Department of Agriculture, Trade and Consumer Protection
Division of Agricultural Development
Agricultural Development & Diversification Program (ADD)
Grant Project Final Report

Contract Number: 23054

Grant Project Title: Development of production profile for Savoy spinach under Wisconsin conditions

Amount of Funding Awarded: $12,000

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What was the original intent of the grant?

The specific goal of this project is to develop a suite of management recommendations to optimize commercial production of Savoy spinach in Wisconsin. Initial research will be focused on muck soils as growers have experience producing spinach in these locations. Specific Objectives include:

1) Identify varieties suitable for production on muck soils
2) Determine optimal planting rate
3) Develop labeled weed management practices
4) Quantify effect of planting date on yield and quality, sensitivity to insects, and appropriate insect management techniques.

By developing management practices for commercial production, we could provide guidance to vegetable growers on muck and mineral soils in producing spinach. In turn, these growers would be able to produce raw product for delivery to Kleen Pak and other spinach re-packers in the Midwestern United States. This would provide Wisconsin vegetable growers a new crop enterprise at competitive price with rotational crops and transportation savings to regional packers. This research provided preliminary data for temporal fresh produce production system that could provide year round supply by moving production with the seasons from the Rio Grande River Valley in Texas all the way to Northern WI. This is critical as 70% of fresh produce consumed in the United States is grown in California or produced South of the US border. In spinach, over 90% of the commercial production occurs in two California counties. USDA has determined that regionalized produce production will be critical for ensuring a safe and abundant supply of fresh produce in the future. Midwest production benefits from current fresh produce infrastructure through potato packing sheds in WI, commercial spinach growers in Oklahoma, Arkansas, and Texas. In addition, water resources are not as limiting along the Mississippi River corridor as is occurring in California or the Western Plains.

What steps did you take to reach your goal

A series of field research trials were conducted at the Arlington Agricultural Research Station. In the fall of 2008, multiple spinach varieties were evaluated for yield and quality. In 2009, trials evaluated different seeding rates of spinach, weed management, and insect management issues that emerged in the crop.

During the fall of 2008, a critical cooperator to the project passed away. Dr. Teddy Morelock was a key resource for securing multiple indeterminate types of spinach. Indeterminate spinach was crucial because it does not bolt when planted in long day length environments and allows for multiple harvest dates. Seed became scarce during planting of trials in 2009, but projects were completed.

Muck planting was difficult due to poor weather. Attempts at conducting variety trials on muck were thwarted by flooding in late spring of 2009. Muck growers have expressed interest in planting spinach for commercial packaging. Contract opportunities need to be explored to secure fair prices for Wisconsin growers and excellent quality for re-packers.

No commercial spinach harvesting equipment is available in Wisconsin. Band saw harvesters can be retrofit onto traditional harvest equipment, but at a cost of $12,000 to 24,000. Most of this equipment is available in distant locations. The nearest harvester is in Oklahoma.

There was limited communication between UW-Madison and Tosca Limited. Dr. Bussan was remiss in communicating project progress and accomplishments with Tim Vandermuse at Tosca. The project has huge implications for future of Wisconsin in its role in meeting regional and national demand for fresh produce.

To facilitate communication, Dr. Bussan should have visited Tosca and Tim Vandermuse to develop stronger working relationship. Despite the shortcomings, all research projects were and are being successfully completed. Contract possibilities with Wisconsin growers and packing sheds need to be explored.

In addition, several fresh spinach packing companies have expressed large concerns about food safety of Midwest spinach production. Humid environment promotes pathogen infection and growth on field grown spinach. Several new techniques have been developed for minimizing food safety concerns of spinach and ensures post pack shelf life of 20 or more days. Dr. Jeri Barak and Dr. Amy Charkowski in the Department of Plant Pathology have expressed willingness for future collaboration.

What were you able to accomplish?

Production systems

Spinach varieties with potential in Wisconsin based on yield are listed below. Evergreen is traditional spinach prone to bolting. Other varieties are intermediate daylength varieties that would resist bolting.

Variety	Yield (ton/A)	S.D.
Tyee	8.835909	0.60013
SPD317	6.695465	0.494685
C2608	7.448422	0.619359
5086	6.009032	0.584702
SPE420	6.618708	1.664157
C2606	5.60514	0.350361
SPP318	5.846744	1.403626
EverGreen	5.799228	1.12506

We successfully established spinach planting densities of 0.70, 1.22, 1.67 million plants per acre. Optimal density would depend on the size of spinach at harvest, the number of harvests, and the survivability of the plants and price. Research is underway in the summer of 2010 as part of the continuation of this project to ascertain the answers to this question. In addition, varieties listed and others are being planted every other week to confirm growth and development and productivity of different planting dates.

Insect management

Insects were scouted weekly in research plots for optimizing production and weed management. Spittle bugs, grasshoppers, and other generalists were identified, but thresholds need to be established. Thresholds will likely be low due to quality aspects of leafy greens. In addition to direct feeding insects, contaminants such as slugs, larva, and eggs need to be evaluated during washing practices.

Weed Management

Results of weed management research is attached in separate file. Outlook provided excellent weed management with minimal injury. Treatments were used that meet tolerances established for baby spinach. This is difficult with harvest potentially scheduled within 10 to 14 days of spray. Note harvest in mid-November.

What conclusions can you make based on project work the analysis of collected data?
Savoy and baby leaf spinach is feasible in Wisconsin. Production season could run from May 20 through October 31 with some risk of frost damage. Harvest capacity must be created to commercialize production and field scale trials should be initiated to confirm preliminary results and to train growers. Part of harvest capacity includes vacuum cooling for shipment of spinach greater than 30 to 50 miles.

What do you plan to do in the future as a result of this project?
We are repeating variety, planting date, and density trials. We have written a USDA SCRI proposal to investigate the potential for a regional spinach production system that would move Pacific Coast spinach production to the Midwet.

What information or additional resources are needed to commercially develop this enterprise?
Greatest current need is development of practices to improve food safety. Re-packers in Oklahoma, Indiana, and North Carolina have agreed to conduct commercial tests to evaluate the controlled atmosphere packaging of spinach and subsequent shelf life and food safety.

How should the agricultural industry use the results from your grant project?
These are preliminary results. Small plot results need to be confirmed. Pre-commercial trials involving growers, packing sheds, and retailers are necessary to confirm results and commercial capacity.

SPINACH HERBICIDE EFFICACY EVALUATION - ARLINGTON - 2009

Jed B. Colquhoun

Location: Arlington Ag Research Station - Horticulture Farm Field 604

Plot Information:

Soil Type: Plano Silt Loam; pH 6.9; OM 4.4%.
Variety: 'Tortoiseshell'
Date Planted: 8/26/09
Row Spacing: 4 double rows/6' wide plot
Plant Spacing: 1 inch
Date Harvested: 11/17/09
Plot Size-Design: 6' x 15', 3 Reps
Rating Dates: 9/26, 10/8

Application Equipment: CO^2 Backpack Sprayer. GPA 20, PSI 30, MPH 3.3,
Nozzle - XR8003VS, Nozzle spacing 18", Height 18".

Incorporation Equipment: N/A

Herbicide Application Data:

Date	8/26/09	9/21/09	
Time	-----	-----	
Treatment	PRE	EPOST	
Soil Moisture			
SF	dry	moist	
1"	dry	moist	
3"	moist	moist	
Soil Temp (F°)			
2"	76.0	75.0	
4"	75.0	70.0	
Air Temp (F°)	81.0	74.0	
Wind	2-4 NE	2-4 S	
%RH	60.0%	63.0%	
Sky Condition	90% cloud	40% cloud	
Crop Stage	PRE	1-2 leaf	
Weed & Size	PRE	-----	

Fertilization and other pesticides: none

Irrigation: 1/2 inch on 9/4, 9/11, 9/18

<u>Weed Abbreviations:</u>

COLQ = Common Lambsquarters
SHPU = Shepherds Purse
YEFT = Yellow Foxtail

Spinach Herbicide Efficacy - Arlington, WI - 2009

Trt No.	Treatment Name	Rate	Rate Unit	Growth Stage	9/26/09 % Injury	% Control 9/26/09 COLQ	% Control 9/26/09 SHPU	% Control 9/26/09 YEFT	10/8/09 % Injury	11/17/09 Yield lbs/A
1	Dual Magnum	10	FL OZ/A	PRE	1.7 b	60 bc	60 a	63.3 abc	1.7 b	3408.2 a
2	Dual Magnum	10	FL OZ/A	PRE	6.7 b	70 ab	53.3 a	86.7 a	5 b	2093.6 a
	Roundup Weathermax	1	PT/A	PRE						
3	Outlook	5	FL OZ/A	PRE	6.7 b	93.3 ab	93.3 a	95 a	5 b	2903.8 a
4	Nortron	2	PT/A	PRE	5 b	25 c	36.7 a	30 bc	8.3 b	2215.0 a
5	Paramount	2.67	OZ/A	PRE	1.7 b	71.7 ab	61.7 a	16.7 c	3.3 b	2847.6 a
6	ET	0.9	FL OZ/A	PRE	90 a	90 ab	90 a	90 a	95 a	0.0 b
7	Alphanex	40	FL OZ/A	EPOST	5 b	90 ab	91.7 a	68.3 ab	6.7 b	1814.1 a
8	Spinaid	50	FL OZ/A	EPOST	0 b	90 ab	91.7 a	61.7 abc	5 b	2631.4 a
9	Handweeded				0 b	100 a	100 a	100 a	1.7 b	2656.3 a
LSD (P=.05)					8.14	38.67	47.79	48.57	8.93	1797.06

Means followed by same letter do not significantly differ (P=.05, LSD)

Executive Summary

Project Title: Revitalization of the Mid-American Fresh Market Spinach Industry

Project Type: Research and Extension Project

Legislatively defined goals being addressed:

1. Research in plant breeding, genetics, and genomics to improve crop characteristics
   a. product, taste, quality, and appearance;
   b. environmental responses and tolerances;
   c. pest and disease management, including resistance to pests and diseases resulting in reduced application management strategies
2. Efforts to identify and address threats from pests and diseases
3. Efforts to improve production efficiency, productivity, and profitability over the long term (including specialty crop policy and marketing);

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Summary: The majority of U.S. fresh spinach is consumed as baby leaf or juvenile crop (9 to 15 cm in length) with over 90% sourced from a condensed area of several California counties. Risks associated with sourcing a vast majority of the current fresh spinach crop and the long term sustainability and security of a centralized production system came into focus when food-borne illnesses were linked to spinach in 2006. Spinach packing sheds and grocery retailers have expressed concerns related to transportation costs for hauling spinach and other fresh produce as nearly 50% of the crop travels by truck for more than 60 hours and over 2,300 miles to reach packaging facilities and markets on the eastern seaboard. Current spinach production is located in arid regions of California requiring surface waters for irrigation downstream from other agricultural industries and also at the expense of drinking water in major metropolitan areas. In order to return production to the Midwest, spinach packers will require year-round uninterrupted

supply, high product quality, extended shelf life (e.g. 20+ days), minimal food-borne illness risks, and good agriculture and handling procedures.

The goal of this research is to redevelop a mid-American fresh market spinach industry that will provide year-round supply to consumers east of the Rocky Mountains through a coordinated production scheme from the Upper Mississippi to the Rio Grande River Valleys. In meeting this goal, outcomes of this project will include the development of production systems that optimize production of high quality baby leaf and juvenile spinach for 52 weeks each year with 20+ day shelf life and minimal risk for food-borne pathogens. Objectives include 1) establishment of a suitable marketing scheme of cooperating growers throughout mid-America in collaboration with packers and retailers, including an economic and sustainability assessment of mid-American spinach production, 2) establishment of best management systems regionally adapted for conventional and organic spinach production in mid-America, 3) post harvest management and food safety risk mitigation of fresh spinach, and 4) effective extension of information to mid-American vegetable growers.

Critical Stakeholder Need: The midwestern and eastern spinach procurement operations and packers have identified development of a new regional production system as a high priority and are looking for ways to reduce input and transportation costs and to mitigate serious risks posed to the industry by food-borne pathogens.

Outreach Plan: The principal investigators will meet at least twice a year with grower, processor, and regulatory agency representatives to discuss research progress and needs. Training materials, fact sheets and presentations will be made at local, regional and national grower and industry meetings, and at scientific meetings. Grower trainings will be conducted in conjunction with field days.

Economic, Social and Environmental Benefits: The 2006 *Escherichia coli* 0157:H7 disaster involving California spinach has led to renewed interest in the diversification of production to other regions of the United States to ensure that threats to food safety and national food security are minimized while transportation efficiency and farmer profitability are maximized._This food-borne pathogen outbreak resulted in direct loss of farm income with a significant reduction in retail demand and associated loss in consumer confidence. The unavailability of locally or regionally grown product compels processors and packers to source raw product from distant locations to fulfill their contracts and maintain their customers. This exacerbates high shipping costs, increases the risk of spreading novel strains of pathogens and, overall, is an unsustainable system.

Stakeholder Engagement: Stakeholders played a major role in the conceptualization of a revitalized, Mid-American Fresh Market Spinach Industry. They included provisions for yearly reviews of project objectives (including research priorities) and of the project's milestones related to reduction in food-borne pathogens, increased quality of raw product, and marketability to trading partners within and outside the U.S. Stakeholders will be continually engaged in reviewing the outcomes of the research and in reviewing the impacts the project will have on the industry.

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Revitalization of the Mid-American Fresh Market Spinach Industry

1. Introduction

The mid-American region, stretching from Wisconsin to Texas, has a long and rich history of fresh market and processing spinach (*Spinacia oleracea*) production. The industry has declined dramatically since the advent of bagged baby leaf spinach which currently is grown almost entirely in California and shipped nationally and internationally. The 2006 *Escherichia coli* 0157:H7 disaster involving California spinach has led to renewed interest in diversifying production to other areas of the United States to minimize threats to food safety and national food security while maximizing transportation efficiency and farmer profitability. This new interest, coupled with the dramatic increase in transportation costs and the demand for local produce, creates an opportunity to revitalize the mid-American fresh market spinach industry. Historic production data indicate that it should be possible to produce baby leaf spinach in this area; however, the California production system does not apply to this diverse region. The spinach varieties commonly used for baby leaf production in California are highly susceptible to white rust, which is the limiting disease in the mid-south. The daily high and low temperatures in Wisconsin vary widely, necessitating the selection of germplasm with wide regional adaptation. Best management practices must be established for specific environmental conditions across this diverse production region. To successfully execute this regional production model, marketing and distribution channels using existing salad packing plants in the mid-west and the east coast must be established. Thus, to create an environmentally, economically, and socially sustainable regional food network, a systems-based approach addressing all aspects of the production and distribution system over the entire mid-American region is critical.

The long-term goal of this project is to increase fresh-market spinach production in the mid-American region to supply the demand of regional markets. To meet this goal we have identified four general project objectives:

- **Objective 1.** Address marketing, economic, and social issues.
- **Objective 2.** Determination of Production Best Management Strategies (Component Analyses).
    - a. Assessment of breeding materials (cultivar and planting date evaluation)
    - b. Pest management strategies
    - c. Organic production
    - d. Food safety
- **Objective 3.** Synthesis of component analyses into systems evaluations.
- **Objective 4.** Extension of information to stakeholders and industry.

1.1 Stakeholder Involvement.

Our stakeholders have played a major role in the development of the mid-American spinach production plan and will contribute to the project through regular reviews of its progress, updating research needs and adjustments of objectives, if needed. Based on these discussions, the processing industry may revise the research and outreach needs listed in this project proposal, as some problems are solved and new ones are identified. The objectives of this proposal are taken directly from research priorities outlined by the spinach industry as discussed at annual meetings. Dissemination of information between researchers, extension specialists, and stakeholders; identification of research needs and planning of research and extension activities will occur at these annual meetings. In addition, technology and information will also be transferred to stakeholders at regional and national grower meetings, field day events, statewide vegetable newsletters, and through popular press and scientific articles.

Both the stakeholders and the advisory committee members have had, and will continue to have, significant input on major goals of the project. Consultation meetings have been conducted which involved the Wintergarden spinach board members, spinach producers and one major salad packing company. Plans have been made to ship a truck load of spinach from the Texas Winter Garden to a salad plant in the eastern U.S. during the second year of the project for quality evaluation. If needed, additional loads may be shipped in the second and third years. The spinach will be produced on a grower's farm in the Wintergarden utilizing the grower's planting and harvesting equipment. A vacuum cooler will be used to prepare the product for shipment under current industry methods.

1.2 Body of knowledge, on-going/recent activities related to the proposed project, and preliminary data

Spinach ranks among the top nutrition-rich vegetables consumed in the United States. High in beta-carotene, pro-vitamin A compounds, lutein (Murphy 2001), and other antioxidants (Howard 2001), spinach has the potential to supply Americans with a diet rich in compounds protecting against a slew of health conditions including cancer, heart disease and macular degeneration (Prior 2003). In addition, spinach is a rich source of folate, vitamin C, calcium, iron, phosphorus, sodium and potassium (Ryder, 1979; Nonnicke, 1989; Dicoteau, 2000). US consumers have recently increased their spinach consumption in response to the availability of the bagged, ready-to-eat product developed by producers in cooperation with packaging facilities on the west coast. Development of proprietary controlled atmosphere techniques has increased the shelf life of fresh baby leaf and juvenile spinach to 20 d after packaging or up to 4 wk after harvest. This convenient product has dominated the fresh spinach market and is a major reason for the decrease in spinach acreage in the mid-South and other historic spinach-growing regions.

The mid-American region has a long history of spinach production. Texas alone produced almost 50,000 A of spinach in 1936, equating to about 2/3 of the total U.S. spinach production, and Zavala County, Texas produced about 2/3 of the Texas acreage or about 1/3 of the total U.S. production (Smith and Anciso, 2006). Arkansas once produced about 12,000 A of spinach during its peak, consisting of about 10,000 A of processing spinach and 2,000 A of fresh market (US Census of Agriculture, 2009). Oklahoma has produced as much as 14,000 A of spinach, the majority of which are going to processing facilities but with some fresh market acreage (US Census of Agriculture, 2009). Wisconsin produced a smaller but still significant acreage of both fresh market and processing (500 A annually) (Census of Agriculture, 2009). During the past 20 yr, however, there has been a dramatic increase of fresh market spinach in California and Arizona with the advent of baby leaf and bagged clipped spinach. California spinach acreage increased from 10,558 A in 1987 to 34,800 A in 2005 while Arizona spinach acreage has increased from 192 A in 1987 to 6,000 A in 2005 US Census of Agriculture. This increase has been at the expense of production in other regions; the Texas spinach acreage decreased from 7991 A in 1987 to 2100 A in 2005 (US Census of Agriculture, 2009).

During the past two years, several events have led to a changing business climate for the West Coast spinach industry. First, in 2006, a major outbreak of food borne illnesses connected with fresh-bagged spinach occurred. Second, the price of fuel has increased significantly to the point that transportation costs from the West Coast have become a major issue for both the spinach industry and the consumer. Third, high land and production costs in California have prompted salad packers to consider other production areas. These issues have caused the spinach industry and most consumers to realize that locally grown produce may mitigate food safety risks, maximize economic returns, and minimize carbon footprints.

The effect of the concentrated acreage of fresh-pack spinach on the fragility of the current spinach market is illustrated by the August 2006 *E. coli* outbreak. The 2006 outbreak of *E. coli* 0157 H7 caused significant damage to U.S. spinach production, with both fresh market and processing spinach acreage reporting significant reductions in consumer demand. California, Arizona and the U.S. reported 22%, 24% and 21% reductions respectively in spinach acreage between 2006 and 2007. The U.S. acreage in 2008 was still 8.8% below 2006 pre *E. coli* levels. Demand for bagged spinach fell 43% from August 2006 until February 2007 and demand for bagged salad containing spinach fell 42% for the same period while bagged salad demand fell only 5% for the same period. The California and Arizona acreage has not fully recovered from the 2006 *E. coli* outbreak and current acreage is still probably below 2005 levels (personal communication with industry sources). In response to the 2006 spinach *E. coli* outbreak which was responsible for three deaths and hundreds of illnesses, California farmers in 2007 formed the California Leafy Green Products Handler Marketing Agreement (LGMA) which represents approximately 99% of the California leafy green production. This agreement sets new standards for industry food safety. These events brought to the forefront the importance of diversification of production regions to national food security.

Geographical diversification of the industry could lead to significant cost-savings. Increased transportation costs due to unpredictable price increases for diesel fuel have led to additional interest in bringing production regions closer to population centers. Decreased transportation costs coupled with the dramatically lower land prices in Arkansas, Oklahoma and Texas could reduce production costs significantly. For example, land rent in California can exceed $2500/A annually while comparable land in Zavala County Texas can be purchased for less than $2000/A.

Thus, the opportunity exists for these historic growing regions to be revitalized through the creation of a mid-American spinach production and market region. To achieve this goal and sustain the industry, however, several issues need to be addressed. First, several questions with respect to marketing and distribution need to be answered. Second, integrated management recommendations must be established for spinach production systems across the diverse agroecosystems of the mid-American region. Third, this current information must be communicated to vegetable growers converting acreage to spinach production.

2. Rationale and Significance

Marketing, economic, and social issues (Objective 1). The mid-American region has the potential to supply a year-round spinach crop and could be very significant in meeting local and regional spinach demands. Arkansas and Oklahoma have similar production seasons, producing fall spinach from October to December. The Texas winter crop is available from December until mid-March. The Arkansas and Oklahoma spring crop is harvested mid-March until mid-May. The Wisconsin harvest season could span from May until October. By distributing production over these growing regions, a year-round spinach supply should be possible. By increasing availability of high-quality spinach that is produced closer to the local market, spinach consumption in the United States could increase, leading to improved nutrition in the American diet, and thus improved public health.

The creation of this production and distribution model for spinach would be significant on several levels. First, this project would decrease the carbon footprint of our food system by decreasing the food miles traveled of a popular fresh vegetable in the Midwest, south, and east coast. Second, this project would provide data that could minimize the environmental impacts of spinach production by providing regionally specific, integrated pest and fertility management approaches, including organic production. Third, by decentralizing spinach production, this project will significantly decrease threats to food security and public health. Fourth, by providing a new production opportunity for vegetable growers in the mid-American region, this project impacts the quality of life and economic security for these growers.

The production of spinach in the mid-American region, while certainly feasible, presents some major challenges. The 'California' production system model cannot simply be moved elsewhere due to several significant factors. Spinach varieties adapted to specific environments with the production region will need to be identified. Best management practices with respect to insect, weed, and disease management will need to be established for both conventional and organic production systems. Postharvest handling and food safety issues will need to be investigated. Finally, marketing, distribution, and economic logistics will need to be determined. Thus, an integrated, systems-based approach addressing all aspects of the production, economics, and distribution must be undertaken.

Post-harvest handling and distribution. Beyond production issues, significant challenges exist in the post-harvest handling, distribution, and marketing of mid-American produced spinach. Most western growers have developed a production model in which most of the product is packed locally with a portion of west-coast spinach production packed in salad plants located in the Midwest and on the East Coast where spinach and other salad components are shipped in bulk. Texas growers who currently produce fresh market spinach do not pack harvested product on-site, but use a repacking facility outside the production area. If production was increased in the mid-American region, these salad plants could pack regionally produced product which would dramatically reduce transportation costs and meet the growing demand for food produced closer to the consumer. Since Texas growers currently produce fresh market spinach but use a repacker rather than pack the product themselves as the western producers do, the development of a mid-American spinach production system will necessitate either working with current existing local shippers to develop packing facilities or using existing mid-western and eastern salad packing facilities that are owned by the current major salad packers.

Determination of Production Best Management Strategies (Component Analyses) (Objective. 2). Spinach is a cool weather crop that performs well in temperature ranges from 30

– 90 °F (-1 to 32 °C). The optimum temperature range for growing spinach is between 50 and 65 °F (10- 18 °C). Spinach is grown during medium daylength periods of the year (< 13 hr of daylight) to prevent premature bolting (Chun et al. 2000, Chun et al. 2001). In order to grow spinach 52 wk/yr, production seasons from north to south with optimal temperatures for spinach production must be coordinated (Figure 1). As impossible as spinach is in winter in Wisconsin, similar challenges exist in producing spinach during 45 °C conditions in Texas during the summer. Intermediate day spinach is resistant to bolting during longer days allowing for summer spinach production in California as well as Wisconsin, but management systems must be refined to optimize production in rotation with other crops throughout the region.

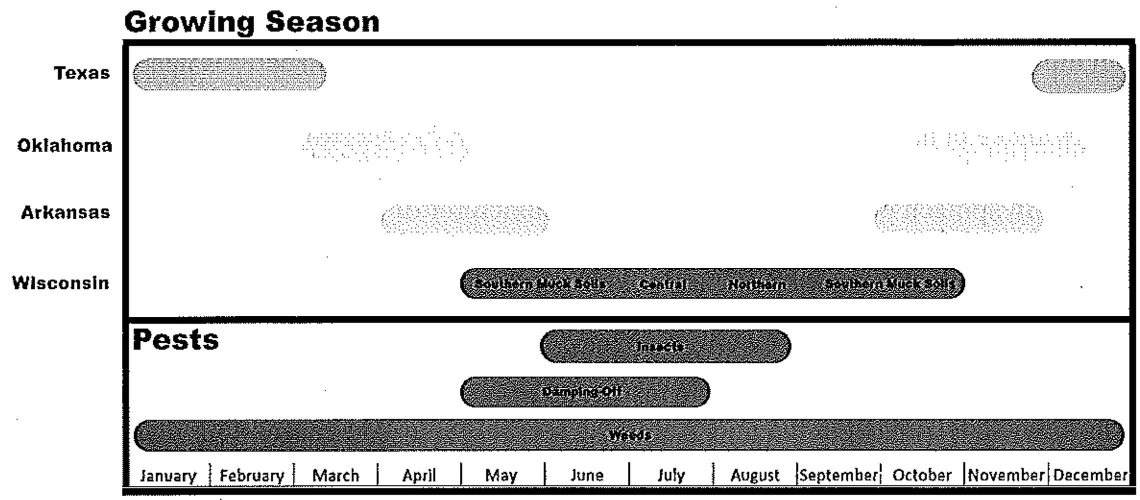


Figure 1. Theoretical spinach production schedules and pest management concerns for mid-American fresh market supply chain.

Spinach is typically planted on raised beds with several rows per bed (4-12) depending on the cultivar and harvest timing and method (California Pesticide Impact Assessment Program 1999). Specifically, baby spinach is grown on beds with 80 to 84-in centers with 20 to 36 rows per bed. Spinach is directly seeded at a depth of ½ to 1 cm and a seeding rate of between 5 and 25 lb/A for processing, depending on the spinach cultivar. Fresh market spinach growers will typically be seeding at over 1,000,000 live seed per acre, but there is limited published data on optimal seeding rates for baby or juvenile spinach to justify such a substantial investment in seed costs. Thus, further research must be conducted to provide economically sound recommendations to mid-American vegetable growers adding spinach to their rotations.

Variety selection. As stated above, a strong effort will need to be made to address issues of regionally-specific variety selection. Different disease pressures such as white rust in the mid-south exclude the use of the spinach hybrids currently grown in California and Arizona. Higher mid-summer temperatures in Wisconsin will challenge the current California-grown cultivars with respect to seed germination, seedling vigor, and quality. New regionally-appropriate varieties will need to be identified to maximize productivity in each environment in the proposed growing region. Further, germplasm evaluation may also help address quality issues that exist in California. Currently, the California baby leaf industry uses flat leaf spinach varieties, which make it difficult to disperse specific leaf quantities mechanically. Using semi-savoy varieties, with contoured leaf surface, should reduce or eliminate issues with product dispersion machines on the salad packing line. Semi-savoy types also have thicker leaves, which may improve product quality. Two recent Arkansas spinach releases 'Wintergreen' and 'Evergreen', high-quality, dark-green semi-savoy types with high levels of white rust resistance, have increased the potential for mid-South production. Because these are open pollinated varieties, seed costs are less compared to hybrid seeds. California and Arizona high density baby leaf spinach production uses hybrid varieties which sell for 35 cents or more per one thousand seeds. Thus, seed cost for baby leaf spinach can exceed $1200/A. Open pollinated varieties cost about $0.20/1,000 seed, which could reduce seed cost per acre by over 40%.

Weed management. Regionally-specific weed management recommendations need to be generated if spinach production is to be successfully expanded. Extreme sensitivity to herbicides and the relatively small acreage of spinach in the U.S. create a void in weed control products, as chemical companies do not spend money on research, development and registration of new products on minor-acreage crops. The spinach industry continues to be in serious need of successful cost-effective weed management strategies, especially in terms of herbicide availability (Wallace et al., 2007). Dual Magnum (s-metolachlor) and Ro-Neet (cycloate) are the most widely used herbicides in spinach. The intensive use of Dual Magnum may lead to a shift in weed species in spinach production fields. The manufacturer of Ro-Neet has limited supplies and may withdraw sales from the market within the next 2 years (Marshall Wixson, Helm Agro, Inc., personal communication, 2008). Stinger (clopyralid) and Spin-Aid (phenmedipham) are the two registered postemergence broadleaf herbicides currently available to spinach producers. Select Max (clethodim) and Poast (sethoxydim) are registered for grass control, but may cause crop injury (Wallace and Petty 2007). Little research has been conducted with postemergence herbicides in baby leaf spinach in the mid-American region. Spin-Aid causes significant leaf burn under certain environmental conditions which is unacceptable in baby leaf spinach production. Additionally, there are crop rotation restrictions (soil residual) when Stinger is applied postemergence. Both herbicides may have limited use in baby leaf production in the mid-American region unless lower rates and different timings can be researched.

Costs of weed management programs not only include actual cost of the chemical and application, but may also include potential reduced yields where herbicides are applied. Wallace and Petty (2008) reported that when compared to the handweeded control, Dual Magnum alone reduced revenues by 19%, while there was no loss with Ro-Neet. However, Ro-Neet will not provide long-term control, and often handweeding is required at significant cost, if labor is available. Postemergence treatments of either Stinger with or without SelectMax further reduced revenues 11%. Spin-Aid caused 40% yield and revenue losses. As a result, continued herbicide screening is needed to evaluate new products, as well as older chemistries with respect to rates, tank-mixes, timings and use patterns.

Insect pest management needs to be addressed to increase profitability of production in the mid-American region. Insect pests in these regions may vary both spatially and temporally. In northern production areas (e.g. Wisconsin), a more discrete set of target insect pests could be expected including colonizing aphid species such as green peach aphid, melon aphid, and black bean aphid. Because of the melon aphid's ability to tolerate hot weather, we may anticipate larger populations of this insect during the mid-season. These species can cause direct damage to plants by extracting photosynthate resulting in significant plant stunting and leaf curling and also by excreting honeydew, which causes sticky, shiny leaves to turn black as a result of growth of sooty-mold fungi. These species may also pose significant indirect risk to the crop by vectoring plant viruses such as alfalfa mosaic virus (AMV) and zucchini yellow mosaic virus (ZYMV). Several species of armyworms and cutworms may also invade and infest spinach crops in the upper Midwest region. Armyworm damage can be clustered as larvae feed gregariously shortly after hatching, causing leaf skeletonization. As larvae mature, they tend to disperse and consume irregular patches of foliage or entire leaves. Cutworms do most of their feeding near the soil line, often cutting off seedlings at ground level. Corn earworm populations, which increase significantly later in the growing season on other agronomic and vegetable crops, can also move onto spinach as these crops are harvested. Although the adult earworm moths will deposit eggs on available spinach foliage, the larvae do not complete development and eventually die late larval instars. Their presence at harvest can result in contamination of processing spinach. Finally, grasshoppers can pose a significant threat as a late-season pest and contaminant at harvest. Although grasshoppers do not prefer spinach, in the later fall months, grasshoppers will move from mature or harvested agronomic crops like soybean and corn into adjacent spinach. Perimeter or border areas of fields generally incur the highest infestation, although populations can be detected in the interior of infested fields.

Organic spinach production. The popularity of organically produced ready-to-eat leafy greens offers an additional opportunity for mid-American organic growers. Wisconsin ranks # 2 in the nation with respect to the number of organic farms. Although the organic acreage in Arkansas is small, acreage has increased from 997 A in 1997 to 10,386 A in 2005 (USDA/ERS, 2005). Weed management is a major issue in conventional vegetable production, but even more so in organic vegetable production. Without conventional herbicides, growers will have to rely on tillage, cultural practices, handweeding, or other methods to control weeds. Not all of the alternative methods are practical. To minimize weed problems, hand-hoeing is usually done, but this is very costly and labor supply is limited (Parish et al. 1995). The average herbicide cost for spinach is $183/A per application (Bridges 1997). Under severe infestations, handweeding can cost up to $914/A in Texas, with the total cost for weed control becoming more expensive when handweeding is employed later in the season (Frank Dainello, Extension Specialist, personal communication). In addition to unique weed management strategies, specific cultivar recommendations are needed for organic crop management. A greater understanding of the impact of organic spinach soil fertility management on postharvest product quality is needed as well.

Food safety. Americans are eating more fresh vegetables: between 1970 and 2008, U.S. per capita consumption of fresh vegetables increased about 67% -- from 108 to 180 lb/yr (USDA, 2008). However, documented cases of food-borne illness associated with consumption of fresh vegetables have increased as well. The U.S. Centers for Disease Control and prevention reported 190 produce-associated outbreaks involving 16,058 illnesses and eight deaths in the 24 years between 1973 and 1997 (Sivapalasingam et al., 2004). In the next five years, 1998-2002, the number of reported outbreaks increased to 279, involving 10,533 illnesses and 7 deaths (CDC, 2006). This amounts to a seven-fold increase in annual outbreaks, a three-fold increase in illnesses per year, and >30-fold increase in the number of deaths attributed annually to the consumption of contaminated produce. This trend appears to be continuing. The 2006 outbreak of *E. coli* O157:H7 infections linked to fresh spinach alone caused at least 200 illnesses and 3 deaths. Indeed, the FDA has identified leafy greens as one of the fresh produce commodity groups responsible for the bulk of produce-associated outbreaks, the others being cantaloupes, tomatoes, green onions, and herbs (FDA, 2007a).

Fresh-cut spinach packers and processors generally use sanitizing washes or dips to clean and sanitize spinach prior to packaging. These washes or dips rely on chlorine or other sanitizers to kill harmful microbes. When properly applied these treatments will substantially decrease — but not eliminate — microbial contamination (Beuchat, 2007; Doyle and Erickson, 2008). Therefore, in-field control of microbial contamination is essential. Studies have shown that pathogenic microorganisms may survive in the soil for several months (Doyle and Erickson, 2008). Researchers are also beginning to discover a number of ways in which pathogenic microorganisms may gain entry into plants in the field (Bartz, 2006). This only reinforces the point that minimizing the risk of contamination in the field is critical. Research involving the production of fresh-cut spinach clearly needs to address this.

3. Approach, activities, methods, and inputs

The development of a sustainable and prosperous regionally-based agricultural production and distribution system is an immense undertaking that requires a wide array of participants (land-grant university researchers, industry representatives, farmers, distributors, packers) from a diverse range of disciplines including agricultural production, pest management, food safety, economics, and rural sociology. The design of a research program that addresses these diverse areas creates a challenge to the traditional discipline-based research conducted by land-grant universities. To address these challenges, we have designed a research plan that will allow basic research to be initially conducted in the discipline areas and allow for the integration of the diverse areas into a systems-based research approach. In years one and two of the proposed project, component research will be conducted in areas where information gaps exist. In year three of the project, the optimal strategies found in the component research will be combined into systems experiments that will demonstrate the interactions between the components, both synergistic and antagonistic, and allow for fine-tuning of the systems. During this latter phase of the research project, the best treatments identified from each of the component objectives (best management practices, postharvest handling, distribution and marketing) will be trialed both on research station plots and on working farms and packing sheds to evaluate the optimal systems for each region.

3.1 Market development, economic analysis, and social component (Objective 1)

The confirmation of a market for baby leaf spinach in the mid-American region is the critical first step in the process of revitalization of the fresh market spinach industry. A logical way to approach this problem would be to work with the industry intermediaries (procurement firms, brokers, retailers, etc.) in terms of identifying the current distribution system and exploring possible ways to augment and improve the current system. Dr. Merritt Taylor, a research and extension agricultural economist, has engaged the industry in these discussions and has participated in the emerging corporate sustainability discussions that seek to diversify the sourcing of agricultural products for both environmental and risk diversification motives. Dr. Taylor has considerable experience in the area of marketing horticultural crops and the development of enterprise budgets for specialty crops as a business planning tool.

Meetings have been conducted with four major salad packing companies who have expressed an interest in fresh market spinach production in the mid-south. They seek to bring new growers into this sector and marketing through the existing supply channels would be the most logical way to develop the industry. Producers could build their own packing facilities, but this would be at considerable expense. An additional hurdle for growers to engage in value-added processing would be the need to develop their own sales and product lines. Developing new marketing channels would be far more complicated and costly than working with already established packers who are currently marketing spinach and salad products year round.

To address the social, marketing, and economic aspects of a mid-American regional spinach production system, the following subobjectives will be met:

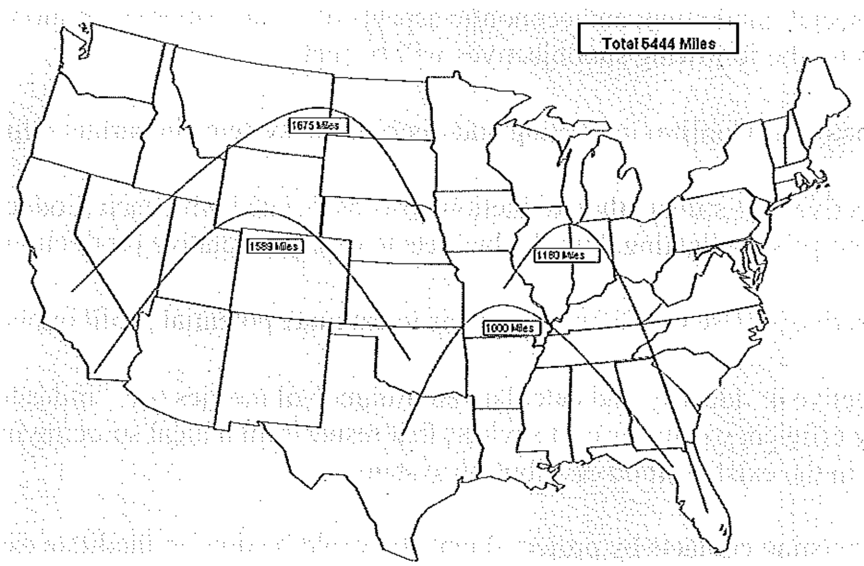
- Subobjective 1: Confirm marketing and distribution systems in partnership with industry.
- Subobjective 2: Estimate the production costs associated with each production region using enterprise budgeting. Use the budgets to examine relative production efficiencies
- Subobjective 3: Use cost/benefit analysis to estimate potential profit opportunities
- Subobjective 4: Identify and calculate environmental metrics (i.e. "miles to market") that quantify efficiency gains or cost savings that result from a local sourcing marketing scheme in the existing food distribution system.

In this project, existing contacts by project scientists would be used to facilitate exchange between salad packers and spinach producers and grower groups in the mid-American region. Several national salad packers have expressed interest in this area and some preliminary steps have already been taken by both producers and packers. The results generated by the production components of this project will be used to demonstrate the feasibility of this venture. Enterprise budgeting will be used as the framework to analyze the relative production efficiency of the project's areas. The budget process estimates the fixed and variable costs allocated for a specific enterprise on a per unit basis, which is typically an acre. The enterprise budgeting framework relies heavily on agricultural engineering concepts allocating fixed machinery costs by performance rates and field efficiency. The process allows the sequencing of production operations and allocating a cost for each field performance.

Budgets are an integral part of planning and risk analysis for agricultural production systems. Business managers (including small, part-time and beginning producers), lending institutions, state/federal service providers, government entities, agricultural support industries, educators, Extension specialists, and legal advisors are all interested in the cost estimates and resource needs outlined in budgets. Relative changes in production efficiency for the identified production regions will be examined through partial budgeting techniques.

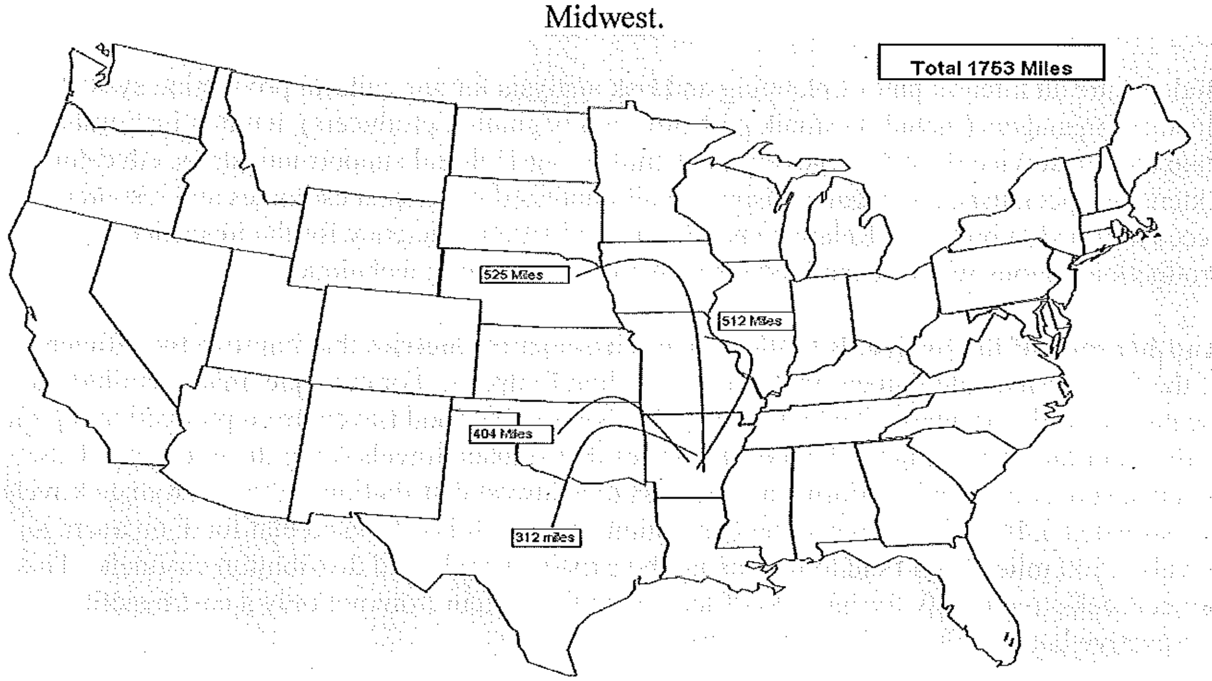
Another goal of the project is to identify environmental metrics that improve the efficiency of the food system and reduces the systems' carbon footprint. For example, many retailers use the metric "miles-to-market" which tracks the distance that food travels from production region to distribution center. Figure 2 details the miles that spinach travels using the traditional U.S. produce supply areas of California and Florida to Midwest distribution centers. Produce travels an estimated 5,444 miles to reach the population centers. It is estimated that food, on average, travels 1,500 miles from field to fork using the existing supply and distribution channels. This project seeks to quantify the gains in efficiency to the system from not only a cost/benefit perspective but also the environmental impact.

Figure 2. Estimated Food Miles for Produce from Traditional Production Regions to Midwest.



A potential gain to the system is reduction of food miles traveled to the same distribution centers with a local sourcing scheme (Figure 3). It should be noted that the food miles metric can be used to quantify numerous efficiency gains including diesel fuel savings, driver hours, and extended product shelf life. Examining only food miles reveals that a local sourcing strategy from Arkansas to the same regions would result in almost 4,000 food miles saved. This project seeks to identify the potential for savings from a local sourcing strategy for babyleaf spinach.

Figure 3. Estimated Food Miles Using a Local Sourcing Strategy to Midwest.



3.2 Development of best management practices for regional conventional spinach production

To develop best management recommendations for the diverse agroecosystems of the mid-American region, component analyses for the major production aspects (seeding densities; weed, insect and disease management; fertility management; organic production management; postharvest handling) will be conducted in the first phase of the project. The best treatments for each region will be integrated in a larger experiment in phase two of this project.

3.2.1 Seeding density and cultivar evaluation

Southern Subregion

Specific objective. To determine optimal cultivars and seeding systems for southern baby leaf spinach production. An experiment will be established to investigate the interaction of row spacing, plant population, and spinach cultivar (Table 1). Experiments will be carried out in Kibler, AR, Bixby, OK, and Uvalde, TX at experiment station sites or commercial production fields. All plots will be fertilized according to soil test results and crop fertility recommendations. Data to be recorded will include stand counts from 0.5 by 0.5 m quadrat in the middle of each plot, whole-plot yield, crop quality ratings, insect infestations and disease ratings when present. A 2-kg leaf sample from each plot will be sorted to quantify weed contamination, percent diseased leaves, and percent insect damage to assess product quality. Experiments will be carried out in the fall and spring growing seasons. Treatments will be replicated four times in a randomized block design with a minimum plot size of 8 ft X 20 ft. Plots will be planted using precision planting equipment to ensure accurate plant populations and plots will be harvested using commercial equipment.

Table 1. Southern subregion seeding density and cultivar treatments

Treatment level	Treatment description
Mainplot factor (number of rows)	12 rows
	18 rows
	24 rows
Subplot factor (cultivar)	1
	2
	3
	4
Sub-subplot factor (seeding rate)	500,000 seeds/acre
	750,000 seeds/acre
	1,000,000 seeds/acre

Northern Subregion

Specific objective. To determine the appropriate seeding method, cultivars adapted to the northern subregion, and optimal planting window. In Wisconsin, the experiment will be located at the Horticultural Research Farm at the University of Wisconsin Agricultural Research Station in Arlington, WI. The experiment will be designed as a split plot with four replications (Table 2), with a minimum plot size of 12 ft X 20 ft. Two seeding strategies will be the main plot: broadcast seeding or row seeding, both on 6-ft beds. Subplot treatments will be cultivar, with 8 cultivars tested. The experiment will be replicated at three planting dates each year in order to represent the range of possible production windows. The target planting dates will be April 15, June 15 and August 1 for spring, summer, and fall production, respectively. Spinach stands will be assessed 3 wk after planting by counting the number of plants in 1-m length of the center rows of each sub plot. During the growing season, insect and disease tolerance of the cultivars will be monitored. All treatments will be harvested 6 wk after planting at baby leaf stage using a band saw cutter. Leaves will be sorted to quantify weed contamination, percent diseased leaves, and percent insect damage in order to assess product quality. Yield of the harvested product will be determined by weighing total and salable product. Taste tests will be conducted to further assess product quality at each planting date.

Table 2. Northern Subregion Spinach Population Treatments	
Treatment Level	Treatment Description
Mainplot Factor (seeding technique)	Broadcast seeding
	Row seeding
Subplot factor (cultivar)	1
	2
	3
	4
	5
	6
	7
	8

3.2.2 Pest Management

3.2.2.1 Insect Management Study

Southern Subregion

Specific objective 1. To establish information on insect biology attacking baby leaf and juvenile spinach in the mid-south. Most of the entomological research on spinach in the mid-south has focused on mature spinach plants produced for the canning industry. Insect populations that develop on spinach that is harvested at an earlier developmental stage can differ greatly from those on mature plants and management tactics should be changed. Additional information on insect biology on early spinach developmental plant stages is needed. To accomplish this, plots will be established at the University of Arkansas Vegetable Station at Kibler and the Main Experimental Station at Fayetteville. At each location, spinach will be planted at monthly intervals from August to May. Whole plant samples will be taken at bi-weekly intervals from each planting until harvest. Insect species composition and abundance will be determined. Emphasis will be on colonizing aphids and lepidopterous caterpillars (beet armyworm, Hawaiian beet webworm, southern beet webworm and corn earworm). Data will be used to establish population dynamics of each insect on each spinach planting. This information will be made available on the UA Vegetable Insect website and will be used to develop practical spinach insect management programs.

Specific objective 2. To refine conventional insect IPM programs to better fit baby leaf and juvenile spinach. Current IPM programs for spinach produced for canning rely on preventative neonicotinoid insecticide applications for aphid management and on traditional insecticide applications for caterpillar management. Coragen has recently shown great promise for controlling lepidopterous caterpillars and is now applied to almost all spinach produced for canning in the mid-south. Refinements are needed for baby leaf and juvenile spinach that is harvested much earlier. Both the neonicotinoid and Coragen applications can likely be reduced on earlier harvested spinach. To refine IPM programs for baby leaf and juvenile spinach, plots will be established at the Kibler and Fayetteville locations. Both aphid and caterpillar population levels will be sampled at weekly intervals by visual examination of a minimum of 20 plants per plot. Treatments will include: 1)) standard preventative insecticides; 2)) applications based on need (5 aphids per inner spinach leaf or 1 caterpillar per plant); and 3)) non-treated. Insecticides will include foliar applied Provado for aphids and Coragen for caterpillars. At harvest, insects will be counted and damage to foliage will be assessed.

Specific objective 3. To develop IPM programs for organic spinach production. Data from specific objective 1 should identify planting dates and production periods when insect population levels remain low and do not require management. When insect management is required, non-traditional ('organic') management schemes will be evaluated. Currently, research at the University of Arkansas has identified some activity of botanical insecticides against aphids on pepper. This work will be expanded to determine botanical activity against green peach aphid on spinach. Green house-produced spinach plants will be infested with aphids from the aphid culture maintained at the UA vegetable insect laboratory. Following establishment, plants will be sprayed with a range of concentrations of each botanical insecticide, up to a point where activity is observed. Follow-up tests will then be conducted to determine effective rates and duration of activity. Similar experiments will be conducted with presently marketed "approved organic" insecticides. When activity can be documented in greenhouse and laboratory bioassays, selected insecticides will be evaluated in small plot trials at the Kibler or Fayetteville locations.

<u>Northern Subregion</u>

Specific objective 1. To monitor the seasonal occurrence and associated population dynamics

of insect pest species at various spinach seeding densities, with different cultivars, and on various planting dates. This objective will directly compare the aphid species profiles detected at different points throughout the crop season and associate them with different cultivars planted under different seeding methods. The seasonal occurrence of different aphid species will be recorded in different treatments and analyzed in relation to the onset of any overt symptoms associated with virus disease progress. In Wisconsin, aphid dispersal and settling will begin in mid-April with the earliest plantings and will be monitored through September to cover the entire growing season. This study will conducted using the experimental setup outlined in Table 2. Within each replicate, a green water pan trap consisting of approximately 1.5-L, clear plastic containers affixed to the top of wire-framed, tomato stakes will be installed. The top of traps will initially be positioned at the soil surface and then adjusted slightly to remain above the spinach crop canopy. Plastic containers will be filled with 0.5-L mixture of propylene glycol plus water and the solution checked (and replaced as needed) weekly throughout the season at the time all alatae are collected. Trapped alatae (winged aphids) will be removed from the solution, counted, and kept in 75% ethyl alcohol for later identification and virus detection. Data collected will be expressed as cumulative counts per species and later logit-transformed for comparison of cumulative counts using mixed model analysis of variance (Proc Mixed, SAS). By completion of this objective, we will improve our understanding of how plant spacing and cultivars can influence host location and settling rates over the course of the planting season.

Specific objective 2. To examine the seasonal occurrence of other insect species infesting spinach. Surveys will be conducted in the seeding density and cultivar evaluation experiments. Species to be monitored will include, but not limited to, armyworms and cutworms, corn earworm, grasshoppers, and crown maggots. Approximately 1 week after planting, initial stand counts will be obtained to determine an estimate of baseline plant emergence. At weekly intervals after this initial count, the number of damaged or missing plants will be recorded over replicated sets of 20 ft of row in each treatment (e.g. cultivar and seeding rate) and planting date. Damaged or infested plants will be pulled, inspected, and tallied for cumulative counts of specific insect infestations, and compared against a final stand count with respect to treatment and planting date. Final percent damage, by pest species, will be estimated and compared against the sum of the final stand count plus total number of damaged plants in each plot. Data will be analyzed using ANOVA, with mean separation by Fisher's protected LSD at $P < 0.05$. Finally, effective, economical, and efficient long term management of foliar insect pests will be implemented in year 3 of the proposed study and beyond. Insect pests determined to be of a high priority for Wisconsin spinach growers in the first 2 years of the project will be targeted in the development and implementation of organically and biologically-based, integrated pest management programs.

3.2.2.2 Weed Management Study

Northern and Southern Subregions

Specific objective 1. To determine current weed management practices, weed management issues, and general technology adoption perspectives of growers in the southern subregion. To accomplish this, a questionnaire will be designed by weed scientists, economist, and social scientist involved in the project. Questions pertaining to production technology, weed problems and other agronomic issues, attitudes toward new or different technology, and economic issues will be included. The questionnaire will be pretested, refined, and conducted in the summer of 2010 in AR, OK, and TX. The survey will target at least 25% of growers in each state and will include home gardeners, growers selling to local farmers' markets, and contract growers. Biological (weed and crop-related), economic, and social information gathered from this survey will be used to fine-tune the weed management treatments proposed and in designing outreach and training activities.

Specific objective 2. To evaluate currently registered herbicides and other candidate herbicides for use in fresh market and processing spinach. Field studies will be conducted at the Vegetable Research Substation, Kibler, AR; Oklahoma Vegetable Research Station, Bixby, OK; Crystal City, TX (Wintergarden Region); UW Arlington Research Station, Arlington, WI; or in collaboration with spinach growers and packers beginning in the fall of 2010 or spring 2011. Trials will be conducted using randomized small plot research methods either on growers' fields or at university research and extension centers. The first experiment will evaluate a set of up to 30 herbicide treatments, consisting of the standard herbicide (metolachlor, 0.65 lb ai/A) applied preemergence (PRE) or early postemergence (EPOST), alone or in combination with clopyralid. Other treatments will include two rates each of dimethenamid, flucarbazone, ethofumesate, thiobencarb (PRE only), clomazone (PRE only), prodiamine, triallate (PRE only), pyraflufen, saflufenacil and linuron (PRE only). Except where indicated, these herbicides will be tested at PRE or EPOST timing. These herbicides are chosen from a long list of candidates previously screened for crop safety. Except for metolachlor and clopyralid, none of these herbicides are labeled for use in spinach. All trials will be conducted using randomized complete block design, small plots (6 ft x 20 ft), with four replications. All treatments will be applied using tractor-mounted or hand-held booms with CO_2-pressurized backpack sprayers, at 15 gal/A spray volume. Data to be collected at 4 wk after planting will include: weed density by species (from 0.5 x 0.5 m), visual weed control rating (0 to 100%), stand count (0.5 x 0.5 m), and visual crop injury rating (0 to 100%). Fresh spinach yield data will be collected 6 wk after planting.

Specific objective 3. Test the efficacy of selected herbicides in conjunction with other cultural practices to attain a sustainable weed management in conventional spinach production system and assess the impact of these systems on various soil and pest status parameters.
In the southern region, during the second year, the top five herbicide treatments will be used in a second experiment involving cultural practices. The experiment will include three factors, which will be tested using a split-split-plot design: 1) Green manure as mainplot (with or without; 2) seeding rate (500,000; 750,000; 1 million) as subplot; and 3) herbicide treatment (5 levels) as sub-subplot. The green manure treatment will be cowpea for fall-planted spinach and winter wheat for spring spinach. This experiment will be conducted in the spring and fall for years 2 and 3. After the fall harvest, winter cereal cover crop will be planted in the mainplot blocks designate to have green manure, and then soil-incorporated 2 wk prior to planting spinach in the spring. The cowpea for green manure application will be planted in the designated blocks in mid-July and soil-incorporated in the last week of August.

<u>Data to collect.</u>

1. Number of weeds and weed biomass per m^2 (by species) 3 and 6 wk after planting
2. % crop injury or stunting at 3 and 6 wk after planting
3. Fresh spinach yield , 6 wk after planting.

4. Soil analysis for each treatment (macronutrients, essential elements, organic matter, pH) before and after each crop cycle. Soil analysis will be conducted at the Soil Testing Facility, Altheimer Laboratory, University of Arkansas, Fayetteville.
5. Costs of herbicides and herbicide applications, and potential losses from weeds existing at harvest.
6. Economic analysis (by Dr. Merritt Taylor) will be conducted by state and across states.

Specific objective 4. To evaluate the efficacy of low herbicide rates at selected planting densities. We believe that at optimum seeding density, herbicides can be used at rates lower than currently recommended because of increased shading from the crop. Wallace and Petty (2008) showed that using higher spinach seeding rates aids in suppression of weeds and that excellent weed control could be achieved with reduced herbicide rates. This would eliminate potential crop injury from herbicide application and reduce weed control cost, thereby increasing profitability. To attain this objective, an experiment will be conducted in years 2 and 3 in two locations in Texas involving two factors: 1) planting densities (two levels) and 2) herbicide treatment (10 levels). The herbicide treatments will include the same top herbicides used for the experiment under specific objective 3, but at 0.75 and 0.5X the rates. Data to be collected will be the same as in objective 3, but without soil analysis.

3.2.2.3. Disease Management Study.

Specific objective 1. To monitor the seasonal occurrence of disease at various spinach seeding densities, with different cultivars, and on various planting dates in the northern subregion. This experiment will be conducted only in the northern region because spinach varieties in the south are bred for resistance to white rust, which is the primary disease problem. The seasonal occurrence and plant health impact of diseases will be monitored among the outlined seeding density and cultivar evaluation experiments located in Arlington, WI. The occurrence of both pre- and post-emergence seedling and damping off diseases (such as Fusarium spp., Pythium spp., and *Rhizoctonia solani*), in addition to foliar diseases (such as *Stemphylium botryosum*, *Cladosporium variabile*, *Colletotrichum dematium*, and *Peronospora effusa*) will be monitored and recorded in different treatments. In Wisconsin, cool soils of early spring (mid-April) can favor the activity of such soilborne diseases as Pythium, Rhizoctonia, and Fusarium. Within each experimental replicate (seeding rate X cultivar), a standardized are of the plot (10 ft of row) will be carefully scouted on a weekly basis and disease symptoms and severity will be recorded. When necessary, plant samples will be collected and taken to the laboratory for pathogen diagnosis. Data collected from each plot will be subjected to statistical analysis (ANOVA with mean separation by Fisher's protected LSD at $P<0.05$) to compare the number and severity of diseases across varieties and to generate disease progress curves to identify key periods for disease management in the Wisconsin spinach growing season. The goals of this portion of the research are to identify key diseases that may be problematic on spinach grown in Wisconsin, to determine the timing of the appearance of such diseases in optimizing a disease control program, and to identify spinach varieties with good disease resistance profiles for production in Wisconsin. Completion of these objectives, will improve our understanding of how plant spacing and spinach cultivars can impact disease control during the growing season.

Diseases determined to be of greatest concern to Wisconsin spinach production in years 1 and 2 of this project will be the focus of further experimentation in years 3 and 4. Additionally, spinach varieties exhibiting the most promising characteristics both horticulturally and in disease resistance will be targeted for further studies to develop a complete and integrated disease management program for Wisconsin spinach production.

3.2.3 Organic Spinach Management

Southern Subregion

Specific objective. To develop best management practices for organic spinach production. The existing few organic spinach growers in the southern subregion practically fend for themselves in terms of producing a crop. There is no research-based information to draw from. Thus, field experiments will be conducted at the Vegetable Substation, Kibler, AR; Wes Watkins Agricultural Research and Extension Center, Lane, OK, where certified organic fields are available; and at the Vegetable Research Station, Bixby, OK and the Del Monte Research Farm, Crystal City, TX on non-certified organic fields. The experiment will be designed as a split-split plot with four replications. The mainplot factor will be soil cover/amelioration, the subplot will be seeding rate, and the sub-subplot will be supplemental weed control treatment. The target planting date for fall spinach is September 7.

Table 3. Southern region organic spinach treatments.

Factor	Treatment	Description
Mainplot (soil cover/amelioration)	Solarization	Applied 60 days prior to spinach planting, using 4-mil clear plastic.
	Cowpea green manure	Planted June 29 and soil-incorporated on Aug 10; seeding rate 8 seeds/linear ft.
	Cowpea green manure	Planted July 13 and soil-incorporated on Aug 24; seeding rate 8 seeds/linear ft
	Sorghum-sudan or Sudex	Planted June 29 and soil-incorporated on Aug 10; seeding rate 30 lbs/ac
	Sorghum-sudan or Sudex	Planted July 13 and soil-incorporated on Aug 24; seeding rate 30 lbs/ac
	Brassica seed meal	Incorporated day before planting spinach.
	No soil cover or amelioration (fallow)	
Subplot Treatments (seeding rate)	500,000 seeds/a	
	1,000,000 seeds/a	

Sub-subplot factors (weed control)	Organic herbicide	OMRI approved burn-down product, to be applied preplant or prior to spinach emergence, as needed.
	Handweeding	
	No weeding	

Spinach will be planted in the first week of September on beds prepared at 80-in centers, with the smallest plot unit being 20 ft long. To keep the integrity of the mainplot treatments over time, mainplots will be separated by 20 ft. At the designated time, cowpea will be flail- or rotary-mowed and incorporated into the soil. The *Brassica* seed meal will be shallow-incorporated into the soil one week prior to planting. Incorporation is necessary to minimize interference with spinach emergence and mitigate the loss of volatile allelochemicals in this material. It is believed that *Brassica* seed meal will be better than a *Brassica* cover crop because *Brassicas* will not grow well when planted in the summer. An OMRI (Organic Material Review Institute)-approved contact herbicide, WeedZap, will be applied as supplemental weed control treatment, as needed. All OMRI-approved herbicides are non-selective, contact-action compounds, which means that they cannot be applied on top of the spinach crop and will only kill emerged weeds. Therefore, this type of herbicide will most likely be applied preplant or any time prior to spinach emergence, to kill emerged weeds. Handweeding will be done as needed; the frequency and man-hours will be monitored for input into the economic analysis. Input costs and profit margins will be compared between treatment combinations. The project will be conducted for three years.

After spinach harvest in the fall in AR and OK, a wheat cover crop will be planted over the whole experimental area to maintain soil cover. No herbicide will be applied on the wheat crop. In the spring, the wheat cover crop will be soil-incorporated in late February and spinach will be planted in mid-March. We expect the crop to be harvested by late April at the latest. The whole field will be left fallow; weeds will be mowed in late May to prevent build up of weed seeds; and the designated blocks will be tilled to prepare for the first planting of cowpea and Sudex cover crops in late June. The remaining plots will be mowed as needed and tilled at the designated time. The solarization treatment will be initiated in the first week of July, in time for the spinach planting in the first week of September.

<u>Data to be collected</u>:

1) Soil parameters - soil organic matter, pH, nutrients. This will be done by collecting soil samples from each sub-subplot at spinach planting and after spinach harvest. The soil samples will be submitted to the Soil Testing laboratory for analysis.
2) Spinach stand, 3 wk after planting. This will be collected from the middle 2 rows, 1 m long.
3) Weed density and visual ratings for weed control, insect damage, and disease infestation will be evaluated at 3 and 6 wk after planting.
4) Spinach yield, 6 wk after planting or when the crop reaches the correct stage for harvest.
5) Data on price of all inputs and the market price of fresh spinach will be collected for the economic analysis of treatments. Economic analysis will be done after the third year by Merritt Taylor, agricultural economist.

Northern Subregion

Specific objective. To conduct an initial assessment of Best Management Practices for organic spinach production in Wisconsin. To address the needs of organic spinach growers in Wisconsin, the organic production treatments will be integrated into both the weed and insect management studies described above. These additional treatments are described in Table 4.

Table 4. Northern subregion organic spinach treatments.

Factor	Treatment	Description
Weed management	Flame weeding	Flame weed before planting and seedling emergence
	Organic herbicide	OMRI-approved burn-down product, to be applied preplant
	Flex tine weeder	1-2 cultivations during early production
	Control	No cultivation

Similar to the conventional component of the trial, the following data will be collected:

<u>*Data to be collected*</u>.

1. Number of weeds and weed biomass per m^2 (by species) 3 and 6 wk after planting
2. % crop injury or stunting at 3 and 6 wk after planting
3. Fresh spinach yield , 6 wk after planting.
4. Soil analysis for each treatment (macronutrients, essential elements, organic matter, pH) before and after each crop cycle. Soil analysis will be conducted at the Soil Testing Laboratory, University of Wisconsin.
5. Costs of herbicide applications and alternative strategies, and potential losses from weeds existing at harvest.
6. Economic analysis (by Dr. Merritt Taylor) will be conducted by state and across states.

All treatments will be harvested 6 wk after planting at baby leaf stage using a band saw cutter. Leaves will be sorted to quantify weed contamination, percent diseased leaves, and percent insect damage in order to assess product quality. Yield of the harvested product will be determined by weighing total and salable product. Taste tests will be conducted to further assess product quality at each planting date.

An additional study parallel to the cultivar evaluation study (3.2.1) for the conventionally managed system will be conducted in an organically managed system to determine the cultivars most suited for organic management. In Wisconsin, the experimental plots will be located at the University of Wisconsin West Madison Agricultural Research Station on their certified organic land. The experiment will be designed as a split-split plot with four replications, with a minimum plot size of 12 ft X 20 ft. Two seeding strategies will be used as main plot treatments: broadcast seeding or row seeding, both on six foot beds. Subplot treatments will include cultivar selection, with 8 cultivars tested. The experiment will be replicated at three dates each year in order to represent the range of possible production windows each year. The target planting date for spring spinach production will be April 15, with a target planting date for summer production of June 15 and for the fall production of August 1. Spinach stands will be assessed three weeks after harvest by counting the number of plants in 1 m length of the center rows of each sub plot. During the growing season, insect and disease tolerance of the cultivars will be monitored. Identical evaluations will be conducted on these treatments as are outlined in the insect management component for the Northern Subregion, section 3.2.2.1.

3.2.4 Food safety

Specific objective. To monitor background bacteria populations and potential contaminants in spinach from organic and conventional farms. We propose to address this issue by collecting samples from both organic and standard-practice production fields in all of the participating states, transporting them to microbiological testing labs at Dole Food Company, Inc., and evaluating them for total aerobic bacteria counts and coliform bacteria counts using Dole's standard microbial assays. This will allow us to monitor background bacteria populations and identify potential contamination events. The data will also allow us to evaluate the impact of organic practices versus standard production practices on the bacterial load of fresh-cut spinach during production and at maturity.

3.3 Synthesis of component best management practices, marketing, and economic data to create regionally-specific systems recommendations

To implement a trans-disciplinary, systems-based approach to the development of management recommendations, integrated experiments will be conducted in year 3 of the project. These experiments will include several important components.

1) From the discrete component experiments described in section 3.2, the treatments yielding the most successful results will be identified for each region. These treatments (variety, seeding density, insect, weed, and fertility) will then be included in a factorial design to be implemented on research stations and several cooperating farms in each region. This design will allow for an analysis of the interactions of crop management components. Thus, systems-based recommendations will be derived for each of the ecosystems comprising the mid-American spinach growing region.

2) To further integrate experiments, product from the cooperating farms will be harvested and sent to cooperating spinach packing facilities. Thus, we will be able to more accurately determine the product quality, including food safety metrics, by industry standards. This will provide further information on both the economic potential of the system by using on-farm input, labor, and yield data.

3.4 Extension Outreach Educational Program

Research and demonstration field days will be carried out each of the years of the program at multiple sites in Arkansas, Oklahoma, Texas, and Wisconsin. Field days will allow local specialty crop producers to witness and understand the technologies being tested at each research site and to speak directly with researchers and extension specialists. Field day sites will include the Vegetable Sub-Station in Kibler, AR, the Oklahoma Vegetable research station in Bixby, OK, the Texas A&M Research and Extension Center in Uvalde, TX and the Arlington Agricultural Research Station in Arlington, WI. The field days will be organized as farmer training days because this is the best opportunity to gather a big group of growers in one place with all the educational resources. A spinach production training module will be developed in the first year and implemented starting in the second year field days.

A regional meeting targeted at both experienced and new specialty crop producers will be organized and made available to producers within AR, OK, and TX. The meeting will include formal presentations by extension and research specialists pertaining to adoption of the new techniques for growing, handling, and marketing spinach and a field tour of on going research. Presentations will also be made at the annual meeting for fresh-market vegetable growers in WI.

General information and results of demonstration and research efforts will be disseminated through an annual project report and specific fact sheets which would be available in printed and electronic forms. Reports will be placed on individual state/university websites. Upon completion of the research, a regional extension bulletin on high density population production of fresh spinach will be published and will include planting and production practices; weed, insect and disease management recommendations; and associated costs. Similarly, regional extension bulletins will be published pertaining to principles, practices, and economics of organic spinach production.

Results of this cooperative research will be presented to those associated with the spinach industry at the annual International Spinach Conference, as well as at local, regional and national meetings including the Weed Science Society of America, American Society for Horticultural Sciences (ASHS) and Southern Region-ASHS. Individual reports and combined summaries will be shared with the stakeholders and funding programs including CSREES/SCRI, regional spinach growers and processors, chemical companies and regional/national grower groups, and the USDA IR-4 Minor Crops Program in order to facilitate potential federal or state herbicide registrations.

The University of Wisconsin Specialists involved in this project largely have split research and extension appointments, thus the project is well founded in outreach and implementation of applied research. The researchers will work closely with grower associations, such as the Wisconsin Muck Crop Growers Association and the Wisconsin Potato and Vegetable Growers Association to conduct the integrated systems phase of the research, as well as to extend and implement resulting information and best management practices. Outreach activities in the northern region will include: grower and industry field days and applied research tours; presentations at a variety of grower meetings, including the annual meetings of the above associations; Extension publications, meeting proceedings articles, and grower newsletters; presentations at regional and national professional discipline meetings; and, publication in peer-reviewed journal articles.

3.5 Potential pitfalls and limitations

Because the mid-American region has grown spinach historically, we do not expect to encounter any major limitations in production in the revitalization of a mid-American spinach production region. Although the possibility exists that germplasm may not be available to help overcome some production issues (i.e. disease and heat tolerance), the large germplasm collection of the late Dr. Teddy Morelock (former Arkansas spinach breeder) minimizes this risk. Materials will be available through the Department of Horticulture, University of Arkansas, Fayetteville. Because the project team has strong ties with the spinach industry which have been integral in the planning stages of this project, the extension of this concept to key industry representatives is expected to be straightforward.

3.6 Hazardous materials

Potential hazards to project participants are similar to those of any commercial-scale farming activity involving tractors and heavy implements. Standard farm safety procedures will be followed to reduce the risk of harm.

3.7 Timeline of project activities

Fall-Winter 2010

- Convene project directors and collaborators and schedule regular project meetings.
- Recruit and hire graduate research assistants.
- Meet with Advisory Board, present plans, and adjust activities based on their input.

Winter-Spring 2011:

- Select cultivars to include in the experiments.
- Establish research sites at all research stations.
- Begin component analyses.
- Begin collection of market price data.

Summer-Winter 2011:

- Continue with component analyses.
- Meet with Advisory Board.
- Present findings at grower conferences and extension meetings; distribute outreach materials.
- Complete and promulgate Annual Report of project activities, findings, and accomplishments.

Spring-Summer 2012:

- Continue with component analyses.
- Host tours, conduct farmer trainings at on-farm trials and research plots.

Summer-Winter 2012:

- Last phase of component analyses.
- Identify best management practices for systems analysis.
- Present findings at grower conferences and extension meetings; distribute outreach materials.
- Complete and promulgate Annual Report of project activities, findings, and accomplishments.
- Begin systems analysis in southern subregion.

Spring-Summer 2013:

- Begin systems analysis in northern subregion..

- Present findings at grower conferences and extension meetings; distribute outreach materials.
- Submit more journal articles of project findings.
- Complete economic and marketing analysis for southern subregion.

Summer-Fall 2013:

- Continue systems analysis in Wisconsin
- Complete and promulgate Annual Report of project activities, findings, and accomplishments.
- Present findings at grower conferences and extension meetings; distribute outreach materials.
- Complete economic and marketing analysis for northern subregion.
- Continue efforts to publish project findings in peer-reviewed journals.
- Maintain project research and outreach programs with other funding sources.
- Work with research assistants to complete requirements and graduate.

3.8 Roles of Key Personnel

Advisory Committee

1. R. Larry Binning – Retired University of Wisconsin Horticulture Department Chair and Extension Weed Scientist Madison, Wisconsin.
2. Jimmy Crawford – member Wintergarden Spinach Producers board and spinach grower Uvalde, Texas.
3. David Hensley – Chair, Department of Horticulture, University of Arkansas, Fayetteville, AR
4. Dennis R. Motes – Director, University of Arkansas Vegetable Research Station, Kibler, Arkansas
5. Stien Pinkston – Wal-Mart produce and floral Bentonville, Arkansas
6. Matt Plymale – Dole Fresh Vegetable (in charge of spinach production) 2959 Monterey – Galinas Highway, Monterey, California
7. Ed Ritchie III – President, Wintergarden Spinach Board spinach grower, LaPryor, Crystal City and Eagle Pass, Texas
8. Merlin Shantz – Spinach Grower, Hydro, Oklahoma

Project Personnel

- Dr. Lynn Brandenberger has 20 yr experience with spinach cultural research and extension in TX and OK including spinach disease research for his dissetation. His research efforts have been in weed control on several vegetable crops, including spinach. He also has been involved in testing crop enhancement materials, effects of drip irrigation and plastic mulch on melon production, fertility needs of vegetable crops, increasing crop inputs for carrot production, and varietal evaluation of spinach and other vegetables.
- Both Drs. Nilda Burgos and Russell Wallace are weed scientists with 10 and 5 years of experience, respectively, on weed control research in spinach. Both are currently conducting spinach herbicide research in their respective states. Dr. Burgos also holds a B.S. degree in Soil Science, specializing in Soil Fertility, and has conducted nitrogen uptake experiments in cultivated and weedy rice in AR. Dr. Burgos will conduct all experiments proposed for AR, except the entomology experiments.
- Dr. A.J. Bussan is the Extension Vegetable Specialist for the University of Wisconsin. A.J. Bussan will be involved in the organic and conventional cultural and soil fertility management studies in the northern region. A.J. will assist with personnel supervision; design, implementation, and analyses of crop production and fertility research studies;

organization, planning, and participation in outreach and extension programs; and completion of appropriate publications.

- Dr. Jed Colquhoun is the Extension Weed Specialist for the University of Wisconsin, focusing on vegetable crops. Jed Colquhoun will be involved in the organic and conventional weed management studies in the northern region. Jed will assist with: personnel supervision; design, implementation, and analyses of weed research studies; and, coordination of pesticide registration projects with registrants and the IR-4 Project.
- Dr. Jim Correll is a plant pathologist with 20 years experience in spinach research and works closely with the University of Arkansas spinach breeder. Dr. Correll has identified the most recent 7 races of downy mildew that have occurred worldwide. He is recognized as the world expert in spinach downy mildew race classification and he has been working with molecular markers for downy mildew spinach resistance genes.
- Dr. Amanda Gevens is a potato and vegetable plant pathologist in the upper Midwest with responsibilities for commercial and fresh market disease management with 7 yr experience and research emphasis in soilborne and foliar vegetable diseases. Dr. Gevens has substantial experience with oomycetous plant pathogens, such as *Phytophthora* spp., *Pythium* spp., and foliar fungal pathogens such as *Alternaria* spp., and *Podosphaera* spp. on a range of vegetable crops. Dr. Gevens will be responsible for the plant pathological studies in the northern subregion.
- Dr. Russ Groves is a vegetable entomologist in the upper Midwest with responsibilities for commercial and fresh market insect pest management with over 10 yr experience and research emphasis on insect vector-borne disease. Dr. Groves has worked extensively with insect-transmitted viral diseases in vegetable crops including Potato virus Y, Potato leafroll virus, Tomato spotted wilt topovirus, Cucumber mosaic virus, Alfalfa mosaic virus as well as leafhopper-transmitted phytoplasma diseases including Aster yellows and phytoplasma in carrots, potatoes, and onion. Dr. Groves will be responsible for the entomological studies in the northern subregion.
- Dr. Paul McLeod is an entomologist with 20 yr experience on spinach insect control. He has researched spinach insect control in AR, OK, MO and TX. He works closely with the vegetable processing industry on insect control issues for spinach, leafy greens, cowpea, and green beans.
- Dr. Erin Silva is an Organic Production Specialist in the upper Midwest who has worked on diversified vegetable production for the last 13 yr. She was the principal investigator of a project in New Mexico investigating the extension of spinach production season in that region. Dr. Silva will be responsible for investigating organic production in the northern subregion and will be the lead investigator for the University of Wisconsin.
- Dr. Larry Stein has 20 yr experience working with spinach cultural research and extension at the Texas A & M Research and Extension Center located at Uvalde, TX in the wintergarden spinach production area. His primary spinach efforts are on spinach fertilizer requirements and fungicides for white rust. He has also participated in the evaluation of spinach breeding lines for white rust resistance.
- Dr. Merritt Taylor has worked with several different specialty crops on budget development. Dr. Taylor will be responsible for the economic and marketing aspects of this project.