Carbon Dynamics of Orchard Floor Applied, Chipped Almond Prunings as Influenced by Irrigation Methods, Soil Type, Cover Crop Management, and Farm Practices

Project No.: **10-STEWCROP4-Kimmelshue**

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Objectives:

The purpose of this project is to improve the industry understanding of how pruning management influences soil carbon (C) stocks and air quality. The end result will be an assessment of C sequestration opportunities and losses associated with application of chipped prunings to the orchard floor versus traditional burning practices across a full range of California orchard conditions. The project will provide information to almond and other tree crop producers to address AB32 greenhouse gas (GHG) reduction targets in 2020 for agriculture. Project objectives include: 1) review of almond production field practices – specifically prunings management; 2) summarize existing research on pruning management impacts of soil carbon and net GHG emissions; 3) provide input parameters to the DeNitrification/DeComposition (DNDC) greenhouse gas soil biogeochemical model; 4) build GIS databases on soils, climate and orchard management; 5) run model to quantify soil carbon impacts of various pruning management strategies across a range of existing soil and climate conditions in California; 6) provide a user friendly web-GIS system to access model results and modeling system; and 7) develop and distribute a summary report that provides results and makes recommendations for future applied research.

Interpretive Summary:

Almond orchards in 25 counties were specifically located using land use data.Two sources of land use data were reviewed and compiled to determine almond acreages in California by county. The Department of Water Resources (DWR) land use database was used as well as the County Crop Reports to verify almond acreages in counties of interest between Red Bluff and Bakersfield.This spatial database is integral in guiding the field survey and is essential for building the database used in the DNDC model. Within this model, spatial cropping data is associated with other spatial information such as soil type and climate to predict C and nitrogen (N) dynamics at specific sites. This information can then be compiled to demonstrate the C offset potential in almond orchards state-wide.

A comprehensive, updated spatial database of almond orchards in California is necessary for this project, but will likely also prove to be indispensable information for other applications that depend on crop mapping information. For example, the Almond Board of California can use this GIS product to inform its sustainability program; prioritize effort devoted to regulatory policy concerning water quality, air quality, and the Endangered Species Act; and generally track its member acreage using standardized, scientific methods.

Studies compiled for the comprehensive literature review point to many aspects that must be considered if orchard floor application of chipped prunings shows potential as a practice for increasing soil organic matter and sequestering C. First, out of all the factors that affect soil C reserves in agricultural systems, management is the most important because it most dominantly influences soil organic C. While certain management practices (e.g. cover crops, irrigation management) can promote significant increases in soil C and potentially decrease greenhouse gas emissions, discontinuation or significant modification of these practices can convert soils from a C sink to a C source. Therefore, any management practice that is designed to sequester C must be considered in the long-term. It is unknown specifically how great the gains in organic C would be if chipped prunings were applied, and if these gains would justify a long-term change in management practices. Second, every soil has a finite capacity to sequester C; the increase in C resulting from a new management practice would eventually level off. However, it is unknown how long that would take in almond orchards in various parts of the state. Thirdly, because of the depletion of C in cropland soils in general, these soils are recognized to have great potential in sequestering C. It is unknown, however, specifically what that potential is in almond orchards in California. Research conducted in California to date indicates that C sequestration and several other ancillary benefits of management designed to augment soil C reserves are evident in some but not all scenarios. The uncertainties evident in the literature review emphasize the need for spatially-specific modeling to help answer some of these questions.

The field survey has been conducted in one county (Butte) in Northern California to date. Though the results are not indicative of the whole state, they are indicative that the survey will be very useful in informing the DNDC model with management trends that influence greenhouse gas flux. While pruning and other production practices vary within regions and are always changing, it is becoming evident that pruning and pruning disposal practices are linked to orchard location as a result of climate and air quality regulation differences.

The GIS database compiled and developed for the DNDC model consists of 16,349 land use polygons designated as almond orchards. Each of these polygons is associated with discrete soil, meteorological, and N-deposition data, and will therefore be modeled as separate units to determine greenhouse gas flux.

Field data from four almond orchard locations in California were investigated for suitability as a calibration and validation dataset for the DNDC model. To date, the site with the best available data for this purpose is at Belridge in Kern County.

GeoSolution, as system for integrating geospatial data analysis and biogeochemical system modeling into a web-based framework, is being developed with a service-oriented architecture that will support various applications associated with this project. GeoSolution will leverage functionality, tools, and data from and with other projects. Upon its completion, GeoSolution will provide services in several ways through multiple types of clients, including web browsers and mobile applications.

Funds provided by the Almond Board of California (ABC) for the efforts described in this annual report are a smaller part of an overall dedicated funding pool. This pool is dominated by a grant received from the United States Department of Agriculture (USDA) Specialty Crop Block Grant (SCBG) program as administered by the California Department of Food and Agriculture (CDFA). The funds provided by ABC have preceeded the SCBG funds and the overall project is to be conducted through September 2012. Therefore, the results presented in this annual report are preliminary in nature and are part of a larger overall project.

Materials and Methods:

The approach to this project is through six main tasks or components of the investigation. These tasks represent steps in achieving the most accurate and regionally-specific results possible through the DNDC model, and include the following methods.

1. **Preparation For Field Survey**
   The most recent Land Use Surveys from the DWR (1994-2007) were compiled for counties of interest between Red Bluff and Bakersfield, California. These surveys were merged into a single GIS database for analysis, and the data was summarized into acreages by county and crop type so that total almond acreage could be determined for each county. County Crop Reports for each survey area and year were also reviewed, in addition to the most recent year available, for the purpose of verifying almond acreage and location by county. (The most recent County Crop Reports that were available during this effort were from 2009; the 2010 Crop Reports will also be reviewed.) The almond acres in these reports were documented for comparison with the DWR survey data.

2. **Literature review**
   The literature review is conducted by reviewing and summarizing information from peer-reviewed scientific journal articles, Almond Board of California annual reports, and University of California Cooperative Extension (UCCE) publications. Topics in the literature review include the role of agricultural soils in climate change, carbon (C) and nitrogen (N) dynamics in orchard soils, the effect of different management practices on C sequestration and flux, and the potential for C sequestration (capacity and longevity) specifically in California almond orchard soils. The literature review will also be directed and informed by the field survey, described below, to provide region-specific background information that will guide the model development.

3. **Field Survey**
   The field survey is conducted by interviewing UCCE extension agents, researchers and growers in key almond-growing regions. To date, NewFields staff has interviewed approximately 10 to 20 percent of expected respondents across the state. Only interviews in the northern part of the state have been conducted at this time. Completion of the interviews is expected this fall and early winter. When complete, the survey will include information from mutiple respondents in all dominant almond growing areas of the state.

Survey topics include preferred pruning practices, preferred agronomic and cultural practices (such as planting density and duration of orchard life), current pruning disposal practices, level of interest in alternative pruning disposal practices, costs of various pruning and pruning disposal practices, orchard removal techniques, and innovations in almond production.

4. **GIS Database Development for DNDC Model**

DWR Land Use data were used as the mapping unit for GIS modeling database development. The USDA NRCS Soil Survey Geographic Database (SSURGO) was used to estimate watershed-wide soil properties. For each map unit the top soil horizon was extracted along with the soil attributes of organic matter, clay, pH and bulk density, which are the minimum soil attributes required by the DNDC model. SSURGO data were downloaded for each county in California. For each Almond orchard polygon, a spatially weighted mean value for each soil attribute was calculated by converting map unit data to raster format and performing a zonal mean using ArcGIS Spatial Analyst.

N-deposition data were downloaded for each station in and around California from the National Atmospheric Deposition Program, National Trends Network (NTN) website. Mean total N-deposition for the 2008-2009 period (2010 data are not yet available) were calculated for each monitoring station in the NTN. A total N-deposition value was assigned to each almond orchard polygon based on the value of the nearest NTN station.

Daily meteorological data were downloaded for each California Irrigation Management Information System (CIMIS) station active from 2008 to 2010. Each of the polygons was assigned to the nearest CIMIS station to compile daily weather data required for DNDC modeling. DNDC requires daily maximum and minimum temperature and precipitation. While daily solar radiation and wind speed are optional, these data are important and will be extracted from the CIMIS databases.

5. **DNDC Model Calibration and Validation**

This task has focused on collecting existing field data from collaborating UC Davis scientist, Weiyuan Zhu, who has led data collection efforts to date. Field data include yield, pruning, irrigation, fertigation, below-ground biomass, nutrient percent, climate, general soil properites, soil initial N, and soil initial C.

6. **Web-GIS Version of DNDC**

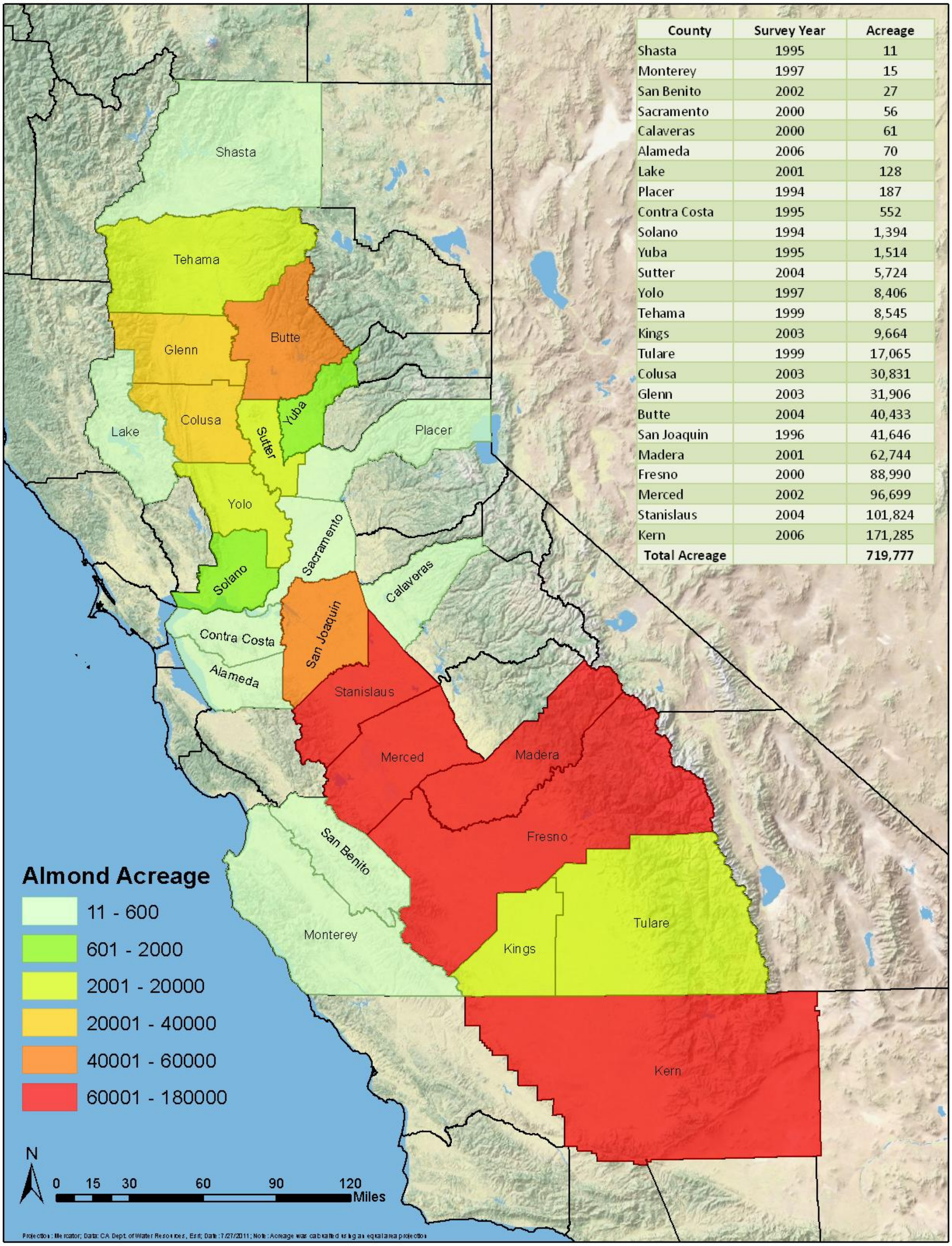
Applied Geosolutions developed a system (GeoSolution) for integrating geospatial data analysis and biogeochemical system modeling into a web-based framework. The geospatial web framework is based on a custom implementation of a number of well-tested and widely used open source components. The framework has a service-oriented architecture that will support applications associated with this project, leveraging functionality, tools, and data with other projects.

GeoSolution will provide services in several ways, through multiple types of clients, including web browsers, mobile applications (Android and iPhone), and directly using standards-compliant protocols, such as Open Geospatial Consortium (OGC) and web map/feature/content/processing services (WMS, WFS, WCS, and WPS).

The core of the program will use django, a Python-based web framework for the development of the website. The GIS portion will utilize GeoNode, a collection of open-source GIS open-source technologies including GeoNetwork and GeoServer.
During the next six months, Applied Geosolutions will be using this architecture to develop the prototype django application to run DNDC, generate reports, and display visualizations of the output.

Results and Discussion:
The results of the project to date are presented below in the same order that tasks were described in the Materials and Methods section above.

1. **Preparation For Field Survey**
   The results from the almond acreage land use data compilation are presented in **Figure 1**. This information serves two main purposes. First, it serves as a guide for the field survey to determine where survey efforts should be focused. Secondly, it provides specific location (shown in Figure 2) information for almond growing areas that will be used in the DNDC model. One of the main unknowns across the state is the distribution of bearing and non-bearing aged almond orchards. Depending on the data source (DWR, County Crop reports, UCCE estimates, etc.) actual acres of of bearing and non-bearing orchards are unknown. Therefore, some minor variability should be expected in the acreage estimates.



County	Survey Year	Acreage
Shasta	1995	11
Monterey	1997	15
San Benito	2002	27
Sacramento	2000	56
Calaveras	2000	61
Alameda	2006	70
Lake	2001	128
Placer	1994	187
Contra Costa	1995	552
Solano	1994	1,394
Yuba	1995	1,514
Sutter	2004	5,724
Yolo	1997	8,406
Tehama	1999	8,545
Kings	2003	9,664
Tulare	1999	17,065
Colusa	2003	30,831
Glenn	2003	31,906
Butte	2004	40,433
San Joaquin	1996	41,646
Madera	2001	62,744
Fresno	2000	88,990
Merced	2002	96,699
Stanislaus	2004	101,824
Kern	2006	171,285
Total Acreage		**719,777**

Figure 1. Almond Acreage in California Counties of Interest (DWR Land Use Data)

2. Literature review

The literature review focused on several main topics that are catogorized in two sections. The first section includes general background information that provides the foundation for understanding the dynamics and roles of C and N, and environmental factors and management practices that affect greenhouse gas flux in agricultural soils. The second category includes information that is specific to almond production and various aspects of applying chipped prunings, including agronomic impacts, costs, convenience, and practical consideration in California. This latter category will be completed when additional information from the field survey is available. Key results from these main sections of the literature review are presented below.

General Information

Agricultural soils have an important role in global climate change through the regulation of atmospheric C (by the processes of decomposition and C mineralization) and other greenhouse gases such as nitrous oxide (N_2O) (Hillel and Rosenzweig, 2009). The organic C pool in agricultural soils is in dynamic equilibrium with gains and losses, and decomposition is the key process in regulating soil C reserves. Soil organic C does not increase indefinitely, but reaches an equilibrium determined by management, climate, biological factors, topography, parent material and time (Sumner, 2000). Each soil has a different capacity to store C, because each soil has a different equilibrium value.

Out of all factors that influence soil C reserves, management is the most important because it causes the most drastic changes in soil C (Sumner, 2000). Specific management practices augment or deplete soil C reserves, because they preferentially remove or accumulate different types of soil organic matter (Lal, 2010). Management practices such as irrigation method, fertilizer formulation, and fertilization timing influence N and C cycles and therefore CO_2 and N_2O emissions.

Because of historic depletion of soil organic C in cropland soils, there is significant potential and capacity to sequester organic C. It is hypothesized that this may be especially true with appropriate management options (Comis et al., 2001). For example tillage is generally not conducted in almond orchards and below-ground organic matter may be sequestered longer. Increasing yield and corresponding tree size or tree density is also a likely potential complementary approach to increasing soil C reserves (e.g. greater C inputs in the soil through leaf fall or prunings management).

Agricultural soils are limited by several factors in how much C they can sequester; the positive effects of C-augmenting management practices diminish over time as soils reach their new capacity to store C (Hillel and Rosenweig, 2009). Ensuring longevity of management practices designed to conserve and increase soil organic C levels is equally as important as implementing them. Ultimately, improving soil organic matter management is a worthy production goal regardless of the resulting effect on greenhouse gas emissions because of ancillary benefits such as improved soil quality and potentially greater crop yields.

Information Specific to California Almond Orchards

Research conducted by UCCE personnel during the last 20 years demonstrated that pruning did not produce higher yields, as was previously believed during most of California's almond production history. For this reason, pruning in general has decreased markedly during this time period. However, a minimal amount of pruning and wood management is necessary for practical reasons such as worker safety, inevitable limb die-back, and disease control (Duncan, undated).

With increasing regulation of air quality, burning is restricted or disallowed in many parts of the state, which has led researchers to investigate the cost, practicality and agronomic implications of reapplying prunings to the orchard floor. While improvements have been made in chipping technology, making the problem of wood chips being swept up during the almond harvest less of a concern than it was previously, there is still concern about the potential of wood chips disrupting the C:N balance in the soil because of their high C content. This disruption leads to less N available for plant uptake and presents potential almond fertility problems. Results from studies to date are inconclusive regarding the time it takes for the chips to decompose and subsequent restoration of nutrient balances (Holtz, 2003; Holtz et al, 2010; Holtz, 2004; Holtz et al, undated). In all these studies, ancillary benefits of organic matter addition such as improved water infiltration and increased beneficial soil microbe populations were observed in soil sampling results. In theory, such organic matter additions would potentially sequester C and make these soils a smaller source of CO_2, the main greenhouse gas.

Researchers in California have also focused on the influence of management practices, specifically irrigation/fertigation method and timing, on N_2O emissions. They have demonstrated that fertilizer formulation has a notable influence on N_2O emissions, which is intensified by certain environmental conditions (Smart et al, undated). Similar studies have shown that N_2O emissions are related to irrigation timing and method.

Nitrogen transformations play an important role in decomposition, productivity and C cycling. Clearly there is more research that is needed to illuminate how N_2O flux phenomena are related to C and N dynamics associated with prunings application and other cultural practices to determine the net flux of greenhouse gases from a particular orchard with specific management. Because the C and N cycles are so interrelated, one can not be considered without the other.

3. Field Survey

The field survey is approximately 10 to 20 percent complete. Results from the survey conducted to date in northern California indicated that pruning and other almond cultural practices represent a "moving target", constantly changing as growers adapt to technology and research information, changing climate, and their own changing personal choices. These practices varied widely within one county (Butte County).

Growers and UCCE personnel interviewed to date estimated that prunings have decreased over the past 20 years from removing about 20 percent of tree mass to approximately 5 to 7 percent of tree mass annually. However, this decrease is somewhat mitigated by the increase in orchard density that has accompanied this trend. Though growers adopted minimal pruning to increase yields, this practice brings with it new problems such as increased disease and uneven ripening, and may have reached its peak for this reason. Similarly, orchard density has likely reached its peak because of the reasons described above, and will likely remain constant or decrease.

In Butte County, cogeneration facilities use chipped and shredded orchard prunings for energy generation. While burning is still practiced, some growers in some areas are using a service that hauls prunings to cogeneration facilities. Depending on the value of cogeneration feed materials, growers have used this service free of charge, and have sometimes been paid for their prunings. Though the value of orchard prunings as a source of organic matter is recognized, orchard prunings are seldom appied back to the orchard floor. This is mostly because of the inconvenience, and the financial benefits of having them hauled to cogeneration (both through potential payment and not having to provide the labor to burn them.)

Because orchard production in the central and southerly regions of California is managed more intensively under a different climate and more restrictive air quality regulations, these survey results by no means fully represent almond production in the state, and will be more meaningful when the survey is complete.

4. GIS Database Development for DNDC Model

A total of 16,349 polygons from the DWR Land Use Database representing almond orchards in California were merged into a single dataset as described in the Materials and Methods section above, and are illustrated in **Figure 2**. CIMIS stations and National Trends Network (NTN) stations are also mapped in **Figure 2**. These almond orchards average 43 acres in area and range from less than 0.25 acres to more than 2,400 acres.

Figure 2. Distribution of almond orchards in California

5. DNDC Model Calibration and Validation

The DNDC model will be calibrated and validated using California almond orchard field data. Sites included for collecting field data are in the following locations:

Site 1 - Belridge
Site 2 - Belridge
Site 3 - Madera
Site 4 – Modesto
Site 5 - Arbuckle
Site 6 - Arbuckle
Site 7 - Arbuckle

Current results of the field data collection are summarized in **Table 1**. The best data set for yield calibration is Site 1, which has irrigation and N fertigation treatments with corresponding yields.

Table 1

Data collection progress on calibration and validation of almond DNDC

Modeling stage	Data needed	Status of the data	Site #	Note
Calibration (& Validation)	Yield data	Ready	1	Good for calibration
		Ready	2 - 5	Not good for calibration; one averaged value for the whole site
		To be requested	6, 7	Not good for calibration; one averaged value for the whole site
	Pruning	Ready	1 - 7	Estimates by Bruce; one value for the whole site
	Irrigation	Ready	1, 2	
		To be requested	3 - 5	One data for the whole site
		To be requested	6, 7	One data for the whole site
	Fertigation	Ready	1, 2	
		To be requested	3 - 7	One data for the whole site
	BG biomass	Ready	1 -7	For peach; Estimates by Ted; one value for all sites
	Nutrient %	In progress	1 - 5	To be field measured
	Climate	Ready	1 - 7	
	Soil general	Ready	1, 2	
		In progress	3 - 7	
	Soil initial N	Ready	1, 2, 7	
	Soil initial C	Ready	7	
Validation	N2O	To be requested	1, 6	Conversation initiated; Have not heard back
		Ready	7	

6. Web-GIS Version of DNDC

The DNDC code is written on the Windows platform, which contains Windows-specific application programming interface (API) functions. GeoSolution, however, will require a different platform - specifically, a command-line version of DNDC that can be run in batch mode. After Applied Geosolutions began porting DNDC code to run under the Linux operating system where GeoSolution will be served, staff realized that integrating Windows-specific code was too extensive to be cost- and effort- effective. Therefore, NUGGET was examined as a replacement. NUGGET is an older version of the DNDC code that has already been ported to a non-Windows system. GeoSolution will be able to leverage any future developments of a newer command line version of the DNDC model.

Applied Geosolutions examined a variety of tools for the architecture of GeoSolution. Several Open Geospatial Consortium (OGC) compliant open-source packages provided useful functions individually but would require significant customization to be suitable. GeoNode, a relative newcomer in the OGC community, provides a very useful function. It ties together several of these open-source packages into a single package, but is still customizable through the well advanced django web framework. It is with GeoNode that Applied Geosolutions will provide most of the needed GIS functionality while leveraging django to build the interface to the biogeochemical model.

Spatially-aware parameter configurations, such as climate and soil database parameters, and input forcing data selections can be controlled through a user-friendly web interface. The results will then be served back to the user as reports, GIS vector data (e.g. shape files or KML file format), or as gridded raster data (e.g. Geotiffs). Time series visualization and other data interrogation tools will also be usable for post-processing or scenario analysis.

The diagram in **Figure 3** shows the integrated system, combining powerful GIS tools on the server and to the client through several channels. Django acts as the central control server, accessing the GeoServer and GeoNetwork programs with its Python-based scripting language. Applied Geosolutions will provide several customized components for the web-DNDC program.

The components of Geosolution illustrated in **Figure 3** are briefly described below.

- **GeoNode** is the glue, written in django, which holds together the various geospatial technologies.
- **GeoServer** provides GeoSpatial services such as rendering image and vector data.
- **GeoNetwork** provides an indexing service of the metadata.
- **GeoExt** provides client web services using OpenLayers.
- **RunDNDC** is a django app that provides the interface to run DNDC and report the results. Using the django framework it can access GeoNetwork and GeoServer to retrieve input parameters and index and display results.
- **DNDC Web Interface** is the DNDC website, that provides access to the DNDC app as well as meta functions such as profile management. Part of this interface may be accessed by a mobile application.
- **Mobile App** could provide partial functionality to the DNDC web tool.
- **GeoSpatial Services** (those with more powerful GIS analysis tools such as QuantumGIS or ArcInfo) have another way of interacting with the data. By connecting to GeoServer directly they can use the WMS, WFS, WCS, and WPS services.

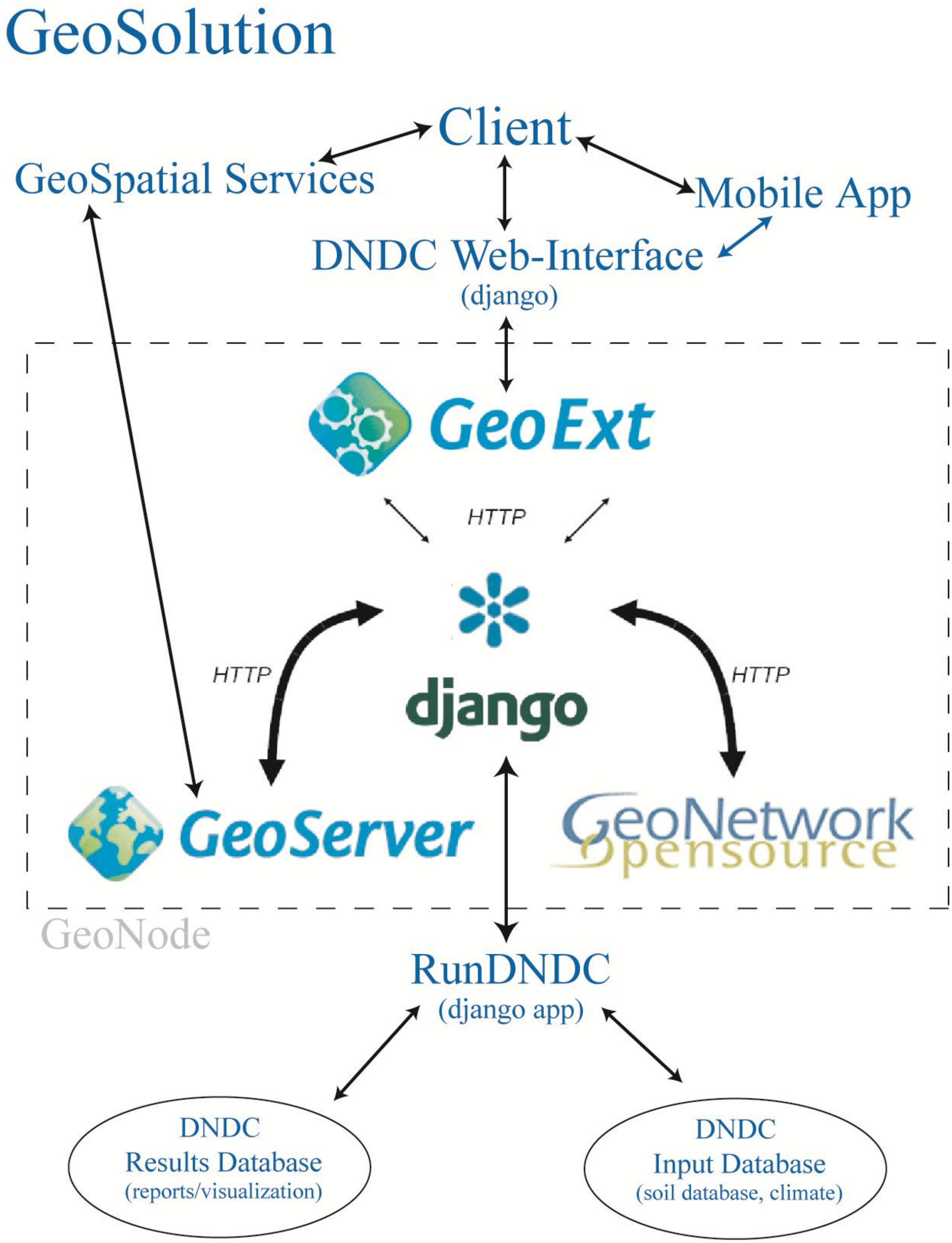


Figure 3. System Architecture

Research Effort Recent Publications:

None.

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