at a growing rate of 750 g/day.

Table 5. Simulated mass balance of a 240 head hogs unit (kg per year)

In		Out			
Animals	23328	Animals	77040		
Feed	186405	Manure	365473	→ where N	2846
Drinking water	447372			P	682
		Water vapor	80079	K	1886
Oxygen	95688	Carbon dioxide	229189		
		Ammonia	726		
		Methane	286		
Totally	752793		752793		

Ongoing work focuses on integrating parts of DSSAT and WEPP into I-FARM. At a later point in time forage and cattle models and water quality models will be incorporated.

Current process to define representative farms

Digital parcel ownership data are available for Crawford and Shelby counties (NSTL, 2003; Shelby, 2002) and were used to create a framework for examining 'representative farms'. Ownership parcels were aggregated by owner, and parcels larger than 8 ha were selected to represent farms. Current and future land-use data were classified into 4 general land-use categories (arable, pasture/forage, permanent cover, and artificial) and used to determine the dominant land-use for each farm. Figure 3 depicts the results of the generalization process for Crawford County. Current (2001) land-use patterns show most of the land as arable land. In a 'future' land-use scenario a large portion of the land is converted to pasture and permanent cover**.** This process provides an opportunity to stratify the county's farms to allow for selection of a representative sampling for modeling purposes.

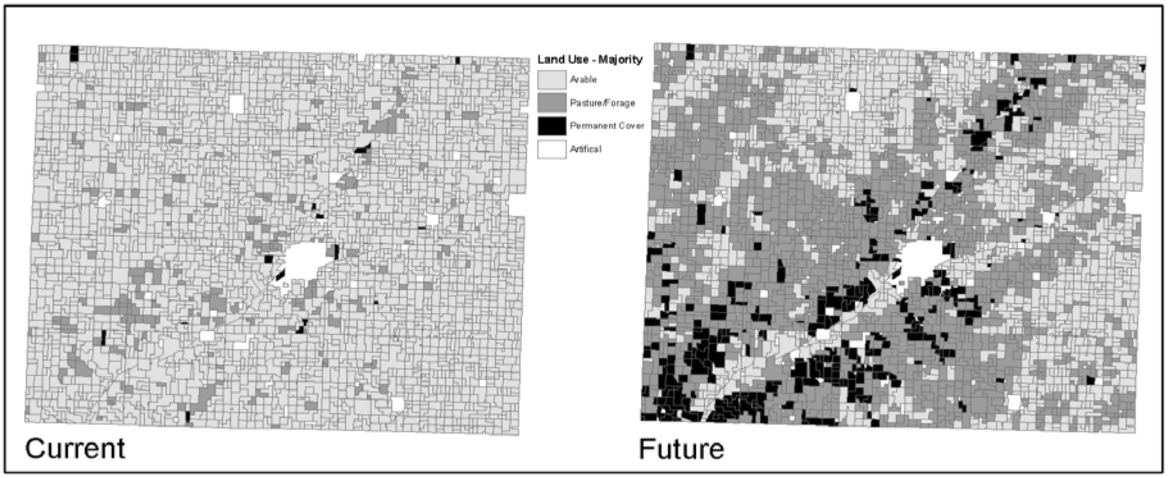


Figure 1 Representative farms in Crawford County, west-central Iowa.

We do not know yet how many farm types will be defined and how many of these farms could cover the two counties. The farms thus defined will be the input for modeling with I-FARM, using the described crop rotations (2-year annual crop rotation vs. 6-year extended annual and perennial crop rotation). Other input will include tillage practices, and the number of livestock on the farm. The resulting simulations will be used to evaluate optimal nutrient and energy balances, requirements for commercial fertilizer application, soil loss due to erosion, and environmental damage to runoff water, ground water, and air.

Conclusion

The modeling environment under development will be able to simulate different land use and management practices and predict effects on soil erosion, nitrogen losses, and carbon sequestration.

More detailed spatially distributed studies should indicate whether there are possibilities to replace considerable amounts of commercial fertilizers by animal manure and fixation by leguminous crops. In the future the model can be used to explore various environmental problems related to agriculture. We hope it will play a role towards sustainable farm development and support planning and policy analysis to benefit farmers, their communities and the environment.

References

Aarnink, A.J.A., E.N.J.v. Ouwerkerk, and M.W.A. Verstegen. 1992. A mathematical model for estimating the amount and composition of slurry from fattening pigs. *Livestock Production Science* 31:133-147.

Ahuja, L.R., L. Ma, and T.A. Howell. 2002. *Agricultural system models in field research and technology transfer.* Lewis Publishers, Washington, D.C.

Ahuja, L.R., K.W. Rojas, J.D. Hanson, M.J. Shaffer, and L. Ma. 2000. Root Zone Water Quality Model. Available by USDA Great Plains System Research Unit. Available at: http://gpsr.ars.usda.gov/products/rzwqm.htm.

Alberts, E.E., C.S. Holzhey, L.T. West, and J.O. Nordin. 1987. Soil Selection: USDA water erosion prediction project (WEPP). Paper No. 87-2542, Am. Soc. Agric. Eng., St. Joseph, MI.

Ascough, J.C. 1995. The GPFARM decision support system for the whole farm/ranch management. Great Plains Agricultural Council Publication No. 154 and Information series No. 79. Colorado Water Resources Research Institute, Fort Collins, CO.

Baldwin, R.L., L.J. Koong, and M.J. Ulyatt. 1977. A dynamic model of ruminant digestion for evaluation of factors affecting nutritive value. *Agric. Systems* 2:255-275.

Boote, K.J., J.W. Jones, G. Hoogenboom, and N.B. Pickering. 1998. The CROPGRO model for grain legumes. In *Understanding Options for Agricultural Production,* 99-128. G. Y. Tsuji, et al., eds. Kluwer, Dordrecht, The Netherlands.

Borland. 2002. Delphi Professional Studio, developer software suite. Release version 7. Borland Software Coorporation. http://www.borland.com/delphi/.

Holden, P., R. Ewan, M. Jurgens, T. Stahly, and D. Zimmerman. 1996. Life Cycle Swine Nutrition. PM-489. Iowa State University Extension, Ames, IA.

Hoogenboom, G., J.W. Jones, and K.J. Boote. 1992. Modeling growth, development, and yield of grain legumes using SOYGRO, PNUTGRO, and BEANGRO: a review. *Trans. ASAE* 35:2043-2056.

ISU. 1999. General Guide for Crop Nutrient Recommandations in Iowa. Iowa State University Extension, Ames, IA.

Jones, J.W., B.A. Keating, and C.H. Porter. 2001. Approaches to modular model development. *Agric. Systems* 70:421-443.

Kohn, R.A., K.F. Kalscheur, and M. Hanigan. 1998. Evaluation of Models for Balancing the Protein Requirements of Dairy Cows. *J Dairy Sci* 81:3402-3414.

Kropff, M.J., J. Bouma, and J.W. Jones. 2001. Systems approaches for the design of sustainable agro-ecosystems. *Agricultural Systems* 70:369-393.

Lander, C.H., D. Moffitt, and K. Alt. 1998. Nutrients available from livestock manure relative to crop growth requirements. Working Paper 98-1. U. S. Department of Agriculture, Natural Resources Conservation Service, Resource Assessment and Strategic Planning.

Lorentz, D. 1997. Estimates of Fertilizer and Nutrient Sales by County - Iowa, USGS, in press.

NASS. 2002. Cropland Data Layer, a crop-specific digital data layer for Iowa in 2001. Available by United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), Research and Development Division, Geospatial Information Branch, Spatial Analysis Research Section. Available at: http://www.nass.usda.gov/research/Cropland/SARS1a.htm.

NSTL. 2003. Personal communication with M.R. Burkart. National Soil Tilth Laboratory, Ames, IA.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51:1173-1179.

Rappoldt, C., and D.W.G. vanKraalingen. 1996. The Fortran Simulation Translator, Introduction and Reference Manual. In: Quantitative Approaches in Systems Analysis No. 5. C.T. de

Wit Graduate School for Production Ecology. Release 2.0. Wageningen University, Wageningen, The Netherlands

Ritchie, J.T. 1998. Soil water balance and plant water stress. In *Understanding Options for Agricultural Production,* 41-54. G. Y. Tsuji, et al., eds. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Ritchie, J.T., D.C. Godwin, and S. Otter-Nacke. 1986. CERES-Wheat: A Simulation Model of Wheat Growth and Development, CERES Model description. Department of Crop and Soil Science, Michigan State University, East Lansing, MI.

Rotz, C.A., D.R. Buckmaster, D.R. Mertens, and J.R. Black. 1989. DAFOSYM: A dairy forage system model for evaluating alternatives in forage conservation. *J. Dairy Sci* 72:3050-3063.

Shanthi, C., J.G. Arnold, J.R. Williams, W.A. Dugas, R. Srinivasan, and L.M. Hauck. 2001. Validation of the SWAT Model on a Large River Basin with Point and Nonpoint Sources. *Journal of the American Water Resources Association* 37:1169-1188.

Shelby. 2002. Personal communication. Shelby County Assessor's Office.

Tsuji, G.Y., G. Uehara, and S. Balas. 1994. DSSAT. Release 3. University of Hawaii, Honolulu

USDC. 2000. Census of Agriculture, 1997. U.S. Summary and Country Level Data. U.S. Dept. Commerce, Bureau of the Census. Geographic Area Series 1b. Washington, DC. 1 CD-ROM.

USGS. 1999. National Elevation Dataset. Available by U.S. Geological Survey (USGS), EROS Data Center. Available at: http://gisdata.usgs.net/NED/default.asp.

van Ittersum, M.K., R. Rabbinge, and H.C.V. Latesteijn. 1998. Exploratory land use studies and their role in strategic policy making. *Agric. Systems* 58:309-330.

van Ouwerkerk, E.N.J. 1992. Modelling the heat balance of pigs at animal and housing levels. In *Second report of the CIGR working group on Climatization of Animal Houses,* 1-17. 2 ed. IWONL, State University of Ghent, Ghent, Belgium.

van Ouwerkerk, E.N.J., and A.J.A. Aarnink. 1992. Gas production of fattening pigs. AgEng '92 Conference Paper 9202 07, Uppsala, Sweden.

Williams, J.R., and K.G. Renard. 1985. Assessment of soil erosion and crop productivity with process models (EPIC). In *American of Agronomy, Soil Erosion and Crop Productivity,* 68-102. R. F. Follett and B. A. Stewart, eds., Madison, WI.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1987. AGNAPS, Agricultural Non-Point Source Pollution Model; A Watershed Analysis Tool. Conservation Research Report 35. USDA, Washington, DC.