# Western Regional Research Project W-128

## *Microirrigation Technologies for Protection of Natural Resources and Optimum Production*

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## PROJECT NUMBER: W128 (Revision)

## TITLE: *Microirrigation Technologies for Protection of Natural Resources and Optimum Production*

**DURATION:** October 1, 1999 - September 30, 2004

**STATEMENT OF PROBLEM:**
Irrigated agriculture is facing increasing public pressure and the threat of increased regulation. These pressures include limited water resources; competition between urban, industrial, wildlife, recreation, and irrigation users; water quality degradation, and the economics. Municipal, industrial, and environmental groups are increasingly concerned with the fact that nearly 80% of the annual water supply in United States is being used for irrigated agriculture. In some instances poor irrigation practices have resulted in environmental degradation due to the transport of nutrients, pesticides, salt, and trace elements to surface and ground waters.

**JUSTIFICATION:**
Few people question that adjustments in irrigated agriculture will be required in the future (NAS, 1996, CAST, 1996). However, the scope of dependence on an irrigated agriculture base that produces 38% of farm revenue with only 15% of the land base requires that economical and technologically sound solutions be developed. Irrigation not only helps provide an economical and stable food supply for the nation but also helps to maintain prosperous and sustainable producers and rural communities. A compelling need exists for solutions that can help maintain higher levels of irrigation sustainability where water supplies can be replenished. In addition solutions are needed that will lengthen the transition period to a less irrigation intensive society in areas where replenishment is less an option.

Most water planners and resource managers recognize that there will be no *magic bullet* that will remove all of the nation's water problems. Instead there is a growing realization that it will take many tools working together to help avoid the significant disruption in the economies and societies grown accustomed to widespread irrigation use. Microirrigation is just one of the many irrigation and water management technology tools, but it is a tool that has several advantages. Microirrigation can reduce the waste of water to a negligible amount and the transport of contaminants to surface water and groundwater. Irrigation events can be fine-tuned to spoon feed water and nutrients just in time to avoid plant stress. It can optimize crop production (maximize economic yield for each unit of water) and in many cases increase the quality of agricultural products.

Some scientists, water planners, and resource managers have been disappointed with the rate of adoption in microirrigation. The U.S. land area that is microirrigated varies on an annual basis but during the last 10 years has hovered in the range of 3 to 4% of the total irrigated area (Irrigation Journal, 1998). It is recognized that some crops and locations are not physically or economically suitable for microirrigation, but this is probably the exception rather than a common situation. Further efforts are justified to reduce the impediments to more widespread adoption.

A cooperative approach towards technology development can be extremely fruitful as evidenced by the significant body of research developed by W128 members over the last 20 years. The cooperative approach allows for the evaluation of group hypotheses and for distillation of common results into general guidelines. It is suggested that the W128 regional project has been very successful in using this approach. The cooperative approach can also be utilized as a peer review process for hypotheses developed by individuals with the hopes of expanding or advancing the overall scientific understanding. Research to adapt or modify technologies fall into this category. Another advantage of the cooperative approach is its utilization as a strong feedback mechanism to point out where there is not enough information or theoretical understanding to develop general guidelines. In the proposed revision, W128 members will utilize the distillation process, peer review process and the feedback mechanism to accomplish the project objectives. In many cases, it will be necessary to refine and adapt microirrigation technologies for site specific conditions (crops, soils, water quality and availability, climate and irrigation system characteristics). In other cases, it will be necessary to improve and develop management strategies to take advantage of the inherent capabilities of microirrigation. To increase the adoption rate of appropriate microirrigation technologies, it will be necessary to assess and improve the decision criteria utilized in the adoption process and it will be necessary to improve technology transfer.

## RELATED CURRENT AND PREVIOUS WORK:

### Overview

Microirrigation was first used in the United States in the late 1950's and early 1960's for greenhouse research and production. The first field research and demonstration studies were initiated in California in 1969 on avocados, strawberries, and tomatoes (Bucks, 1995). The USDA Western Regional project W128 concerning microirrigation followed shortly thereafter in 1972.

The progress of the science of microirrigation can be partially illustrated by the periodic International Congresses that have been devoted to the subject. The First Congress in Israel in 1971 had 21 papers. The Fifth Congress was held in Orlando, Florida in 1995 with 156 presentations. Phene (1995) reflected on the historical record of research during this period and concluded that although much progress had been made, there still remained much research work to be done. Some of the prominent areas of research need listed were plant water and nutrient requirements under microirrigation; chemigation; system design and uniformity; system hardware, sensors, and automation; and modeling and decision support systems; economics, and horticulture and agronomic research to adapt to the capabilities of this relatively new irrigation method. Phene (1995) went on to point out that the bulk of the coordinated microirrigation research in the United States has been conducted by two USDA regional projects, W128 and S264 (Note: S264 was formerly S247 and S143). In comparing the subject of papers in the 1985 and 1995 International Microirrigation Congresses, Phene (1995) showed that predominant research areas remained essentially the same. This was not to criticize the progress of research but to indicate that there needs to be more continued research. This seems especially true particularly in the areas of adaptation and refinement of the technologies to remove stumbling blocks that have been encountered. The proposed W128 project seeks to develop such information. Further literature review will discuss current and previous research related to the proposed project objectives and where this research has fallen short or will be extended by the proposed W128 project.

### Water/Nutrient Management and Chemigation

Bucks and Davis (1986) listed a number of potential advantages for microirrigation. They include increased beneficial use of water, enhanced plant growth and yield, reduced salinity hazard, improved application of fertilizer and other chemicals, limited weed growth, decreased energy requirements, and improved cultural practices. The first four potential advantages are the most important in ensuring efficient use and protection of water resources. Phene et al. (1992) listed several characteristics of SDI systems that can contribute to maximizing water use efficiency, including negligible soil evaporation, percolation, and runoff. Developing careful utilization and management procedures for these potential microirrigation advantages is a major research thrust of the proposed W128 project.

Establishing and maintaining concentrated root systems near microirrigation emitters is one potential method of making more efficient use of water and nutrients. Regulated deficit irrigation (RDI) which is limited to relatively arid areas is a controlled root volume technique especially suited to microirrigation. RDI research conducted in Australia on peaches (Chalmers et al., 1981) and pears (Mitchell et al., 1984), Washington on apples (Middleton et al., 1981; Proebsting et al., 1977; Peretz et al., 1984; Evans et al., 1993, Ebel et al., 1995; Drake and Evans, 1997) and grapes (Evans et al., 1990; Wample, 1996) have produced beneficial responses. Additional work in California, Israel and other arid locations on several crops has also shown that carefully managing the severity and duration of a uniform, constant level of water stress on fruit trees and some other perennial crops can be advantageous. RDI been found to control vegetative growth, increase fruiting, advance fruit maturity, increase precocity and increase soluble solids. Annual water diversions have been shown to be reduced by 20% or more. In the proposed project, previous work will be extended to additional tree crops and through developing improved strategies to manage soil water and nutrients within the RDI context. Plant and soil water monitoring can potentially better define acceptable water stress levels and duration.

A major difficulty in the estimation of water-use efficiency in irrigated agriculture is the uncertainty in the drainage calculations (Hutmacher et al., 1994). In addition to the reduction of water losses, knowledge of the drainage component is also important in the quantification of downward leaching of soluble nutrients such as nitrates. From an environmental perspective, one must assure that these chemicals are not transported below the rootzone toward the groundwater. The drainage rate can be determined from soil water potential gradients and unsaturated hydraulic conductivity values from below the root system. However, the characterization of the appropriate soil hydraulic conductivity functions is difficult. Many methods are available (Klute and Dirksen, 1986). In situ methods are preferred because results are more representative of field conditions although they are complicated and time-consuming. Recently, the inverse estimation of soil hydraulic properties has emerged as an attractive, accurate technique for laboratory experiments (Eching and Hopmans, 1994), but the utility of laboratory-measured soil hydraulic data for application of field studies is difficult and needs further study.

Field studies of the pattern of root development and water uptake are especially important for the optimization of irrigation water use efficiency. Water should not be applied in areas where roots are absent, or at a rate higher than the roots can possibly take up. Thus, emitter spacing and irrigation scheduling must be flexible according to the planting pattern and crop characteristics. In general, root development under drip irrigation is constrained to the soil volume wetted by the emitters, near the soil surface with root length density decreasing with depth (Goldberg et al., 1971; Stevens and Douglas, 1994; Michelakis et al., 1993). However, recent studies have shown that root water uptake is not always in direct proportion to root length density (Clothier et al., 1990) and that plants can quickly adapt their spatial pattern of water uptake in response to irrigation water application distribution (Clothier and Green, 1994). Furthermore, it is important that empirical sink functions used in water flow and solute transport models under drip irrigation reflect the field-observed root water uptake patterns. However, few of these water uptake models have been independently tested under field experimental conditions (Molz, 1981). Studies, such as those by Coelho and Or (1996), are needed to provide accurate spatial and temporal root water uptake distribution data and models. It is hypothesized that variables such as emitter position relative to the active roots as well as irrigation amount and frequency will affect the soil water regime in general, and specifically the spatial and temporal changes in soil water content as controlled by root water uptake and leaching. Gaining a better understanding of these interrelationships, as proposed in this project, will provide alternative means for proper and efficient drip irrigation water management practices.

Irrigation scheduling and water management takes on many forms (Hoffman et al. 1985). Some of these techniques are soil-based, some are plant-based, and some are climatic-based and some are a combination of two or more approaches. In specific circumstances, all of these methods can be particularly meritorious for microirrigation. Climatic-based approaches typically take the form of a water budget with a calculated reference ET multiplied by a crop coefficient. In the proposed project, efforts will be made to develop and refine crop coefficients for a number of crops under microirrigated conditions. Soil-based or plant-based methods which use sensors and controls to initiate and terminate irrigation are highly appropriate for the typical microirrigation system with its high degree of automation and application uniformity. Several of the proposed substudies will be comparing different types of sensors and controls for irrigation to more traditional irrigation scheduling techniques. A thorough review of the use of sensors for irrigation management is provided by Phene et al. (1990).

Comparison of microirrigation to the more traditional forms of irrigation is an important research area because it underlies the decision process concerning adoption of microirrigation systems. Although these comparisons are important, they have often been neglected because of the difficulty in performing statistical comparisons with the scale and operating factors associated with irrigation. In a thorough review of SDI research, Camp (1998) was only able to identify 3 papers where SDI was compared to other irrigation methods. In the broader microirrigation area, only 16 papers at the Fifth International Microirrigation Congress touched on irrigation system comparisons (Lamm, editor 1995). The proposed work will extend previous work by performing some in-field statistical comparisons as well as with some larger demonstration-type studies intended to showcase the technologies to producers.

The combined management of irrigation and nutrient management has long been recognized as an inherent advantage of microirrigation systems. It has received increasing research focus in recent years because of water quality concerns. Indeed, it was essentially the entire focus of the current W128 project, *Microirrigation: Management Practices to Sustain Water Quality and Agricultural Productivity* due to expire in September 1999. Proposed work in the new project would seek to extend these concepts to new crops and to deal with shortcomings in adapting the technology to producer operations. Some of the proposed work would be related to in-field studies while others would be broader modeling efforts. In a CRIS search of other related regional projects W-82, *Pesticide and other Toxic Organics in Soil and their Potential for Ground and Surface Water Contamination* was identified as having somewhat related objectives. However, the objectives of W-82 appear to be much more strongly related to modeling efforts.

Microirrigation can also serve as a precisely targeted delivery system for pesticides (chemigation). Thus, microirrigation chemigation is based on the principles of precision farming where system inputs are qualitatively and quantitatively matched to the needs of the crop. Subsurface drip (SDI) and surface drip systems can be used to for the injection of systemic pesticides and some biocontrol agents while surface microsprinklers may be used to apply biocontrol agents over larger areas and on plant canopies. Use of subsurface microirrigation irrigation systems for systemic insecticide or fungicide application has the advantage of compatibility with integrated pest management principles. However, the use of pesticides through microirrigation systems is much less advanced as compared to nutrient fertigation. No papers directly related to pesticide chemigation were given at the Fifth International Microirrigation Congress (Lamm, editor, 1995). The slow advance is partially because of the increased concern about operational failures that might result in pesticide contamination of water resources. In a more recent review (Evans, 1998) did find at least eight studies where pesticide chemigation had been practiced with microirrigation. Washington State University, a member of W128, is currently involved in a NRI project concerning use of systemic insecticides through microirrigation system. The proposed W128 project will extend the relatively narrow research database on pesticide chemigation. Proposed studies are primarily related to identifying appropriate chemicals, delivery systems and evaluating their effectiveness.

**System Design, Operational Procedures, and Uniformity**

The proper design and operation has always been a high research priority, because within that design and operational strategy lies the inherent microirrigation advantage of precise and uniform application. Its high priority is partially due to microirrigation's relatively short 30-40 year history and also due to the fact that precise irrigation application demands precise design and management. Camp (1998) identified 25 papers that touched on design of SDI systems, yet Lamm et al. (1995) indicated that most design guidelines are generally very specific to regions, crops and soils. Design guidelines may always necessarily contain this local aspect, but the proposed W128 project seeks to broaden these guidelines through the coordinated critical feedback members can give to each other. System characteristics and component operation are also areas in which W128 seeks to make improvements. This will include component testing as well as computer modeling to improve management.

The importance of uniformity to microirrigation systems and the continued development of uniformity evaluation tools remains a major research topic. Some of the present evaluation methods (ASAE EP-458, distribution uniformity, emission uniformity) are better suited to certain types of evaluations and locales. The search for a more common or unifying evaluation tool continues. The proposed W128 research seeks to develop better evaluation tools as well as to evaluate redistribution of water and chemicals with the present uniformity evaluation tools.

**Decision Criteria and Economics**

Although there is general agreement in scientific circles that the adoption of microirrigation technology is not well understood, there is only a small amount of directly related research. Much of the identifiable research has been conducted in W128 member states of California, Florida, Hawaii, Kansas, Texas and Virginia. The proposed W128 research takes the initial first step to rectifying this information void by agreeing that <u>all states</u> will perform cost/benefit analyses for all microirrigation technologies they are investigating or promoting.

**Technology Transfer**

Most media experts agree that there is no single correct medium for transferring knowledge because of the vast differences in people's abilities and learning modes. Some people are more suited to visual learning while others can easily handle auditory learning. The proposed W128 project will continue to use a wide array of technology transfer techniques. The Internet is emerging as an effective tool for technology transfer (Sistrunk, 1998, Golden et al.1994) and some special emphasis will be placed on using it during the proposed project. Transferring this knowledge to the Internet often requires some adaptation and interpretation because the new

Internet media presents material on screen instead of in paper format (Ritchie and Hoffman, 1997).

**OBJECTIVES:**
1. To evaluate and refine microirrigation management strategies to promote natural resource protection and optimal crop production.
2. To improve, modify, and evaluate microirrigation system design and components for natural resource protection and optimal crop production.
3. To assess and develop decision criteria for adoption of microirrigation technologies.
4. To promote appropriate microirrigation technologies through formal and informal educational activities.

**PROCEDURES:**
**Procedures for Objective 1**
Water and Nutrient Management
Several states (**Arizona**, **California, Florida, Idaho, Iowa, Kansas, Minnesota, Texas, USDA-WMRL, USDA-CPRL, Virginia, Washington,** and **Wyoming**) will be conducting water and nutrient management studies. The specific research needs of each state differ but all states agree to collect and report certain key data elements. In all irrigation experiments where a crop response is recorded, regardless of how irrigation is scheduled, applied irrigation water will be expressed as an equivalent depth of water considered over the entire planting area, and a crop water demand will be calculated using a reference ET and Kc approach. In order to compare across experiments, cumulative ETc and applied irrigation will be plotted over time, and the assumptions underlying the calculation of ETc will be specified. If yield is measured, an irrigation-applied WUE will be calculated. Relevant irrigation system characteristics (e.g., uniformity), soils/climate, and nutrient practice information will also be specified.

**California, USDA-WMRL,** and **Washington** will be evaluating regulated deficit irrigation (RDI) on tree crops. **California** will continue a large multi-county experiment evaluating RDI for prune trees as a means of saving water and reducing nutrient leaching. Additional studies will compare surface and subsurface drip, and microsprinkler irrigation for almond production using various levels of irrigation and RDI. Levels or patterns of water stress experienced by the tree throughout the growing season will be analyzed in conjunction with the amount of applied water. Further work with pear trees under different irrigation regimes will be used to determine whether over-irrigation enhances the development of a root disease (Armillaria sp.), and results in water stress despite adequate irrigation once the disease is established. **USDA-WMRL** will be evaluating the effect of irrigation management and nutrient management on the development of peach trees using surface irrigation (control), microirrigation, and SDI. Three levels of applied water are anticipated with the irrigation being controlled through feed back with a weighing lysimeter. RDI treatments will not be imposed for the first three years following establishment. Fertilization will also be a treatment variable. Plant response will be measured by determining plant height, diameter, and transpiration using sap flux measurements. Soil water status will be measured using capacitance type soil water monitoring. **Washington** will be extending current work on RDI of wine grape to different varieties and investigations of the effect of the length of the deficit on wine quality. At present, the end of a deficit period is determined by measurements of the distance between internodes of new growth on the canes. Determining the end points needs to be refined and compared with other physiological markers that also indicate stress levels.

**California** will attempt to estimate the magnitude of the soil water balance components, their spatial and temporal distribution, and root water uptake patterns for selected crops under drip irrigation. TDR combined with digital image processing of root systems will be used to assess the influence of deficit irrigation on the quantity and quality of wine grapes using various rootstocks in drip irrigation. **Kansas** will examine the effect of irrigation capacity, plant population and nutrient management on field corn production using SDI. Crop water use, crop yield components (population, seeds/ear, seed weight) and economics will be utilized to determine optimal strategies for allocating input resources (water, nutrients, and seed). Additional research will examine the effect on corn production of irrigation frequency when coupled with deficit irrigation. **Arizona** will be working towards development of a better irrigation scheduling technique to manage irrigation water while keeping maximum productivity. Field experiments will be conducted to develop growing degree day-based crop coefficients for several crops under arid conditions. **Florida** will utilize a drainage lysimeter facility to make estimates of water requirements for caladium tuber production and for the development of a crop coefficient for caladiums. Plots using microirrigation will be compared to the more traditional subirrigation method in grower-cooperator production areas with irrigation events scheduled according to results from water requirement study. In addition to the common data set, disease incidence will be monitored and production levels will be compared. **Kansas** will conduct field studies to evaluate the yield response of soybean to surface and subsurface applications of irrigation water. Near surface and subsurface soil water contents will be measured and used to assist with scheduling irrigation and to evaluate drip irrigation wetted regions. **USDA-CPRL** will be evaluating different water management criteria for SDI and surface drip of row crops (corn, soybean, and cotton) in a semi-arid environment on a Pullman clay loam soil to enhance water use efficiency. Automated controls using IRT (infrared thermometers) and more conventional irrigation scheduling based on water balances and ET estimates will be compared. **Texas** will compare performance and efficiencies of microirrigation with those of other relatively efficient sprinkler irrigation methods [LEPA (Low Energy Precision Application) and LESA (Low Energy Spray Application)].

Sweet corn (se type, full season) will be grown in **Idaho, Iowa, and Virginia** to evaluate several common methods of scheduling irrigation (AZSCHED, checkbook water balance, modified pan evaporation and sensors). Sweet corn was chosen because it is a high value crop grown by a high percentage of vegetable growers in these states. Previous research has shown these varieties respond well to clear plastic mulch and microirrigation. Where appropriate, common procedures will be utilized by all three states such as soil water sensor placement, target plant population, irrigation decision criteria, nutrient utilization and leaching. Differences in soils and climate will be useful in determining how much optimal management strategies vary across the region. **Guam** will investigate irrigation scheduling and nutrient management on vegetable crops (cucumber and head cabbage) grown on very shallow (15-30 cm deep) soils under humid, tropical climatic conditions. Automated in-situ soil water sensor-based irrigation scheduling will be compared with the ET base scheduling method. Crop response in terms of production and leachate will be measured.

**Kansas** will continue to refine development of BMPs for nitrogen and phosphorus nutrient management for field corn production under SDI. Research with application of livestock wastewater through SDI systems will continue. In addition to design and component issues to be discussed under Objective 2, the wastewater research will evaluate redistribution of water, nutrients and salinity in the soil profile. **Arizona** will also be evaluating the yield response of field corn to various nutrient levels applied using SDI. The focus will be to determine the minimum rate or the amount of fertilizer that will maximize productivity and yet will guarantee minimum contamination or pollution of the environment. **Minnesota** will evaluate the impact of different irrigation methods (sprinkler irrigation and drip irrigation) coupled with multiple fertilizer application schemes for both slow release fertilizer and turkey manure on potato yield and nitrate leaching. Information from these studies will be used to test and validate computer simulation models that predict potato yield and N leaching. **Wyoming** is evaluating surface (flood), sprinkler and drip irrigation under full and deficit irrigation for sugarbeet production in terms of net returns and nitrate leaching. Spatial and temporal distributions of water and chemicals in the soil and groundwater will be determined. These data will be used in conjunction with modeling efforts to develop strategies to diminish groundwater contamination of nitrate and pesticides and to sustain net return from sugarbeets. **Florida** will assess and describe soil water extraction and recharge (irrigation and precipitation) patterns under a citrus canopy as influenced by position under the canopy. Bromide will be used as a tracer to characterize solute movement patterns given the irrigation and rainfall conditions. Field data will be used to evaluate usefulness and limitations of LEACHM as a simulation model for predicting solute movement in a citrus grove on deep sand soils. **Guam** will evaluate nitrogen and potassium fertigation requirements for vegetables using five levels of N and K. Performance will be based on crop production and leaching potential. Nutrients will be applied on a weekly basis. Soil water status will be monitored using tensiometers. **Florida** will evaluate release and redistribution into the soil of nutrients and heavy metals from compost in vegetable production under varying microirrigation levels.

<u>Chemigation</u>
Application of chemicals through microirrigation systems (chemigation) offers the potential of optimizing crop protection activities to maintain high crop quality and high levels of crop production while protecting natural resources. However, to achieve this goal, chemigation will require accurate applications, uniform distributions, precise placement, and proper management techniques to maximize effectiveness and minimize negative environmental impacts. Four primary areas of W128 work have been identified for chemigation. They are to evaluate the uniformity of application and distribution of applied chemicals as affected by microirrigation system design, to evaluate appropriate chemigation products for suitability and efficacy, to develop and evaluate best irrigation water management strategies when used in conjunction with chemigation and to evaluate chemigation effects on microirrigation system components and performance.

Application of chemicals through microirrigation systems (chemigation) offers the potential of optimizing crop protection activities to maintain high quality and high levels of crop production while protecting natural resources. However, to achieve this goal, chemigation will require accurate applications, precise placement and proper management techniques to maximize effectiveness and minimize negative environmental damage.

**California, Washington, Virginia** and **Kansas** plan to work cooperatively on this subobjective. Crops, pests, soils, climates and appropriate chemicals vary considerably across the region so it is impractical to conduct identical studies. Instead, it is agreed that participants will collect a common data set. Using this approach, broader regional guidelines and procedures can be developed based on the results obtained in the individual studies. The common data set will include: field measurements of system application uniformity, names of applied chemicals or products, the labeled rate for method and applied rates for the experiments, the application procedures used, and an assessment of environmental impacts (efficacy on pests, plant uptake, estimates or direct measurements of leaching). The soil sampling/extraction method will also be recorded since some chemicals do not move through the soil in the same manner as the water. If models are used to predict pesticide movement (leaching and/or uptake), a description of the model and the parameters that are used will be recorded.

**Washington** will be evaluating insectigation on hops using SDI. The treatments will be a conventional daily irrigation cycle and an experimental irrigation regime triggered by the soil matric potential at the 40 cm depth. Pesticide movement and leaching away from the dripline will be measured on both a temporal (1-112 days) and spatial (radially-- 0-30 cm and vertically 0-105 cm) basis. In addition to the field sampling protocol, irrigation time delays will be tested using a variety of laboratory experiments including batch sorption-desorption and aging experiments. **Kansas** will continue field and laboratory chemigation research examining the spatial and temporal injected chemical distribution uniformity as affected by the microirrigation system design and system component characteristics. These data will be used in Objective 2 to help develop improved chemigation design and management guidelines. Similarly, **California** will conduct both field and laboratory evaluations of chemigation distribution and uniformity. Water and chemical travel times through all portions of the irrigation system will be measured as well as water and chemical discharge uniformities during the chemigation events. **Kansas** will evaluate effectiveness of chemigation with appropriate materials through SDI systems for repelling rodent pests away from the dripline during the dormant season. Experimental research will concentrate on determining appropriate materials and application rates. **Virginia** will be evaluating the use of soil fumigants applied through SDI on peanut for nematode and disease control.

**Procedures for Objective 2**

Objective 2 concentrates on improving microirrigation system design and components to promote natural resource protection and optimal crop production. In addition to improving the basic hydraulic performance of microirrigation systems, improvements in system design include efforts to increase precision of irrigation application and efforts to develop computer software aimed at easier and smoother system operation and management. Development, modification and evaluation of the various components of the microirrigation system are closely aligned with overall design and management. Interrelationships between the states for Objective 2 are not as direct as those for Objective 1 because of the specific nature and perception of the most pressing Objective 2 research needs. Nevertheless, the indirect cooperation in developing and evaluating improved designs, components, and management protocols helps avoid duplication of research and inefficient use of resources.

**Arizona, Hawaii, Guam,** and **Kansas** will continue working on development of procedures to evaluate microirrigation system hydraulic performance. **Hawaii** will evaluate system uniformity of microirrigation systems as affected by hydraulic design, manufacturer's variation and possible plugging. Efforts will be made to evaluate the effectiveness of various uniformity parameters and to define their interrelationships. Further work will attempt to develop design criteria for uniformity in microirrigation design based on water resources, economic value of crops and environmental concerns. **Arizona** will be involved in studying uniformity of both water and chemicals under subsurface drip irrigation system. Uniformity as defined by soil profile distribution of water and chemicals will be compared with the more traditional uniformity evaluations involving system hydraulics and system flowrate variations. **Arizona** will also be working towards improved software for design of microirrigation systems. **Kansas** will continue long-term studies aimed at evaluating the longevity of deep (40-45 cm) SDI systems using groundwater in the Central Great Plains for field corn production. Information from these studies about longevity will be utilized in Objective 3 to assess the economics of SDI. **Kansas** will continue research trying to develop designs and operating procedures for utilizing livestock wastewater through SDI systems. Initial research will evaluate the clogging potential of various microirrigation components when irrigating with filtered but not chemically treated water from animal waste lagoons. It will also be necessary to determine long-term filtration and chemical treatment needs for wastewater application with SDI in terms of clogging, system longevity and distribution uniformity. Since livestock wastewater is created year round, further work will examine the constraints imposed by winter on use of SDI systems for wastewater disposal. **USDA-CPSWPRC** will also conduct livestock wastewater studies with SDI using partially processed water. Modeling will concentrate on determination of hydraulic and nutrient loading rates to the soil. **Kansas** will conduct laboratory studies and subsequent computer simulation studies to measure and evaluate injected chemical discharge and distribution profiles for various drip irrigation lateral designs and management schemes. Results from these studies will be used to develop chemigation related design and management criteria for the use of long length drip laterals in SDI systems. **Guam** will conduct field experiments to evaluate clogging potential of driplines by comparing short sections (30 m) from various manufacturers. Driplines are susceptible to clogging on Guam due to high (4000 to 6000 ppm) concentration of minerals in irrigation waters and surface temperatures of exposed driplines as high as 55 degree C. Emitter discharge will be measured over time to evaluate clogging.

Determination of appropriate system characteristics for microirrigation systems will be the focus of studies by **California, Kansas,** and **USDA-CPSWPRC.** **California** will attempt to merge precision agriculture and microirrigation technologies to achieve high crop water use efficiencies and while minimizing transportation of fertilizers and pesticides to the environment for tree crops. These efforts will require characterization of the spatial variability in California Pistachio tree structure and yield using geographical information systems (GIS), and developing hardware suitable for applying water and fertilizer on a site-specific basis to individual orchard trees. It will also be necessary to evaluate the microirrigation system hydraulics and water management strategies for applying water on a predetermined non-uniform basis. This work will develop irrigation technologies to regulate nutrient and water delivery at the single tree level. The overall research will also be utilized to develop an integrated precision horticultural management model to optimize yield and enhance environmentally sound resource use. **Kansas** will conduct field studies to evaluate the yield response of soybean to surface and subsurface applications of irrigation water in the semi humid region of eastern Kansas. Subsurface driplines will be placed at depths of 30 and 45 cm. Plants will also be irrigated with surface applications of water. Near surface and subsurface soil water contents will be measured and used to assist with scheduling irrigation and to evaluate drip irrigation wetted regions. Soybean yield will be used to assess effects of dripline depth and horizontal position with respect to the dripline. **Kansas** will also conduct field studies to determine the optimum depth (range of 25 – 55 cm) for driplines for field corn production in the deep silt loam soils of semi-arid western Kansas. Corn yields, flexibility in tillage practices, and system longevity will be utilized to assess the optimum depth. **USDA-CPSWPRC** will be evaluating possible solutions to shallow soil compaction (8-10 cm) which is occurring on agronomic crops using conservation tillage and SDI in the southeastern Coastal Plain. The study will examine two types of shallow conservation tillage with cotton and high-population soybeans.

**California** will evaluate chemigation using solutionizer machines, originally designed to inject gypsum into microirrigation systems, but now being used for injecting many other fertilizers. Machines will be evaluated for their injection rates, concentrations and their chemigation uniformity.

**Idaho** and **Iowa** will compare Watermark sensors and tensiometers with gravimetric soil water check for irrigation scheduling of sweet corn. In related work, **Virginia** will utilize an Enviroscan unit (which has the ability to estimate root development) and tensiometers to schedule irrigation. **Kansas** will install soil water sensors that can be connected to data loggers to evaluate their time response to wetting front progression and soil water changes on two different soil types. Sensor banks will be installed in large lab soil lysimeters and connected to a data logger system. Sensors will be scanned before, during and after drip irrigation events. Outputs from sensors will be evaluated for precision, accuracy, and time response.

Several states (**Colorado, Minnesota, Texas and Wyoming**) will utilize computer models to improve management of microirrigation systems and to evaluate potential new management strategies. **Colorado** will refine a crop management decision support system (Cropflex) to help producers to manage microirrigation and fertilizer to reduce ground water contamination. New databases will be developed for the various crops grown within the region. The specific information needed is crop water use coefficients, growth stages, the corresponding maximum allowable depletion, and the fertility requirement to produce a unit of yield. **Texas** will determine the suitability of utilizing mathematical SDI models that simulate flow to design SDI systems to be used for wastewater disposal. A model developed at **Texas** will be run utilizing the soil water retention and relative hydraulic conductivity data collected from a tank supplied with septic tank effluent. Simulated soil water patterns from the model will be compared with measured soil water patterns. **Minnesota** will utilize information developed in Objective 1 to test and validate computer simulation models that predict potato yield and N leaching. Once validated these models will provide tools to project the long-term impact of various management practices on crop yield and N leaching. These simulations can help identify sustainable BMPs for the outwash region of the upper mid-west. **Wyoming** will study water flow and chemical transport processes in irrigation fields using a comprehensive computer package for irrigation, CHAIN_IR (Zhang, 1997). Predictions of soil water flow and chemical concentrations changing with time and space will be compared with the measurements from the field experiments in Objective 1. Various irrigation systems will be simulated including flood, furrow, sprinkler, and drip irrigation (surface and subsurface) under both full and deficit irrigation. Sensitivity analyses will help determine the most significant physicochemical parameters and factors that dominate or control the processes of water flow and chemical transport in irrigation systems.

**Procedures for Objective 3**

During the course of this 5-year project, new or improved microirrigation technologies will be developed and promoted to the producers. An essential element in the decision criteria for the adoption phase is a cost/benefit analysis. **All states** agree to assess and report at the W128 meeting the cost/benefit ratios of all technologies they are promoting as best management practices (BMPs). This assessment may be very elaborate or minimal depending on the technology being promoted. In the simplest form, the assessment will at least determine the out-of-pocket costs of the technology versus the financial benefits.

Several states **(Arizona, Kansas, Texas, Idaho, Virginia, California, Florida, USDA-WMRL, USDA-CPRL,** and **Wyoming)** will be comparing the benefits and costs of adopting microirrigation over more traditional forms of irrigation such as surface or sprinkler irrigation. This may include environmental as well as direct economic costs and benefits. Water quantity and water quality constraints imposed by the physical hydrology or institutional regulation have an effect on the adoption rate of water technologies. These constraints will also be noted and be added to the developed decision criteria. **All states** agree to report at the annual W128 meeting any observance of unusual or new criteria utilized by producers to adopt microirrigation technology. These criteria might be something as simple as ergonomic consideration for field workers or as complex as tax planning. These notations will help W128 members develop a more complete understanding of the various factors affecting adoption of new microirrigation technology and lead to better decision, design and analysis tools.

**Procedures for Objective 4**
The W128 regional research project has generated a substantial knowledge and data base of appropriate microirrigation research over the last 20 years. The adoption by producers of microirrigation technologies has not always matched the expectations of the scientific community and public regulatory agencies. However, it should be noted that microirrigation is not always the optimum irrigation method for some crops and locations. In other cases, technology transfer has been hindered by unsuitable presentation methods. The research challenge of Objective 4 is to promote appropriate microirrigation technologies through formal and informal educational activities and to evaluate the effectiveness of the educational activities.

**All states** agree to utilize a broad mix of traditional and non-traditional educational mediums to meet the objective. This will include but will not be limited to field days, tours, demonstration sites, college class seminars, targeted training sessions (e.g. NRCS staff, Consultants), regional, national, and international conferences, newsletters, newspaper and popular press articles, audio and video tapes, slide sets, factsheets, extension bulletins, research publications, refereed journal articles and Internet-based educational material. A key aspect of the research is to evaluate the effectiveness of these efforts. Effectiveness will be evaluated based on clientele feedback, numbers of information requests, types of information requests (i.e. basic or advanced), numbers of conference attendees, and technology adoption rates.

Some of the educational activities are traditional and should not need further elaboration. Others have unique aspects that will be discussed here.

**All states** expressed the need to develop a publication concerning design and management guidelines for microirrigation systems. The unique characteristics of each state's crops, soils and climate may preclude a general W128 regional publication. However, states that develop such publications will agree to report on the processes and considerations used in the development at the annual meeting of W128. This reporting and feedback process from the W128 membership will help distill the general criteria and the specific information requirements for successful adoption of microirrigation systems.

**W128 members** will propose to coordinate, develop, moderate, and present a technical session at a national or international conference during the third year of the project. Possible conferences would include, but not be limited to the Irrigation Association, the American Society for Agricultural Engineers (ASAE), Agronomy and Soil Science Society (ASA), and the American Society of Horticultural Science (ASHS).

W128 members believe that the multidimensional range of disciplines and educational mediums will provide high credibility and increased acceptance of the research by producers. Educating producers is a critical part of the successful implementation of this technology. However, educating consultants who are often largely responsible for data interpretation is of equal importance. **W128 members** will conduct targeted training sessions for consultants and staff from Cooperative Extension, USDA-NRCS, other state and local agencies.

The amount of publications generated from W128 research during the last 20 years is over 1000 but often the material is in a format not readily usable by farmers or students. Sometimes its availability is limited to libraries located at universities. The Internet can help broaden the availability of this information and also provides a method of interaction between author and clientele for feedback and clarifications. **All states** agree to work towards improving microirrigation technology transfer through Internet-based educational material.

A dedicated Internet site will be set up at **New Mexico** where information and computer programs related to microirrigation will be posted. The Internet site will be limited to only microirrigation information and will concentrate on presenting information generated by past research in W128 and current research related to Objectives 1-3. Links will be established to other microirrigation websites, particularly those maintained by W128 members.

The site will not only contain written and graphical information but will also include analysis tools such as spreadsheet templates and computer models. An example of a spreadsheet template to be added to the website is the drip irrigation cost/benefit analysis program that was developed by Washington State Dept of Ecology but is not currently available on the Internet. Other computer programs to be added are evapotranspiration models and drip irrigation design programs that have already been developed by W128 members.

**All states** will send educational material and computer programs in appropriate format to the webmaster of the new microirrigation research site where it will be installed. Each state will then evaluate the information on the site and make suggested changes to the originator of the information for improvement of the material. The material will also be evaluated by students taking irrigation courses taught by W128 members. As contacts are made with producers that use the Internet, they also will be encouraged to evaluate the usefulness of the information.

Appropriate popular articles and success stories that have been written by W128 members will be presented on the Internet site. In some cases, the articles may need to be rewritten to include a larger amount of graphic material than was presented in the original articles.

**EXPECTED OUTCOMES:**

It is expected that microirrigation technologies will be further adapted and refined, so that producers can more easily utilize the technologies on their own operations. On the surface these adaptations and refinements may appear subtle, but they are essentially removing impediments to microirrigation adoption. For example, developing RDI (regulated deficit irrigation) technologies is highly appropriate to microirrigation research. It not only conserves water but also can increase water use efficiency and enhance crop quality. Thus it provides a win-win situation. Another example of benefits of the proposed work would be the lessening of foliar diseases through adoption of microirrigation.

Many valuable crops are grown in the highly productive farm areas of the W128 member states, yet water resources are vulnerable to overuse and/or pollution. The combined management of water and nutrients, an integral part of the proposed research can help sustain these important crop production areas.

Efforts at developing new chemigation materials and methods can result in improved product efficacy, improved worker safety, and reduced environmental hazards. Reducing human/wildlife exposure to dangerous pesticides in the environment has a tremendous value.

Modeling efforts will not only assess the effectiveness of current technologies but will also identify potential new modifications to existing microirrigation technologies. For example, combining of nutrient management with water management and pesticide chemigation might help ensure optimum production and thus high efficiency from all inputs.

Technology transfer is such an important aspect to the project, that Objective 4 is totally focused on it. All states agree to utilize a broad mix of traditional and non-traditional educational mediums to meet the objective. Effectiveness will be evaluated based on clientele feedback, numbers of information requests, types of information requests (i.e. basic or advanced), numbers of conference attendees, and technology adoption rates. One additional and somewhat unique aspect to the project will be the proposal of a national or international technical session concerning microirrigation technologies to one of the major US scientific bodies. This proposed session would be organized, coordinated and presented by W128 members.

**ORGANIZATIONAL STRUCTURE OF W128:**
The organization and implementation of the project will be in accordance with the "Manual for Cooperative Regional Research."

The Regional Technical Committee will consist of representatives from each cooperating Agricultural Experiment Station and federal agency cooperating in this project. The representative(s) will be appointed by their respective Experiment Station or Research Director. The above will constitute the voting membership of the technical committee.

The Regional Technical Committee will be responsible for planning and executing of the research project. It will be responsible for coordinating research activities of each cooperating Experiment Station and federal agency and for the developing of appropriate research methods and procedures.

A Director from the Agricultural Experiment Stations of the Western Region appointed by the Agricultural Experiment Station Directors of the Western Region will serve as Administrative Advisor and an ex-officio (non-voting) member of the technical committee. A representative of the Cooperative State Research Service will serve as an ex-officio (non-voting) member of the technical committee.

An executive committee, consisting of a chair, vice-chair, and secretary will be elected from the voting members of the technical committee. The executive committee will serve one year in each elected office with the provision that the vice-chair will ascend to chair, and the secretary to vice-chair. A secretary will be elected each year. The executive committee will have the authority to act on behalf of the technical committee.

The chair, with the approval of the Administrative Advisor, will notify technical committee members of the time and place of meetings, prepare the agenda, and preside at meetings of the technical committee and executive committee. The chair will also be responsible for naming appointments to subcommittees for specific assignments. The chair will be responsible for annual and final reports. In the absence of the chair, the vice-chair will perform these duties. The secretary will record and distribute the minutes of the meetings.

**REGIONAL PROJECT W128 TITLE:**
*Microirrigation Technologies for Protection of Natural Resources and Optimum Production*

**SIGNATURES:**

M J Burke
ADMINISTRATIVE ADVISOR

1/12/99
DATE

Richard C. Heimsch
CHAIR, REGIONAL ASSOCIATION OF DIRECTORS

3/24/99
DATE

Colien Cox
ADMINISTRATOR, COOPERATIVE STATE RESEARCH, EDUCATION AND EXTENSION SERVICE

8/31/99
DATE

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**ATTACHMENTS:**

**PROJECT LEADERS:**

| State/Agency | Participant | Official Rep | Area of Specialization |
|---|---|---|---|
| **EXPERIMENT STATIONS** | | | |
| **Arizona** | | | |
| University of Arizona | M. Yitayew | X | Irrigation mgmt. & design |
| **California** | | | |
| University of California--Davis | D. J. Hills | | Irrigation scheduling & design |
| University of California--Davis | J. W. Hopmans | | Hydrology |
| University of California--Davis | P. H. Brown | | Horticulture/Tree crops |
| University of California--Davis | K. A. Shackel | X | Plant water relations |
| University of California--Davis | L. J. Schwankl | | Irrigation engineering |
| **Colorado** | | | |
| Colorado State University | I. Broner | X | Decision support systems |
| **Florida** | | | |
| University of Florida | A. Csizinszky | | Horticulture/vegetable crops |
| University of Florida | C. D. Stanley | X | Soil science/water mgmt. |
| **Guam** | | | |
| University of Guam | P. Singh | X | Soil & water management |
| **Hawaii** | | | |
| University of Hawaii | I. P. Wu | X | Hydraulic design |
| **Idaho** | | | |
| University of Idaho | H. Neibling | X | Irrigation engineering |
| **Iowa** | | | |
| Iowa State University | H. G. Taber | X | Horticulture & plant nutrition |
| **Kansas** | | | |
| Kansas State University | M. Alam | | Water management & SDI |
| Kansas State University | G. A. Clark | | Water management & SDI |
| Kansas State University | F. R. Lamm | X | Water management & SDI |
| Kansas State University | T. P. Trooien | | Water management & SDI |
| **Minnesota** | | | |
| University of Minnesota | S. Gupta | X | Soil science/modeling |

**PROJECT LEADERS: *(continued*)**

| State/Agency | Participant | Official Rep | Area of Specialization |
|---|---|---|---|
| **New Mexico** | | | |
| New Mexico State University | T. Sammis | X | Hydrology |
| **Texas** | | | |
| Texas A & M University | B. J. Lesikar | X | Waste management |
| Texas A & M University | D. Porter | | Irrigation water management |
| **Virginia** | | | |
| Virginia Polytech Instit & State Univ. | D. J. Bosch | | Production economics |
| Virginia Polytech Instit & State Univ. | N. L. Powell | X | Soil science & SDI |
| **Washington** | | | |
| Washington State University | R. G. Evans | X | Irrigation mgmt. & design |
| Washington State University | R. L. Wample | | Viticulture |
| **Wyoming** | | | |
| University of Wyoming | R. Zhang | X | Soil science/modeling |
| **USDA-ARS LOCATIONS** | | | |
| **USDA-CPRL (Texas)** | | | |
| Cons. and Production Res. Lab | T.A. Howell | X | Irrigation engineering & SDI |
| **USDA-CPSWPRC (S. Carolina)** | | | |
| C. Plains Soil, Water & Plant Res. Ctr. | C. R. Camp | X | Irrigation engineering & SDI |
| **USDA-WMRL (California)** | | | |
| Water Management Research Lab | J. E. Ayars | X | Irrigation & drainage engr. |

**RESOURCES:**

| Participant | Objectives 1 | 2 | 3 | 4 | SY %Res. | SY | %Ext. | %Teach. | PY | TY |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | | | | | | | | | | |
| M. Yitayew | X | X | X | X | 75% | 0.25 | 0% | 25% | 1.0 | 0.1 |
| **California** | | | | | | | | | | |
| D. J. Hills | | X | X | X | 100% | 0.05 | 0% | 0% | 0.0 | 1.0 |
| J. W. Hopmans | X | | X | X | 100% | 0.1 | 0% | 0% | 0.0 | 0.0 |
| P. H. Brown | | X | X | X | 100% | 0.1 | 0% | 0% | 0.0 | 0.0 |
| K. A. Shackel | X | X | X | X | 100% | 0.1 | 0% | 0% | 0.0 | 0.0 |
| L. J. Schwankl | X | X | X | X | 0% | 0.1 | 100% | 0% | 0.0 | 0.0 |
| **Colorado** | | | | | | | | | | |
| I. Broner | | | X | X | 20% | 0.2 | 80% | 0% | 1.0 | 0.0 |
| **Florida** | | | | | | | | | | |
| A. A. Csizinszky | X | | X | X | 100% | 0.2 | 0% | 0% | 0.0 | 0.3 |
| C. D. Stanley | X | | X | X | 80% | 0.4 | 20% | 0% | 0.0 | 0.4 |
| **Guam** | | | | | | | | | | |
| P. Singh | X | X | X | X | 80% | 0.75 | 15% | 5% | 0.0 | 1.0 |
| **Hawaii** | | | | | | | | | | |
| I. P. Wu | | X | X | X | 60% | 0.2 | 25% | 15% | 0.5 | 0.5 |
| **Idaho** | | | | | | | | | | |
| H. Neibling | X | X | X | X | 33% | 0.5 | 67% | 0% | 0.0 | 0.0 |

**RESOURCES:** ***(continued)***

| Participant | Objectives 1 | 2 | 3 | 4 | SY | %Res. | %Ext. | %Teach. | PY | TY |
|---|---|---|---|---|---|---|---|---|---|---|
| **Iowa** | | | | | | | | | | |
| H. G. Taber | X | X | X | X | 0.2 | 50% | 50% | 0% | 0.0 | 0.0 |
| **Kansas** | | | | | | | | | | |
| M. Alam | X | X | X | X | 0.1 | 0% | 100% | 0% | 0.0 | 0.0 |
| G. A. Clark | X | X | X | X | 0.2 | 75% | 15% | 10% | 0.5 | 0.0 |
| F. R. Lamm | X | X | X | X | 0.2 | 100% | 0% | 0% | 0.0 | 0.2 |
| T. P. Trooien | X | X | X | X | 0.1 | 100% | 0% | 0% | 0.0 | 0.0 |
| **Minnesota** | | | | | | | | | | |
| S. Gupta | X | X | X | X | 0.05 | 75% | 25% | 0% | 0.0 | 0.0 |
| **New Mexico** | | | | | | | | | | |
| T. Sammis | | | X | X | 0.35 | 75% | 25% | 0% | 0.0 | 0.0 |
| **Texas** | | | | | | | | | | |
| B. J. Lesikar | | X | X | X | 0.2 | 50% | 50% | 0% | 0.0 | 0.0 |
| D. Porter | X | | X | X | 0.1 | 25% | 75% | 0% | 0.0 | 0.0 |
| **USDA -CPRL** **(Texas)** | | | | | | | | | | |
| T. A. Howell | X | | X | X | 0.3 | 100% | 0% | 0% | 0.1 | 0.6 |
| **USDA -CPSWPRC** **(S. Carolina)** | | | | | | | | | | |
| C. R. Camp | | X | X | X | 0.1 | 100% | 0% | 0% | 0.0 | 0.0 |
| **USDA -WMRL** **(California)** | | | | | | | | | | |
| J. E. Ayars | X | | X | X | 0.2 | 90% | 10% | 0% | 0.0 | 0.3 |

**RESOURCES:** ***(continued)***

| Participant | Objectives 1 | 2 | 3 | 4 | SY %Res. | SY | SY %Ext. | %Teach. | PY | TY |
|---|---|---|---|---|---|---|---|---|---|---|
| **Virginia** | | | | | | | | | | |
| D. J. Bosch | | | X | X | 100% | 0.05 | 0% | 0% | 0.0 | 1.0 |
| N. L. Powell | X | X | X | X | 100% | 0.25 | 0% | 0% | 0.0 | 0.5 |
| **Washington** | | | | | | | | | | |
| R. G. Evans | X | | X | X | 70% | 0.35 | 25% | 5% | 0.0 | 0.5 |
| R. L. Wample | X | | X | X | 100% | 0.1 | 0% | 0% | 0.0 | 0.0 |
| **Wyoming** | | | | | | | | | | |
| R. Zhang | X | X | X | X | 60% | 0.2 | 0% | 40% | 0.2 | 0.1 |