University of California
Division of Agricultural Sciences

PROJECT PLAN/RESEARCH GRANT PROPOSAL

Project Year: 2009-2010 **Anticipated Duration of Project**: Three Years

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Project Title: The use of walnut shell as a bio-charcoal soil amendment and its effect on soil fertility and carbon sequestration

Keywords: Bio-charcoal, Walnut Shells, Waste management, Carbon Sequestration, Soil Fertility, Nutrient Management
Commodity(s): Walnuts **Relevant AES/CE Project No.**

Problem and its Significance:

Today, the walnut industry is facing the following four, non-exclusive, key issues: 1) disposal of orchard waste, 2) sustainable nutrient management, 3) energy costs, and 4) reduction of greenhouse gas emissions. Walnut shells form one of the major orchard waste products within the walnut industry and alternative ways to dispose of them are needed. Since walnut production is a high-price commodity enterprise, the economic and environmental sound production of walnuts is essential and, therefore, sensible nutrient management is pertinent. In recent years, on-farm energy costs have drastically increased concomitant with a demand to curb greenhouse gas emissions derived from the usage of fossil fuels. Consequently, alternative energy sources, preferably renewable sources, are being sought after. In this proposal, we address all four of these issues through an integrated assessment of the potential use of locally produced bio-charcoal, derived from pyrolyzing walnut shells to produce renewable energy, as an amendment to the soil in order to improve nutrient use efficiency, sequester soil carbon and reduce nitrous oxide (i.e. a very potent greenhouse gas) emissions. If this potential use of bio-charcoal is practically and economically feasible, then it will present a win-win-win-win situation for the walnut industry by reducing greenhouse gas emissions, improving nutrient management, and producing energy while disposing of a major waste product.

Climate change is widely recognized as being a serious threat to the world's managed and natural ecosystems and could greatly affect the agricultural economy on the regional, national and global scale. Increases in greenhouse gases (GHG's) such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), anthropogenically generated through fossil fuel and biomass burning, have been associated with increases in mean global temperatures, changes in seasonal precipitation patterns and rising sea levels. Hayhoe *et al.,* (2004) predicted that an increase in mean air temperature and changes to seasonal precipitation could potentially lead to an adverse shift in agricultural crop growing seasons and possibly lead to diminished yields and quality within California cropping systems. The mounting concern with climate change related environmental impacts has prompted California to try and reduce its emissions of GHG's through the adoption of "The California Global Warming Solutions Act of 2006 (AB32)". This piece of legislation will place caps on emissions and will require the complete compliance of industries, most specifically the manufacturing, refinery and utilities industries, to reduce their GHG emissions by 25 % by 2020. The agricultural industry is currently under voluntary compliance for AB32, but a reduction in fossil fuel

dependence and usage may well provide a sound basis for a carbon cap and trade system, which would lead to greater agricultural sustainability and food security within the State.

Agriculture can play a major role in mitigating GHG emissions by sequestering carbon in the form of CO_2 from the atmosphere by increasing soil carbon. Despite this, the accumulation of carbon within the soil pool is generally a slow process and can be upset through intensive management practices such as tillage. However, more recently a new approach to carbon sequestration within the terrestrial environment has been proposed (Lehmann *et al.*, 2006; McHenry, 2008; Laird, 2008). The addition of bio-charcoal produced from green waste biomass into agricultural soils may provide a much larger and longer term sink of carbon in soils, enhance soil quality, reduce greenhouse gas emissions, as well as producing a renewable energy source to reduce the use of fossil fuels. Bio-charcoal is produced when green wastes such as walnut shells are gasified in the absence of oxygen in a process termed pyrolysis. The pyrolysis process produces a renewable energy source from the biomass itself in the form of a gas or other byproducts (e.g. bio-oil) which can be used instead of fossil fuels. A waste product of the pyrolysis process is a fine black carbon residue named bio-charcoal.

Bio-charcoal, however, has the potential to enhance both carbon sequestration in soils as well as enhancing nutrient use and general soil quality and fertility (Glaser *et al.*, 2002). Previous research in annual crops such as maize, rice and soybean have shown that additions of carbonized organic matter, such as bio-charcoal, can increase plant growth and produce higher yields of up to 200 % after application (Kishimoto & Sugiura, 1985; Glaser *et al.,* 2002). It has also been observed that the incorporation of bio-charcoal can improve soil nutrient availability to plants and enhance nutrient retention (Steiner *et al.,* 2008) due to its high cation exchange capacity (Liang *et al.,* 2006). Therefore, the bio-charcoal improves soil fertility and production capacity while maintaining high levels of soil organic matter (SOM) (Glaser *et al.,* 2002; Chan *et al.,* 2007).

The walnut industry generates tons of waste from walnut shells every year. The walnut grower involved in the here proposed project, has started using the waste shells to produce a renewable energy source through a BIOMAX 50 pyrolyzer, however, approximately 1 % of the carbon from the shells going into the BIOMAX is retained as bio-charcoal carbon. We suggest that this waste product could be used as a soil amendment which could help with soil nutrient retention, sequestration of carbon, reduction of nutrient leaching and nitrous oxide fluxes to the atmosphere, while reducing the amount of waste generated from the walnut shells and providing an alternative use for that waste.

This study is needed to effectively demonstrate at the farm-level that biomass sourced carbon and nitrogen, when added to the soil, has the potential to improve soil fertility and crop productivity while mitigating climate change through reduction of greenhouse gas emissions and sequestration of carbon. Furthermore, the proposed approach will reduce the need for synthetic fertilizers and fossil fuel usage as well as providing an alternative usage for the green waste generated in the walnut industry.

Objectives:

The main objectives of the proposed study are:

1. Identify and evaluate the use of waste walnut shells and pryrolyzed walnut shells as an organic soil amendment, in order to understand the role of bio-charcoal in carbon sequestration, soil productivity, soil fertility, and greenhouse gas reduction.

2. Carry out a life cycle analysis on the different uses for orchard shell waste and investigate the utilization pathways (e.g. as bio-charcoal soil amendments, sold for industrial purposes or applied to soils untreated) and their significant contribution to the sustainable production of walnuts (i.e. environmental impacts versus benefits and agro-economic costs versus gains).

These objectives will be addressed by newly proposed measurements (see below) and building upon an existing dataset, previously developed as part of an "on farm" soil carbon study for a soil carbon reporting database project, collected at the 56 acre walnut orchard, Dixon Ridge Farms, Winters, California. The previously collected data provides a background on the carbon and nitrogen contents of the soils within the orchard and will jump start the here proposed work.

Plans and Procedures:

Objective 1: Soil Fertility and Carbon Sequestration

Experimental Design

As part of our previous carbon reporting project, we sampled and measured total soil carbon and nitrogen content of 1 m depth soil cores of a 56 acre walnut orchard at Dixon Ridge Farm, Winters, California. This orchard will be the experimental site for this proposal. Dixon Ridge Farm is split into 3 blocks of 20, 26 and 11 acres (numbered 1 to 3 in Fig. 1). Trees are spaced 30 x 30' (48 trees/acre) for 8 acres and 24 x 24' (75 trees/acre) for 12 acres in block 1 and 24 x 24' for blocks 2 and 3. Blocks 1 and 3 have the same variety (Hartleys) and a solid set underground irrigation system, whereas block 2 has the Chandler variety and an overhead irrigation system. All blocks have a cover crop and each receives additions of compost to supply nitrogen to the trees. In all blocks applications of untreated walnut shells have been added over the past 2 years. As blocks 1 and 3 have the same management treatment and walnut variety, these blocks will be used for the experiment. Figure 1 shows the randomized split plot design that we will implement in order to minimize environmental variation and homogenize sampling, as well as ensuring that the application of the bio-charcoal and walnut shells can be easily performed by the grower.

Table 1: Chemical properties of bio-charcoal and walnut shells (ND = not determined)

Amendment	% Carbon	% Nitrogen	PO_4-P (Soluble P) (mg/l)	K (Soluble)(mg/l)	pH
Bio-charcoal	46.4	0.58	0.48	933	10.6
Walnut Shell	47.3	0.41	ND	ND	ND

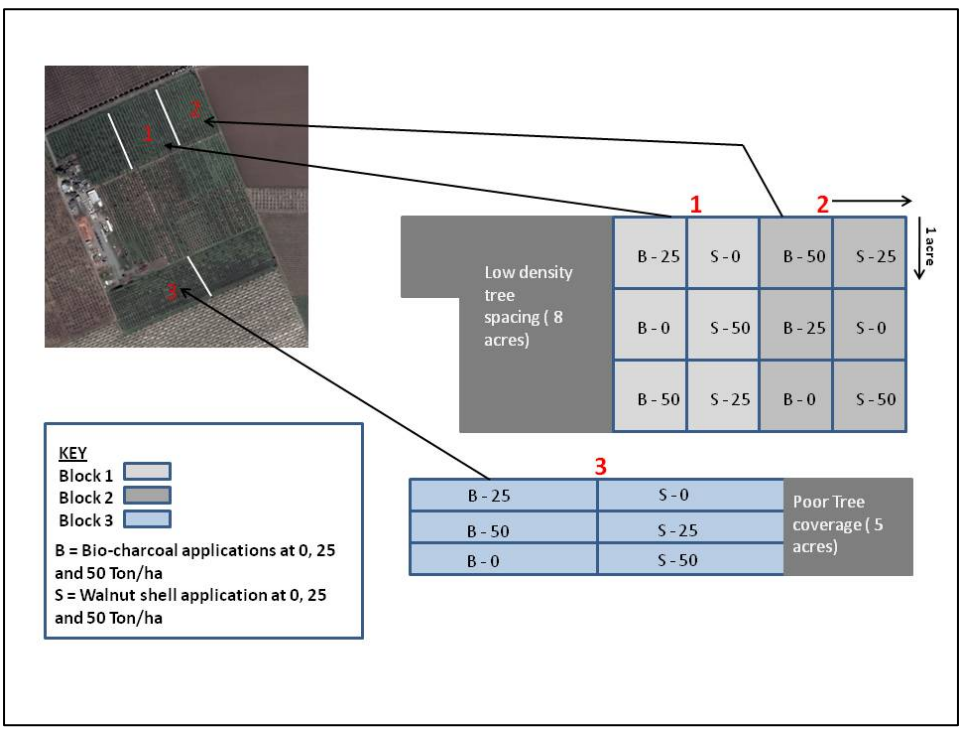

Fig. 1: Location and design of the proposed experiment at Dixon Ridge Farm.

The experimental design consists of three blocks of six acres. Inside each block there will be 6 treatments, one treatment per acre and 75 trees per acre. The treatments will be 0, 25 and 50 T/ha of bio-charcoal addition and 0, 25 and 50 T/ha of walnut shell additions. These rates are chosen to represent approximately 250 kg N/ha/yr, 125 kg N/ha/yr, and 0 kg N/ha/yr based on the percentage of nitrogen the shells and bio-charcoal contain (table 1). The bio-charcoal produced by pryrolysis in the BIOMAX 50 will be applied to the field as an agitated water/ash slurry and then injected approximately 15cm into the soil using a fertilizer injector in order to not create a potential dust hazard. The shells will be applied using a broadcast compost spreader.

Soil Sampling

Deep soil cores will be taken once a year for total carbon and nitrogen analyses. Soil cores will be collected at three depths (0-20 cm, 20-50 cm and 50-100 cm) in triplicate within each of the six treatments in the three blocks. Composite samples will be air dried and then passed through a series of sieves (8 mm and 2 mm). The 2 mm sieved samples will then be ground and homogenized using a ball mill grinder. Samples will then be micro-balanced and analyzed for total C and N using a COSTECH elemental analyzer which uses flash on ignition combustion and chromatographic separation to measure multi elements. Samples will also be analyzed for the labile fraction of the soil organic matter (SOM) pool, i.e., particulate organic matter (POM), before the addition of both the soil amendments and also throughout the growing season (3 sampling times) in the top 0-20 cm only. This will enable changes to the labile pool to be observed and be detected as this soil pool accumulates more quickly than the larger SOM pool and it will enable to assess changes in soil quality. Gravimetric soil moisture content and bulk density will be measured on all soil cores. Soil temperature and moisture probes will be installed within each of the treatment one acre blocks and data will be collected continually using a data logger.

Metal (Cu, Pb, Fe) and elemental analysis (e.g. NO_3, NH_4, P, K, Zn, Mg, Ca) will be conducted on soil samples (0-20 cm) taken before and after intense management events to measure soil fertility and evaluate the effect the soil amendments have upon soil fertility. Samples are analyzed using microwave acid digestion/dissolution of the sample and quantitative determination by AAS and ICP-AES conducted by the UC Davis ANR Analytical Lab.

In order to investigate any possible leaching of nutrients such as inorganic nitrogen in the form of nitrate (NO_3-N), lysimeters will be installed in all of the treatments and replicates. Lysimeters will collect soil pore water which percolates through its porous chamber; this pore water will be analyzed spectrophotometrically for inorganic N.

N_2O Emissions

In order to acquire comprehensive assessments of N_2O emissions, we propose to measure soil N_2O emissions within each of the treatments in all three blocks just before and during the most intense management events within the orchard. With funds from another already funded project we are developing mobile gas capture systems to measure N_2O emissions *in situ*. Once these systems are developed, we will be able to employ them also in this orchard at targeted times to capture the majority of the occurring N_2O fluxes. These measures will give us an idea of the greenhouse gas emission reductions by applying bio-charcoal and walnut shells. Furthermore, ecosystem modeling exercises, conducted under another already funded project, can be validated based on these field measures of N_2O emissions. Once the model is validated, baseline N_2O emission budgets can be predicted to evaluate whether the bio-charcoal and walnut shell soil amendments play a significant role in reducing annual soil N_2O emissions.

Objective 2: Life Cycle Analysis (LCA)

In order to evaluate the environmental impacts of the different options to dispose of the waste walnut shells, we will carry out a Life Cycle Analysis (LCA) and determine

the global warming potential (GWP) of each biomass usage process from the start to the end of the shells life span.

LCA's are a systematic and well developed tool for identifying and evaluating any potential environmental benefits or impacts associated with a product, in this case walnut shells, throughout its entire life span, from its extraction to its disposal and eventual accumulation into the environment. The LCA will enable the listing and full quantification of all possible environmental burdens and benefits over the whole life cycle of the walnut shell waste. The LCA will take into account material and energy uses during collection, transportation, utilization, conversion, and disposal and can quantify GHG emissions, resource depletion and energy usage through the whole life sequence. The results of the LCA will be used to evaluate all environmental impacts in the utilization of walnut shells for different applications.

We will conduct a case study where we will evaluate the use of untreated walnut shells versus the bio-charcoal derived from the pyrolysis of walnut shells as soil amendments through LCA and elucidate both the environmental problems and benefits that each pathway/life cycle has in terms of energy usage, carbon sequestration potential, GHG emissions, and soil fertility. Further LCA will be conducted to investigate the environmental impacts and benefits that other utilization processes for waste walnut shells may have. For example walnut shells have many other potential uses such as, substrate for metal cleaning or polishing techniques, oil well drilling, paints, explosives, cosmetic cleaners and cooking oil.

The information and inventories of benefits and impacts generated for each potential use of walnut shells through the LCA will enable the selection of the most acceptable technique in terms of resource and environmental management. In this case study, the criteria of the results, namely a reduction in energy and resource use and GHG mitigation, would be assessed for every usage route for walnut shells. Data would then be analyzed and ranked in order of the best uses for the walnut shells based upon their environmental merits.

References

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BUDGET REQUEST Budget Year: 2009-2010

Funding Source

Salaries and Benefits

Postdocs/RA's	25% Time	$ 8875.00
SRA's		$
Lab/Field Assistance	25 % Time	$ 8418.00

Subtotal	Sub 2	$ 17,293.00
Employee benefits (30 %)	Sub 6	$ 5188.00
	SUBTOTAL	$ 22,481.00

Supplies and Expenses

Initial experimental set up and sample analysis to include:

Yield measurements (x1/yr)

Total soil carbon and nitrogen analysis (x 1/yr)

POM separation (x6/yr)

Soil metal analysis (x6/yr)

Soil inorganic nitrogen analysis (x6/yr)

Trace Gas (N_2O) measurements (x6/yr)

Soil Lysimeters		$ 1500
Teflon Tubing for Lysimeters		$ 500
Soil Temperature Probes		$ 1000
Soil Moisture Probes		$ 900
	Sub 3	$7400

Equipment	Sub 4	$ 0
Travel	Sub 5	$ 0
	TOTAL	$ **29,881.00**

Department account number _____

Budget Support Summary & Justification:

Our total request of $29,881 is justified for the use of a 25% time Postdoctoral Research Scholar who will coordinate the experimental set up, all soil sampling and trace gas measurements. A junior specialist at 25 % time will help with initial set up and installation as well as helping with field measurements and with soil preparation and gas analysis. We anticipate that set-up costs will amount to $3500 and will include the installation of soil lysimeters, temperature and moisture probes, where we also anticipate the costs of this equipment to be $3900. Further supplies and expenses costs will arise from soil analysis for total carbon, nitrogen, soil fractionation, inorganic nitrogen and metal analysis. Prof. Johan Six is providing 2% effort at no cost to the project

	_____	Date _____
	Originator's Signature	
COOPERATIVE EXTENSION	County Director _____	Date _____
	Program Director_____	Date _____
AGRICULTURAL EXPERIMENT STATION	Department Chair_____	Date _____
LIAISON OFFICER	_____	Date _____

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