Coupling Bioenergy Production and Precision Conservation: a Spatially Distributed Modeling Approach

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6 October 2008

Houston, TX

Improving Life through Science and Technology

Outline

- **Introduction**
  - Bioenergy and Precision Conservation
  - models in plots, watersheds, and now farms
- **Objective**
- **Methods**
  - farm and landscape description
  - the model APEX
  - benchmark cropping systems
- **Results**: average and spatially distributed effects
  - grain and biomass yield
  - erosion, sediment yield, nitrogen losses
- **Concluding remarks**

Introduction

- **Precision Conservation** encompasses a set of technologies and procedures to implement conservation management considering the spatial and temporal variability across natural and agricultural systems[1]
  - apply conservation measures when and where needed
  - increase the return in conservation per investment unit

- **Bioenergy crops and bioenergy cropping systems**
  - intensification of residue extraction from current systems
  - introduction of new crops
  - re-discovery of old and design of new rotations
  - design of landscape-based rotations

[1] Berry J.R. et al., 2003. J. Soil and Water Conservation 58:332-339.

Introduction

- **Homogenous, field-scale**
  - cropping systems research
  - cropping systems models EPIC, CropSyst, RZWQM, APSIM,…
  - crop models DSSAT-group, Sirius, Sucrose …
  - other models, Roth-C, Century, SoilN …

- **River basin-scale models**
  - SWAT, …

- **Linking field- to farm- and small watershed-scales**
  - **APEX**

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Objectives

- Estimate, using a simulation model, the productivity and environmental impact of a virtual farm with different combinations of simple cropping systems in each landscape position

- Provide a robust quantitative assessment of **onsite** and **offsite** environmental impacts for each system considering their spatial distribution

  - For this presentation we focused on grain and biomass yield, erosion, and to a minor extent, on N losses

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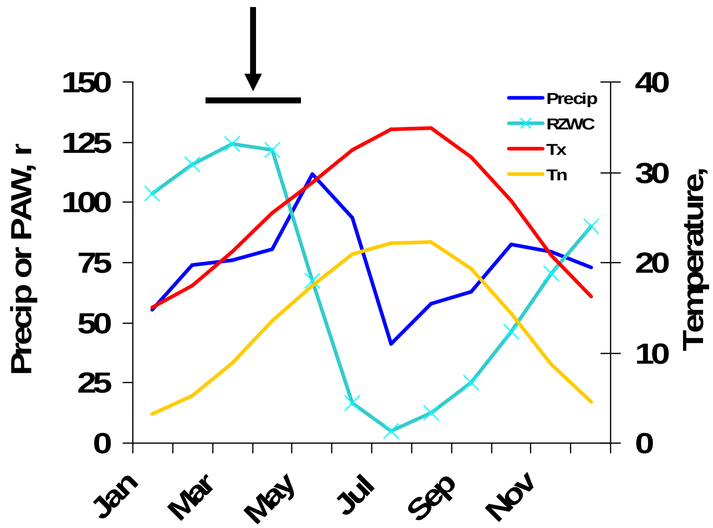
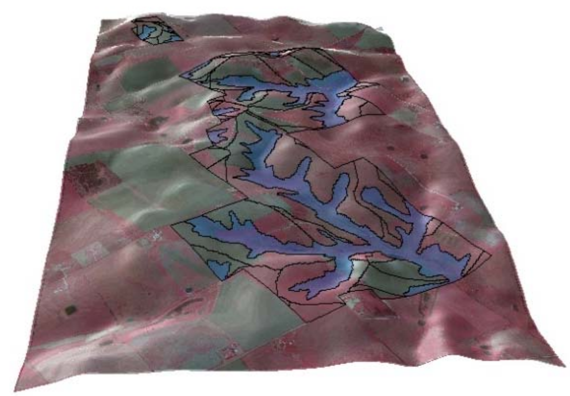
Methods – farm description

- 340-ha USDA-ARS experimental farm in the Blackland Prairie of Central Texas (Riesel)
- Clay soils (montmorillonitic)
- Average temperature ~19° C
- Precipitation ~900 mm/yr (spring / fall)
- ET_o ~2000 mm/yr
- Land use continuous cropping (corn / sorghum / wheat / oats) and bermudagrass
- Erosion control is a priority

- USDA-ARS has a long-term database of this farm's hydrology and erosion





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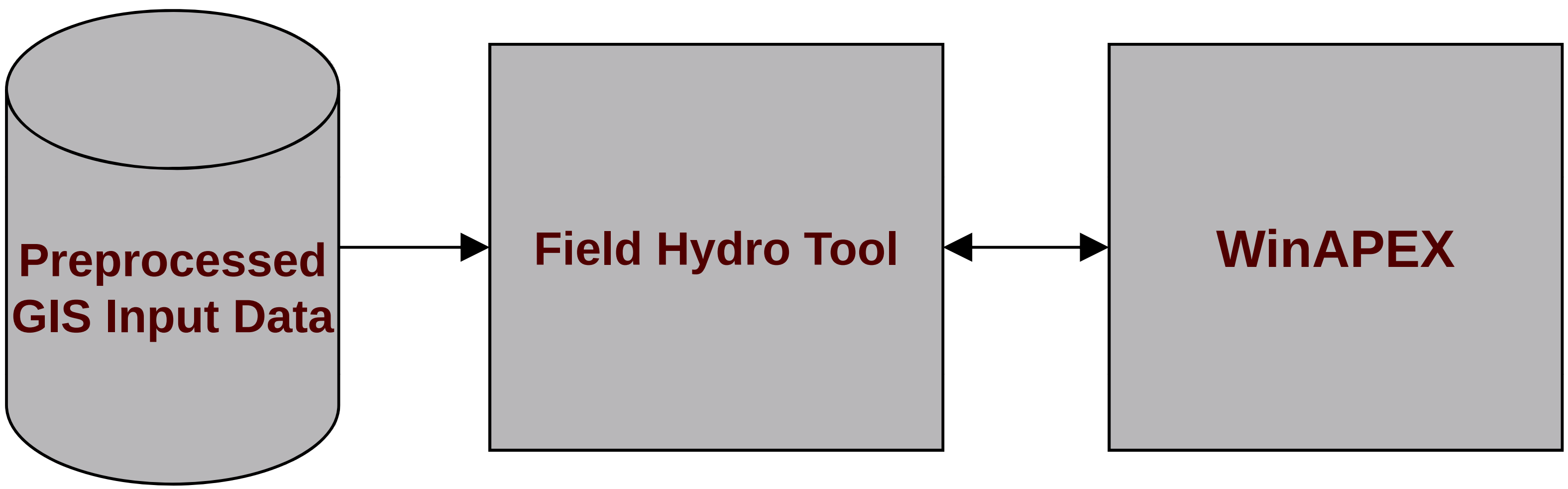
Methods – Landscape Segmentation

- The **Field Hydro Tool** executes a sequence of processes within ArcGIS 9.2 to subdivide a farm into hydrologically connected sub-areas based on terrain attributes. It renders a spatially indexed set of parameters for upland and lowland sub-areas used as inputs in the **APEX** model



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Methods – simulation model

- **APEX**: a model for assessing crop and soil processes in micro-catchments or farms. It runs on a daily time-step and computes the soil water balance, the nutrients and soil carbon balance, crop growth, the removal and transport of sediments and other components in water, the export of nutrient with harvest and other net removals, and the impact of tillage practices and structural conservation practices on hydrology and soil properties

Methods - scenarios

- corn- corn continuous cropping under reduced-tillage
- corn-wheat continuous cropping (one crop per year)
- switchgrass entire farm
- corn-wheat upland / switchgrass in lowland
- switchgrass upland / corn-wheat in lowland

  - Tillage: three operations + seeding + harvest
  - Fertilizer: corn 110 kg N/ha 25 kg P/ha
    wheat 70 kg N/ha 20 kg P/ha
    switchgrass 70 kg N/ha

Outputs provided are the average of 100 years

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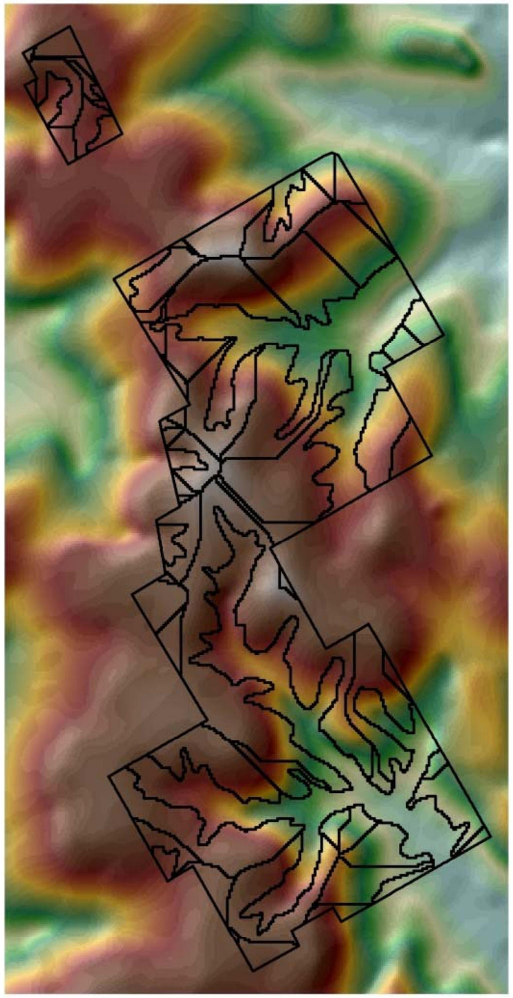
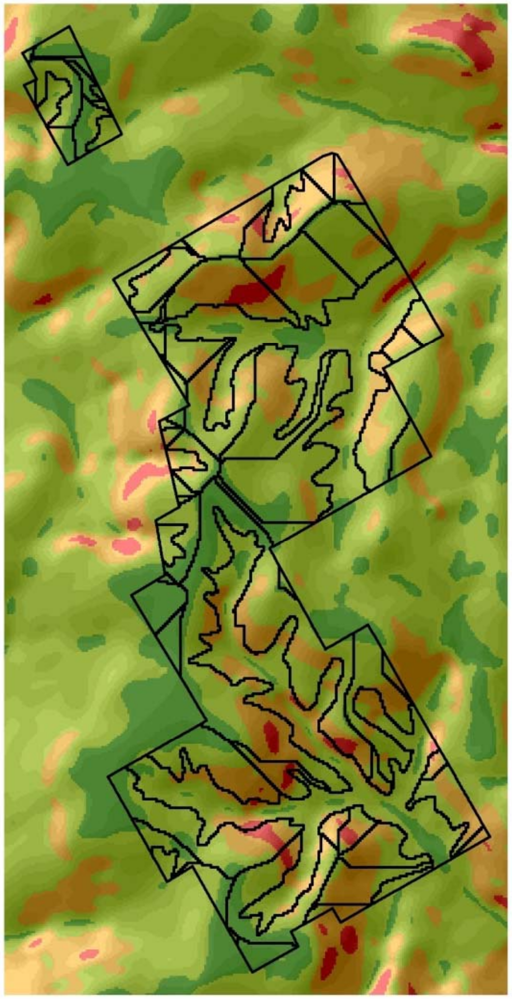
Results – landscape segmentation

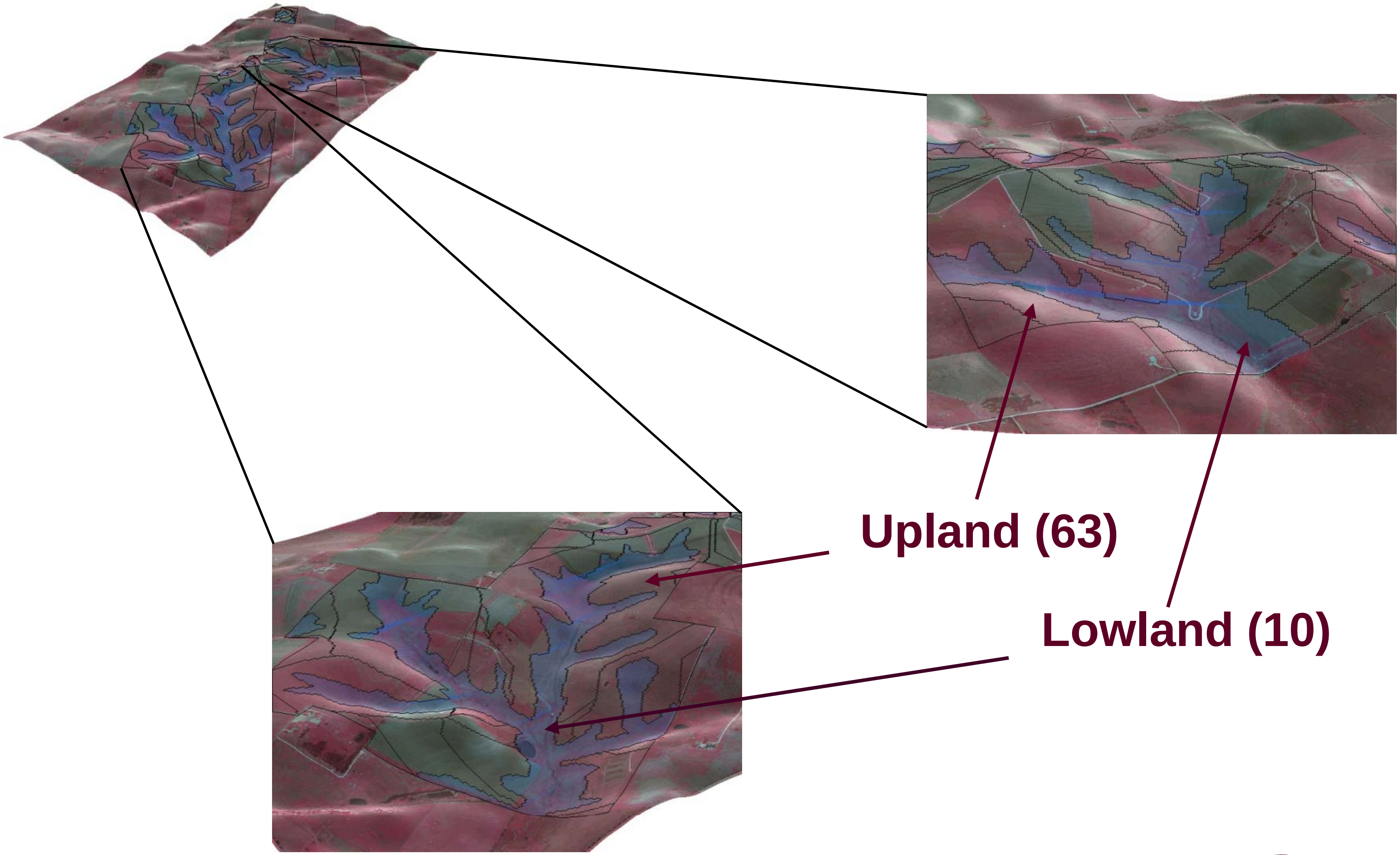
Relief



Slope



Results – landscape segmentation



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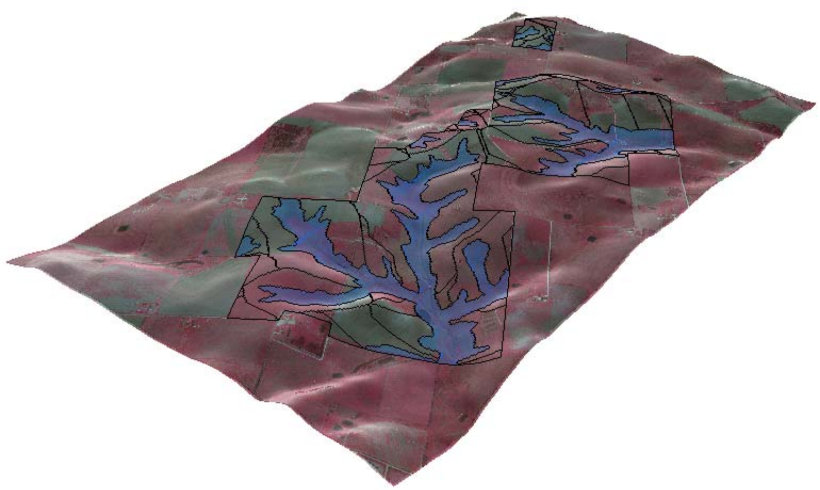
Results – landscape segmentation

- The original 338-ha were subdivided in 73 sub-areas: 10 lowland and 63 upland
- 30% lowland - 70% upland
- 30 upland sub-areas drain as edge of field (~33 ha)
- 33 upland sub-areas drain into the 10 lowland sub-areas (~203 ha)
- 10 lowland sub-areas drain as edge of field (~102 ha, with two dominant sub-areas occupying 92% of lowland)



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Yield, biomass, carbon inputs

System	Grain harvest	Residue harvest	Biomass produced	Biomass returned	Carbon returned
	------------------------------ Mg ha^{-1} yr^{-1} ------------------------------				
Corn-Corn	4.1	0	13.7	9.6	4.1
Corn-Wheat	2.9	0	9.7	6.8	2.9
Switchgrass	-	6.5	11.2	4.7	2.0
SWGS/C-W	2.0	2.0	10.2	6.2	2.7
C-W/SWGS	0.9	4.5	10.8	5.4	2.3

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Runoff, erosion, sediment yield

System	Runoff	Erosion	Yield	Redist. sediment	Off-site yield	Off-site yield
	mm	------------------	Mg ha^{-1} yr^{-1}		------------------	%
Corn-Corn	223	16.0	11.6	7.3	4.3	27
Corn-Wheat	182	8.9	5.3	3.3	2.0	22
Switchgrass	184	0.1	0.1	0.0	0.0	26
SWGS/C-W	182	6.6	4.2	3.3	0.9	13
C-W/SWGS	184	2.4	1.1	0.0	1.1	45

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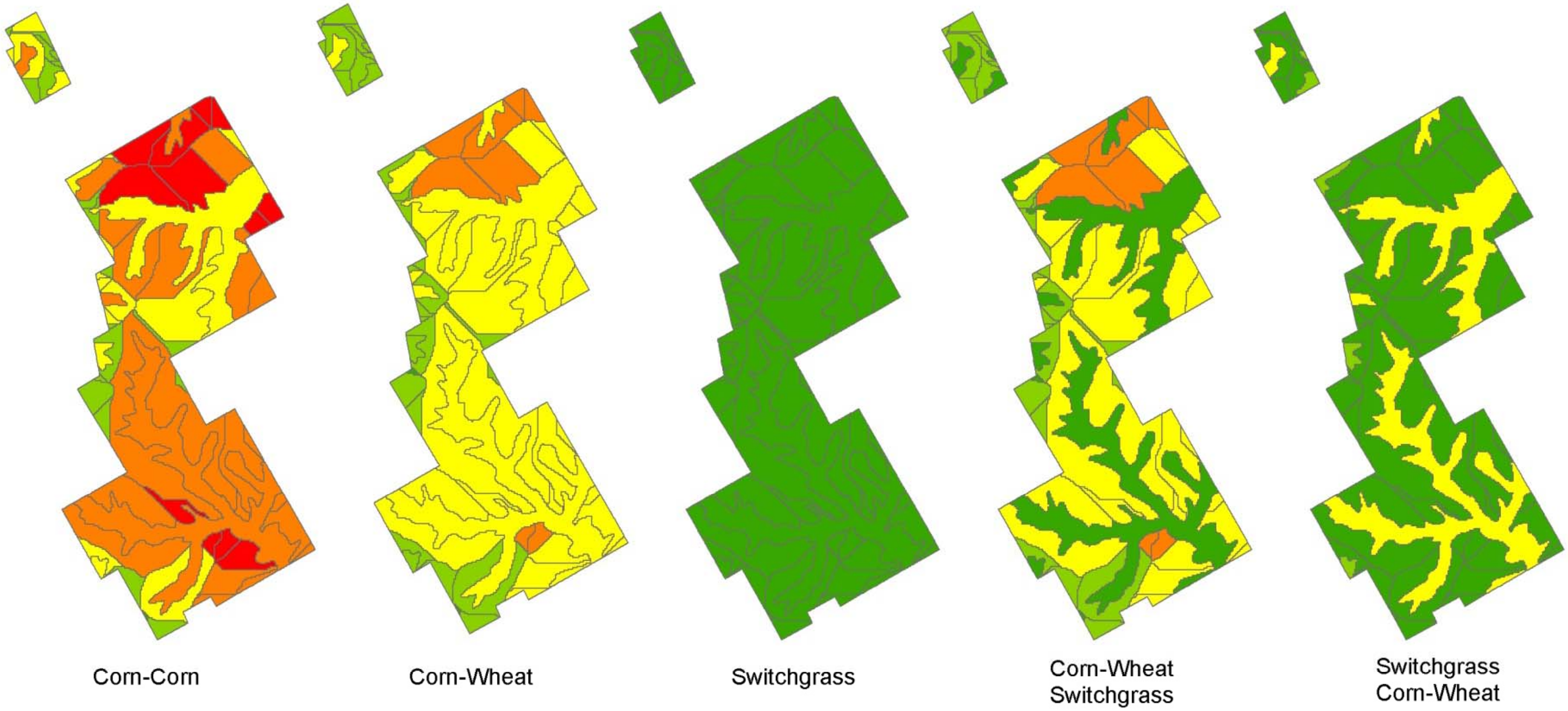
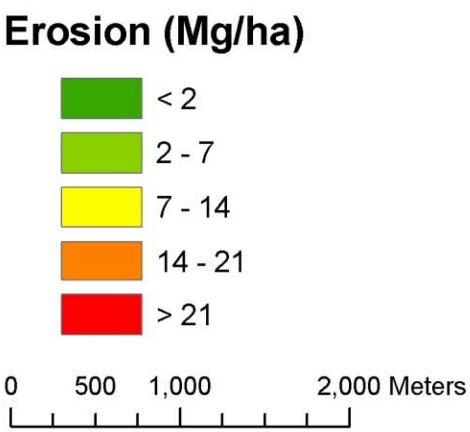
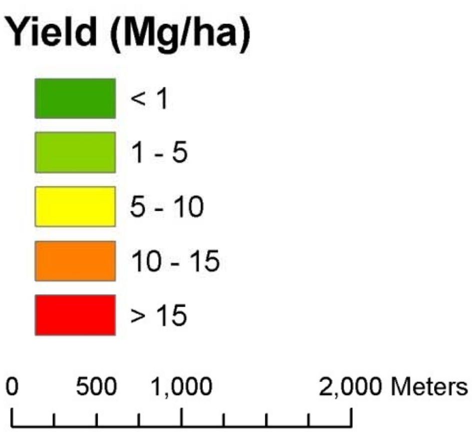




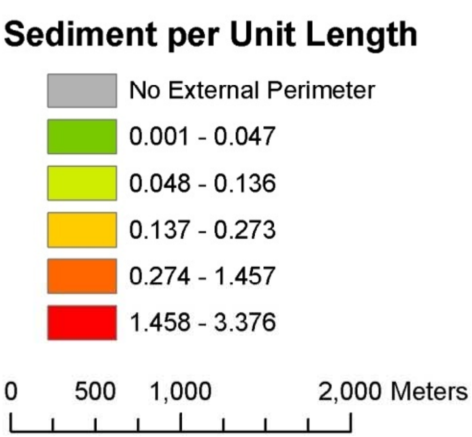
Erosion: Onsite Impacts

- Cropping systems / tillage control erosion
- erosion can be highly localized
- perennial bioenergy crops locations



Sediment Yield: Onsite Impacts

- high erosion – high yield are correlated
- Fractional yield depends on area size and type



Sediment Yield: Offsite Impacts

- control of offsite effects is highly localized
- Control of onsite and offsite effects can be coupled or decoupled

Whole-farm grain and sediment yield

System	Grain harvest	Residue harvest	Sediment yield	dS/dG	dS/dB*
	---------------- Mg yr^{-1} ----------------			----- Mg Mg^{-1} -----	
Corn-Corn	1390	0	1150	-	-
Corn-Wheat	990	0	520	1.6	1.6
Switchgrass	0	2200	5	0.8	2.3
SWGS/C-W	690	670	130	1.5	2.4
C-W/SWGS	300	1530	360	0.7	1.7

* biomass valued as 0.5 of grain

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N balance components (kg N ha^{-1})

	C-C	C-W	SW
➢ gross mineralization	254	155	118
➢ net mineralization	89	61	55
➢ fertilizer input	110	89	73
➢ volatilization	36	25	22
➢ denitrification	19	31	12
➢ runoff	20	10	2
➢ percolation	0.	1	0.
➢ removed with harvest	71	59	60

- Spatial variation of soil moisture and N cycling
- Initial soil C and N with depth too high

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Concluding Remarks

- Modeling approach provides strong support for:
  - spatially distributed quantification of grain and biomass yield and onsite/offsite impacts
  - efficient application of spatially targeted conservation practices and
  - quantitative assessment of landscape-based cropping-systems design
- Future work will include spatially-variable simulation (and validation) of carbon and nitrous oxide emissions, and overall system optimization

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Acknowledgments

- Larry Francis provided excellent technical support to link the Field Hydro Tool and the WinAPEX interface

- Funding for this research provided by Texas AgriLife Research – Cropping Systems Initiative 2007

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Questions