2004 Water Use Efficiency Proposal - Section B Agricultural Research

Project Information Form

Applying for: ☐ Urban ☑ Agricultural

1. (Section A) **Urban or Agricultural Water Use Efficiency Implementation Project**
   - ☐ (a) implementation of Urban Best Management Practice, #_____
   - ☐ (b) implementation of Agricultural Efficient Water Management Practice, #_____
   - ☐ (c) implementation of other projects to meet California Bay-Delta Program objectives, Targeted Benefit # or Quantifiable Objective #, if applicable _____
   - ☐ (d) Specify other: _____

2. (Section B) **Urban or Agricultural Research and Development; Feasibility Studies, Pilot, or Demonstration Projects; Training, Education or Public Information; Technical Assistance**
   - ☑ (e) research and development, feasibility studies, pilot, or demonstration projects
   - ☐ (f) training, education or public information programs with statewide application
   - ☐ (g) technical assistance
   - ☐ (h) other

3. Principal applicant (Organization or affiliation): Shrini K. Upadhyaya, Bio. & Agricultural Eng. Dept. University of California, Davis

4. Project Title: Monitoring Wetting Front Advance Rate for Irrigation Management in Flood Irrigated Alfalfa Production Systems

5. Person authorized to sign and submit proposal and contract:

Name, title	David Ricci, Contracts & Grants Analyst
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6. Contact person (if different):	Name, title.	Shrini K. Upadhyaya, Professor
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7. Grant funds requested (dollar amount): *(from Table C-1, column VI)*	**$296,015**
8. Applicant funds pledged (dollar amount):	None
9. Total project costs (dollar amount): *(from Table C-1, column IV, row n)*	**$296,015**
10. Percent of State share requested (%) *(from Table C-1)*	100%
11. Percent of local share as match (%) *(from Table C-1)*	None

12. Is your project locally cost effective?

Locally cost effective means that the benefits to an entity (in dollar terms) of implementing a program exceed the costs of that program within the boundaries of that entity.

(If yes, provide information that the project in addition to Bay-Delta benefit meets one of the following conditions: broad transferable benefits, overcome implementation barriers, or accelerate implementation.)

☑ (a) yes

❑ (b) no

11. Is your project required by regulation, law or contract?

If no, your project is eligible.

If yes, your project may be eligible only if there will be accelerated implementation to fulfill a future requirement and is not currently required.

❑ (a) yes

☑ (b) no

Provide a description of the regulation, law or contract and an explanation of why the project is not currently required.

Cutoff irrigation of flood irrigated checks to reduce tail drainage is not currently required by law.

12. Duration of project (month/year to month/year):	3 years (01/01/06 to 12/31/08)
13. State Assembly District where the project is to be conducted:	8th Assembly District
14. State Senate District where the project is to be conducted:	5th Senate District
15. Congressional district(s) where the project is to be conducted:	California's 1st District
16. County where the project is to be conducted:	Yolo/Solano
17. Location of project (longitude and latitude)	UC Davis (long.=-121.75, lat.=38.56)
18. How many service connections in your service area (urban)?	N/A
19. How many acre-feet of water per year does your agency serve?	N/A

20. Type of applicant (select one):

- ☐ (a) City
- ☐ (b) County
- ☐ (c) City and County
- ☐ (d) Joint Powers Authority
- ☐ (e) Public Water District
- ☐ (f) Tribe
- ☐ (g) Non Profit Organization
- ☑ (h) University, College
- ☐ (i) State Agency
- ☐ (j) Federal Agency
- ☐ (k) Other
  - ☐ (i) Investor-Owned Utility
  - ☐ (ii) Incorporated Mutual Water Co.
  - ☐ (iii) Specify _____

21. Is applicant a disadvantaged community? If 'yes' include annual median household income.

(Provide supporting documentation.)

- ☐ (a) yes, _____ median household income
- ☑ (b) no

Signature Page

By signing below, the official declares the following:

The truthfulness of all representations in the proposal;

The individual signing the form has the legal authority to submit the proposal on behalf of the applicant;

There is no pending litigation that may impact the financial condition of the applicant or its ability to complete the proposed project;

The individual signing the form read and understood the conflict of interest and confidentiality section and waives any and all rights to privacy and confidentiality of the proposal on behalf of the applicant;

The applicant will comply with all terms and conditions identified in this PSP if selected for funding; and

The applicant has legal authority to enter into a contract with the State.

	David Ricci, UCD Contracts & Grants Analyst	
Signature	Name and title	Date

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Monitoring Wetting Front Advance Rate for Irrigation Management in Flood Irrigated Alfalfa Production Systems

A 2004 Water use Efficiency Proposal - Section B, Agricultural Research and Development Feasibility Study

Investigators:

PI: Dr. Shrini K. Upadhyaya, Professor, Bio. and Agr. Eng. Dept.

Co-PIs: (i) Dr. Wes Wallender, Professor, Dept. of Land, Air, and Water Res., (ii) Dr. Dan Putnam, Extension Agronomist, Dept. of Agr. and Range Sci., (iii) Dr. Mark Grismer, Professor, Dept. of Land, Air, and Water Res. (iii) Dr. Khalid Bali, Irrigation/Water Management Advisor, University of California Desert Research & Extension Center, and, (iv) Dr. David Slaughter, Professor, Bio. and Agr. Eng. Dept.

Proposal Summary: The goal of this proposal is to develop rope type water arrival sensors to monitor wetting front advance in a flood irrigated alfalfa field and utilize this information to manage cutoff irrigation scheme to improve irrigation efficiency and reduce environmental problems associated with tail water discharge. Specific objectives of this study are – (i) Develop rope type water arrival sensors for use in flood irrigated alfalfa fields, (ii) Monitor wetting front advance rate as well as inflow and runoff during the 2006 growing season, (iii) Develop a technique to turn the water off based on wetting front advance rates, (iv) Quantify the benefits of cutoff irrigation scheme during the 2007 growing season, and (v) Demonstrate the technique to growers during alfalfa field days.

Cutoff irrigation scheme, if implemented properly, can reduce water use in a flood irrigated alfalfa field by about 15% (Bali et al., 2001). During the first year of this study we will monitor and assess the amount of tail discharge and its quality using carefully designed field experiments in flood irrigated alfalfa checks. We will develop rope type water arrival sensors that can monitor wetting front advance rate and use a telephone modem voice synthesizer to generate a phone call to alert the irrigator when to cutoff the inflow in order to minimize the tail discharge. The advantages of this system in terms of irrigation efficiency, reduction in tail discharge, and total savings in water will be monitored during the second year. During the third year of this study, we will demonstrate this cutoff irrigation scheme to farmers, farm advisors, and extension specialists. An approximate benefit to cost analysis indicates that this project has the potential to produce devices and techniques that can save a significant amount of water in the Bay-Delta region and the state of California, while reducing the environmental pollution by decreasing the amount of tail discharge.

This project addresses following agricultural water use efficiency issues of interest to WRB:
(i) applied research projects on specific soil and plant issues as related to water use efficiency, (ii) potential benefits and costs of improved water use practices associated with crops affecting water use efficiency, and (iii) exploration of new technologies and water management practices to improve water use efficiency.

Monitoring Wetting Front Advance Rate for Irrigation Management in Flood Irrigated Alfalfa Production Systems

Statement of Work, Section 1: Relevance and Importance

Nearly 80% of world's developed water supplies are used for irrigating crops (Howell, 2001; Ayers et al., 2003). This irrigation helps provide more than 35% of world's food supply from about 20% of arable land (Ayers et al., 2003). Surface irrigation is one of the most widely practiced irrigation techniques in the world. In California, nearly 70% of the 10 million acres of irrigated land is surface irrigated. Furrow, basin, and border are the most widely used surface irrigation techniques. Surface runoff and drainage below the root zone from surface irrigated fields contribute to nonpoint source pollution of surface and ground water (Hanson, 2003, Yonts et. al., 1996). These concerns and increasing urban demand for water make it imperative for us to use irrigation water efficiently (Hanson and Putnam, 2000; Grismer, 2001).

Current irrigation practice is largely an art (Burt, 1998). There is an urgent need to shift from art to science so that efficient irrigation management schemes can be developed. A critical piece of information that is necessary to implement an efficient surface irrigation management scheme is the advance rate of the wetting front. Advance rate determines how fast water moves through a field. This rate depends on infiltration rate, inflow rate, slope, surface roughness, and furrow geometries (for furrow irrigated systems). Surge irrigation and reducing field length can improve uniformity of irrigation and reduce drainage. Surge irrigation leads to 30 to 40% reduction in water application and is particularly well suited for furrow irrigation systems. Surface runoff can be reduced by cut-off irrigation, recirculation systems, and runoff storage systems. Although recirculation systems can reduce runoff losses by 85 to 90% (Buller et al. 1998), the pumping costs and water quality issues associated with drainage water remain a concern. An efficient irrigation management scheme should result in minimum tail water discharge. Cutoff irrigation, if implemented properly, can minimize runoff. Cutoff time depends on soil type and texture. Depending on soil characteristics, optimum cutoff time may vary from 60 to 100% of the field length (Grismer and Todd, 1994). Bali et al. (2001) reported that they were able to reduce runoff losses from the typical 17% to 2% in an alfalfa field in the Imperial Valley. This amounted to water savings of approximately 1 ac-ft/ac per year or approximately 15% savings in applied water while maintaining hay yield. When the same runoff reduction method was implemented on a commercial field, the average water savings were approximately 19% of applied water with no significant impact on alfalfa yield (Bali et al. 2005).

With increasing interest in water quality, agricultural irrigation practices will have to be adjusted to minimize the impact of drainage water on environment. Application of improved irrigation practices resulted in significant reduction in the amount of phosphorous and sediments leaving agricultural fields in the Imperial Valley (Guerrero and Bali, 2004). By reducing surface runoff growers may be able to reduce the amount of the pollutants draining to water bodies to meet the current and the expected TMDL standards.

The biggest challenge to more efficient irrigation management in surface irrigated fields is the spatio-temporal variability in infiltration rate (Hanson, 2003, Fekersillasie and Eisenhauer, 2000; Bautista, et al., 2001). Bali (1996) reported that temporal variability in infiltration characteristics has a more pronounced effect on surface irrigation performance than the spatial variability. These infiltration characteristics are expensive and tedious to measure. Moreover, these measurement techniques are not suitable for use by the farmers. Development of sensors that can monitor the wetting front advance rate and estimate advance curve in-situ can be very useful in determining irrigation cutoff time.

Alfalfa is a major crop in Western United States (Putnam, 1996). It is grown on 1.1 million acres in California (Agricultural Statistics, 2003) and accounts for nearly 20 to 27% of the irrigation water use (Hanson and Putnam, 2000). In the Bay-Delta region, alfalfa is a major crop, second only to corn. It is grown on 55, 100 acres of farmland and requires about 298,000 acre-ft of irrigation water (WRB 2004b). This large amount of water usage is primarily due to its long growing season. Alfalfa is sensitive to the availability of soil moisture. Reduced application of water can lead to a reduction in yield (Hanson and Putnam, 2000). Border or flood irrigation is the predominant type of irrigation technique employed in alfalfa production (Schwankl and Prichard, 2003). Border irrigation is one of the most difficult techniques in terms of achieving high irrigation efficiency. As mentioned earlier, cutoff irrigation method can be used to reduce runoff to as little as 2%, from the more common 17% in heavy clay soils (Bali et al. 2001). However, the cutoff time can vary from 60 to 100% of the field length depending on the infiltration characteristics. Since it is difficult to measure infiltration characteristics, a simple, in-situ, real-time wetting front advance sensing system would be desirable. Remote sensing that uses either on-site camera or aerial imagery is not a viable alternative in a flood irrigated alfalfa field, since the view of the advancing wetting front is obscured by alfalfa plants. Ground based wetting front sensors are better suited for this case.

Turnell et al. (1997) used a network of wired water detectors installed along a furrow to determine wetting front advance rate and infiltration characteristics. We investigated the possible use of a network of wireless water arrival sensors to track the wetting front advance in three different locations in California (Woodland, Davis, and Lemoore) in alfalfa production systems. Our study clearly indicated that monitoring wetting front advance can provide a practical method of irrigation management in a flood irrigated field. Typical test results are presented in figures 1a-c. Note that at each location we monitored three irrigations during the 2004 growing season. During each irrigation event, we monitored three checks. In each check we monitored 7 locations separated by 25 feet along the center of the check (Figure 2). We also monitored 5 locations at a distance of 12.5 ft on either side of the center of the check. The location of the sensor placed at the center of the grid was 250′ in check #1, 200′ in check #2, and 300′ in check#3 from the tail end of the field. The experimental data for all three replicates from three locations and all three irrigations were curve fitted using a model similar to the one used by Upadhyaya and Raghuwanshi (1999) in a furrow irrigated processing tomato crop. Results shown in figures 1a through 1c clearly indicate that the wetting front can be accurately tracked by sensors located within the field. Although the wireless sensor network system worked well, repeated installation and removal of the sensors after each harvest made this technique very laborious. It is clear from this study that a network of wireless sensors located above the ground

surface is not very practical at this point in time. In the not too distant future, smart dust type of inexpensive, disposable, wireless sensors may be developed that may make wireless sensor networks more practical for widespread use. However, cost per sensor and problems with the power source (i.e., battery) are major problems at present. Perhaps, simple rope type sensors that are installed a few inches (perhaps 3 to 4 in.) below the ground and located at known distances from the tail ditch can overcome the limitation of this wireless sensor network approach. Since alfalfa is a perennial crop, use of sensors buried a few inches below the ground surface is attractive.

The objectives of this study are:

1. Develop rope type water arrival sensors for use in flood irrigated alfalfa fields,
2. Monitor wetting front advance rate as well as inflow and runoff during the 2006 growing season,
3. Develop a technique to turn the water off based on wetting front advance rates,
4. Quantify the benefits of the cutoff irrigation scheme during the 2007 growing season,
5. Demonstrate the technique to growers during alfalfa field days.

Statement of Work, Section 2: Technical/Scientific Merit, Feasibility:

Objective #1 ***(task #1****): Development of rope type water arrival sensors for use in flood irrigated alfalfa field.*

Simple contact type sensors will be used to detect water arrival. This type of sensor has worked very well in our previous work with furrow irrigated processing tomato production, furrow irrigated sedan grass production, and flood irrigated alfalfa production. Figure 3 shows a schematic of the rope type wetting front advance sensor to be developed during this study. This sensor consists of five simple contact sensors that are separated by a distance of 15 ft. When the water arrives at the contact terminals, an electrical circuit is completed and this information is recorded using a data logger. Based on our preliminary work, we expect that each alfalfa check will need two such rope type water arrival sensors. Using the sensor location information and the time at which the water arrives at the sensor, wetting front advance rate can be determined.

A Campbell Scientific data logger is available for this study. The main task (**task #1**) during this phase of the study will be the development and testing of the rope type sensors. A total of 12 sensors will be developed for use with six alfalfa checks during the 2006 season. We expect this phase to take four months (January 1, 2006 to March 30, 2006). A half time Development Engineer and a graduate student will be working on this task.

Objective #2 ***(tasks #2 and 3)****: Monitor wetting front advance rate as well as inflow and runoff during the 2006 growing season.*

Six alfalfa checks will be selected on the UC Davis campus for monitoring and assessment purpose. A set of two rope sensors will be assigned to each check. These sensors will be installed across the width of the field (i.e. perpendicular to the direction of water flow) such that the location of the first rope sensor (i.e. the one farther away from the discharge end) will be at 50 or 75% of the field length. The exact location (50 or 75% of field length) will be assigned at random to a given check such that three checks will receive one treatment and the other three checks will receive the second treatment. The second rope sensor will be located at a distance of 25 ft. downstream from the first sensor. Figure 3 shows the layout of rope sensors within a check. The sensor will be buried at a depth of 3 or 4 in. from the ground level. The exact depth will be determined by conducting some preliminary studies. During this phase we will simply monitor the current irrigation practice and obtain necessary data for implementing cutoff irrigation during the subsequent phases of this study.

All six checks will be monitored during each irrigation. Inflow to each check will be measured using a portable Doppler flow meter with automatic data logging capability. The tail discharge will be monitored using an area-velocity flow meter equipped with data logger. The tail discharge will be analyzed for nitrate, phosphate, EC and organophosphate insecticide content. Three samples from each check will be sent to the DANR laboratory for analysis. Yield data for each check will be obtained and recorded.

This phase of the study will be **task # 2** and will start during April and end in October 2006. The development engineer, graduate student, and an undergraduate student will work on this phase of the project.

Task #3 will deal with the analysis of the data obtained in task #2. Using inflow rates and wetting front advance information, we plan to develop an irrigation cutoff strategy. We expect to use the same model as we used during our previous study (cf. figure 2) which is based on the work of Upadhyaya and Raghuwanshi (1999). Moreover, we expect to finalize the location of the rope sensors within the check for irrigation cutoff purposes. The computer facilities and software needed for data analysis (SAS statistical package) are available at the Department of Agricultural and Biological Engineering. During this phase of the study we will estimate total tail discharge under current irrigation practices. Furthermore, we will document the amount of environmentally harmful chemicals in the tail discharge (nitrate, phosphate, EC and organophosphate insecticide). This phase will start during July and continue until December 2006.

Objective #3 ***(task #4)****: Develop a technique to turn the water off based on the wetting front advance rate.*

Since inflow mechanism can vary from field to field (i.e., valves, siphon tubes, etc.), we plan to develop a simple technique of alerting the irrigator when to cut the inflow off. We intend to use the cell phone for this purpose. The data logger will dial the cell phone and send a message to the irrigator using a commercially available phone modem voice synthesizer. The message will identify the check and time at which its inflow should be turned off.

This task **(task #4)** will be pursued during the period of January 2007 to March 2007. Solution of technical issues related to the interface between the data logger and the phone modem voice synthesizer will be investigated to create a successful interface.

*Objective #4 **(tasks #5 and 6)**: Quantify the benefits of the cutoff irrigation scheme during the 2007 growing season.*

The same six checks that were used during the previous season (task #2) will be used during this task. Three of the checks will have rope sensors at the desired location as determined in task #4. These checks will be selected for cutoff irrigation management scheme implementation. The other three checks will be used to implement prevailing irrigation practices as carried out during the 2006 growing season. This will allow us to minimize the errors associated with unpredictable factors such as weather and provide a direct comparison between the cutoff irrigation management scheme and the more common irrigation practice. The inflow and tail discharge will be measured as outlined in task #2. Yield data will also be obtained in each of the checks. Irrigation cutoff time will be determined using the inflow and wetting front advance rate information (cf., task #3) for checks selected for cutoff irrigation management. This information will be sent to the irrigator using the cell phone technology as outlined in task #4.

This task **(task #5)** will span the 2007 growing season (April to October, 2007). The development engineer, graduate student, and an undergraduate student will participate in this part of the study. The same facilities as used in task #2 and the technology developed in task #4 will be used in this phase of the study.

Task #6 will involve analyzing the data to determine the amount of tail drainage and the amount of water saved using this cutoff irrigation strategy. This phase of the study will last from November 2007 to December 2007.

*Objective #5 **(tasks #7 and 8)**: Demonstrate the technique to growers.*

We will demonstrate the technology to farmers, farm advisors and extension specialists. We intend to select three locations for this purpose with the assistance of our collaborators. Three fields will be selected -- one each in Sacramento, San Joaquin, and Imperial Valleys.

The rope sensors will be installed at selected sites. The first few irrigations will be used to check the validity of the technique. Subsequently, a field day will be arranged to demonstrate this technique to growers, farm advisors, and extension specialists.

Task #7 consists of completing the demonstration including all necessary preparations. This task will span January 2008 to October 2008. The development engineer and the graduate student will participate in all stages of this task. An undergraduate student will assist during the summer months.

Task #8 will consist of documenting all the details of this project and preparing the final report. This task will commence in November 2008 and will be concluded in December 2008. The development engineer and the graduate student will assist in preparing the report.

Table 1 summarizes various tasks, costs associated with those tasks, time frame, and deliverables:

Table 1. Summary of tasks, associated costs, timeframe, and deliverables as per the project plan.

Task No.	Task	Deliverable	Schedule		Cost
			Start date	End date	
1	Develop rope type water arrival sensors	Rope type water arrival sensors.	01/01/06	03/30/06	$35, 563
2	Field monitoring and assessment	Field data related to inflow, tail discharge, water quality, and wetting front advance rate.	04/01/06	10/31/06	$41, 623
3	Analysis of the field data.	Irrigation cutoff time model, amount of tail discharge and its quality.	07/01/06	12/31/06	$23, 046
4	Develop a technique to turn off irrigation water when desired.	Interfacing between the data logger and voice messaging system.	01/01/07	03/30/07	$25, 724
5	Field implementation of the cutoff irrigation strategy.	Successful implementation of cutoff irrigation technique.	04/01/07	10/31/07	$53, 914
6	Analysis of 2007 field data.	Quantification of amount of water saved due to reduced runoff.	11/01/07	12/31/07	$14, 931
7	Field demonstration of the cutoff irrigation technique	Successful demonstration of cutoff irrigation technique.	01/01/08	10/31/08	$84, 901
8	Prepare final report	Completed final report	11/01/08	12/31/08	16, 313

Preliminary Plans and Specifications and Certification Statements: N/A.

Environmental Documentation:

As a research feasibility study, the study activities will be conducted in accordance with all federal, state and local laws and with the University of California environmental health and safety policies and regulations. Existing irrigation facilities and research structures on the UC Davis campus farm will be used for this study. Demonstrations will be conducted on farmers' fields using simple sensors and communication technologies developed in this study. No new structures or irrigation infrastructure will be constructed as a part of this study. Thus no local, county, State, or federal permits will be needed to conduct the study.

A "project" as defined by California Environmental Quality Act (CEQA), California Code of Regulations, Title 14, Division 6, Chapter 3, Section 15378 is:

"… the whole of an action, which has a potential for resulting in either a direct physical change in the environment, or a reasonably foreseeable indirect physical change in the environment...."

This research study does not meet the CEQA definition of a "project" requiring an environmental impact study. This proposed research feasibility study will not result in any direct or indirect physical change in the environment. The project will involve the use of conventional agricultural farming practices and data collection methods that have been used on the UC Davis campus as well as other research facilities for many decades. There is no reason to believe that this proposed research will result in significantly different levels of direct or indirect physical change in the environment when compared to any prior alfalfa research project conducted on the UC Davis campus farm or in the Imperial Valley.

Statement of Work, Section 3: Monitoring and Assessment

- Under objective #2, tasks #2 and #3 measure inflow, tail drainage, and chemical contamination (nitrate, phosphate, EC and organophosphate insecticide) in the tail water. Since prevailing irrigation practices will be employed during the first year (2006 growing season) of study and the study is a replicated trial, we will get a good estimate of runoff loss and water quality issues associated with drainage water. As we plan to use flow meters to measure flow and services of the analytical lab for the measurement of chemical contamination of water, we expect our results to be accurate (no more than 2% error).
- Under objective #4, tasks #5 and #6 are intended to implement the cutoff irrigation technique and measure the reduction in tail drainage due to this irrigation management scheme. Measurement techniques and accuracy of measurements are expected to be similar to the ones to be realized in tasks # 2 and 3.

- Ten percent or more decrease in tail drainage [Bali et al. 2001 and Bali et al. 2005 estimated a 15-19% reduction in Imperial Valley] while maintaining current alfalfa yield levels will be considered as an indication of success of implementing the cutoff irrigation management scheme using wetting front advance monitoring by rope type water arrival sensors.
- External factors such as weather will influence the outcome of the experiments. However, measurements over multiple years and proper statistical design of the experiments will help to minimize the effect of such stochastic factors.
- All data and results will be available from the project director in an electronic form to the Water Resource Board and other interested parties. We also expect to publish the results of this study in journals that should make the results available in the public domain.
- The cost associated with this monitoring and assessment part is essentially the cost associated with objectives # 1 to 4 (tasks # 1 to 6). Note that objectives # 1 and 3 (tasks # 1 and 4) are complimentary to objectives # 2 and 4 (tasks #2, 3, 5 and 6). *Therefore the cost associated with monitoring and assessment is $194, 801*.

Qualifications of the Applicants and Cooperators:

1. Resumes

SHRINIVASA K. UPADHYAYA

Professor, Biological and Agricultural Engineering Department

EDUCATION:

Ph.D. (1979)	Agr. Eng., Cornell University, Ithaca, New York
M.Sc. (1975)	Agr. Eng., University of Manitoba, Winnipeg, Manitoba, Canada
B.Tech.(Hons)(1972)	Agr. Eng., IIT, Kharagpur, West Bengal, India

RESEARCH INTEREST:

Precision farming, Sensor development, Instrumentation, GPS, GIS, Soil dynamics, Soil compaction and Infiltration, Machinery design, Variability and mapping.

WORK EXPERIENCE:

July 1992 to Present	Professor, Dept. of Bio. and Agr. Eng. Dept., UC Davis.
July 1987 - June 1992	Associate Professor, Dept. Bio.and Agr. Eng. Dept., UC Davis.
Sept. 1983 - June 1987	Assistant Professor, Dept. Bio. and Agr. Eng. Dept., UC Davis.
Sept. 1981 - Aug. 1983	Assistant Professor, Dept. Agri. Eng., Univ. of Del., Newark, DE
Jan. 1979 - Aug. 1981	Research Associate, Dept. Agr. Eng., Cornell University, Ithaca, NY.

PATENT: 1. Hydro-Pneumatic Seed Singulation for Plant Propagules **US Patent No. 4917029**.
2. Method and apparatus for ultra precise GPS based mapping of seeds or vegetation during planting – **US Patent No: US 6516271B2**.
3. Upadhyaya, S. K., M. Ehsani, and M. L. Mattson. 2003. Method and apparatus for ultra precise GPS-based mapping of seeds or vegetation during planting. **US patent No. 6,553, 312 B2.**
4. Upadhyaya, S. K. and P. Andrade. 2004. Development of a soil compaction profile senor. **US Patent No. 6,834,550.**

HONORS AND AWARDS:

Soil Dynamics Award, Tiberias, Israel, 1997
American Society of Agricultural Engineers Certificate of Appreciation, 1995 and 2003.
American Society of Agricultural Engineers Paper Award, 1983 and 1995.
JSPS Fellowship for Research in JAPAN, 1993

PROFESSIONAL AFFIALTION:

1) Member, American Society of Agricultural Engineers (ASAE)
2) Associate Editor of Journal of Precision Agriculture.
3) Associate editor of the Transaction of the ASAE.
4) California representative for the NCR-180, Site Specific Crop Management Committee.

RECENT RELEVANT PUBLICATIONS:

Sakai, K., T. Kobayashi, M. Takai, and S. K. Upadhyaya. 1994. Neural network mapping to obtain 2D distributed field information—application to spatially varied infiltration data. Journal Faculty of Agriculture, Hokkaido University 66(1):63-68.

Upadhyaya, S. K., W. J. Chancellor, J. V. Perumpral, R. L. Schafer, W. R. Gill, and G. E. VandenBerg (Editors). 1994. Advances in Soil Dynamics, Vol. 1. American Society of Agricultural Engineers Monograph Number 12. 313 pages.

Upadhyaya, S. K., K. Sakai, and J. L. Glancey. 1995. Instrumentation for in-field measurement of soil crust strength. Transactions of the ASAE (American Society of Agricultural Engineers) 38(1):39-44.

Fattah, H. A., and S. K. Upadhyaya. 1996. Effect of soil crust and soil compaction on infiltration in a Yolo loam soil. Transactions of the ASAE (American Society of Agricultural Engineers) 39(1):79-84.

Liu, W., S. K. Upadhyaya, T. Kataoka, and S. Shibusawa. 1996. Development of a texture/soil compaction sensor. Proceedings of the Third International Conference in Precision Agriculture, Minneapolis, MN. pp. 617-630.

Upadhyaya, S. K., J. Jafari Far, S. Shafii, and H. A. Fattah. 1997. Crust-breaking device improves water infiltration into furrows. California Agriculture 51(5):21-23.

S. K. Upadhyaya and N. S. Raghuwanshi. 1999. A semi-empirical equation for cumulative infiltration in furrow irrigation systems. J. Irr.and Drainage Eng. 125(4): 173-178.

Pelletier, M. and Upadhyaya, S. K. 1999. Development of a tomato yield monitor. Computers and Electronics in Agriculture. 23:103-117.

Josiah, M., T. Shikanai, U. A. Rosa, M. Koller. 1999. Mapping infiltration variability in a tomato production system. ASAE Paper No.: 99-1146. ASAE, St. Joseph, MI 49083.

Koller, M., S. K. Upadhyaya, U. A. Rosa, and M. Josiah. 1999. Application of remote sensing in a tomato production system. ASAE Paper No.: 99-1135. ASAE, St. Joseph, MI 49083.

Koller, M., S. K. Upadhyaya, and U. A. Rosa. 2000. Neural network analysis of remote sensing data in crop production. ASAE Paper 001096, ASAE St. Joseph, MI 49085.

Slaughter, D. C., M. G. Pelletier, and S. K. Upadhyaya. 2000. Sensing soil moisture using NIR spectroscopy. Applied Engineering in Agriculture.

Upadhyaya, S. K., W. J. Chancellor, J. V. Perumpral, R. L. Schafer, W. R. Gill, and G. E. VandenBerg (Editors). 2000. Advances in Soil Dynamics, Vol. II. American Society of Agricultural Engineers Monograph, ASAE, St. Joseph, MI 49085. 294 pp.

Upadhyaya, S.K., K. P. Lancas, A. G. Santos-Filho, and N. S. Raghuwanshi. 2001. Evaluation of one-pass tillage equipment versus conventional tillage system. Cal. Ag. 55(5):44-47.

Josaih, M. N., S.K. Upadhyaya, U. Rosa, P. Andrade, and M. Mattson. 2001. Mapping field variability in infiltration rate and evapotranspiration in a tomato production system. ASAE paper Number 011017.

Andrade, P., J. Aguera, S. K. Upadhyaya, B. M. Jenkins, U. A. Rosa, and M. Josiah. 2001. Evaluation of a dielectric based moisture and salinity sensor in-situ applications. ASAE Paper 011010.

Andrade, P., S. K. Upadhyaya, B. Jenkins, and A.G.S. Filho. 2002. Evaluation of UC Davis Compaction Profile Sensor. ASAE Paper. 021185. ASAE, St. Joseph, MI 49085.

Abidine, A, B. Heidman, S. K. Upadhyaya and D. Hills. 2004. Application of RTK GPS based auto-guidance system in agricultural production. California Agriculture. 58(1):44-47.

Ehsani, M. R., S. K. Upadhyaya, and M. L. Mattson. 2004. Seed location mapping using RTK GPS. Trans. ASAE 47(3):909-914.

Josaih,M, S. K. Upadhyaya, and U. A. Rosa. 2004. The relationship between variability in crop yield and variability in soil physical characteristics. Proceedings of the First International Conference on Emerging Technologies in Agricultural and Food Engineering. P26-32.

WESLEY W. WALLENDER

Professor of Hydrology and Engineering
Departments of Land, Air and Water Resources (Hydrology Program) and
Biological and Agricultural Engineering

EDUCATION AND REGISTRATION

Ph.D. Utah State University, Engineering, June 1982.
M.S. University of California Davis, Water Science, June 1978
B.S. Utah State University, Agricultural and Irrigation Engineering, September 1981
B.S. Oregon State University, Agricultural Engineering Technology, June 1976
EIT Engineer-in-Training Exam, May 1979
PE Professional Engineer, California, 1987

RESEARCH AREA: Research includes modeling and measurement of precipitation- and irrigation-driven watersheds from submeter to kilometer scales. Specific subject matter interest includes water, energy and chemical transport for sustainable agroecosystems. Teach undergraduate courses in fluid mechanics, GIS and spatial analysis, and irrigation system design and graduate courses in continuum mechanics as well as surface irrigation hydraulics. Funding in excess of $6 million supporting the completion of 30 graduate student theses. More than 110 refereed journal articles and book chapters.

WORK EXPERIENCE

1982-present. Assistant-82-88, Associate-88-92 and Full-Professor-92-present, University of California Davis.

1992-3. Director, University of California Salinity/Drainage Research Program.

1980-2. Consultant to Keller Engineering, Logan, UT.

1987-present. Registered Profession Engineering Consultant.

PROFESSIONAL, SCIENTIFIC, HONORARY SOCIETIES AND AWARDS

American Geophysical Union, American Society of Agricultural Engineers, American Society of Civil Engineers
Who's Who Among Students in American Universities and Colleges, Phi Kappa Phi, Sigma Xi, Alpha Zeta, Tau Beta Pi, Blue Key
Who's Who in California, 1998
Who's Who in Engineering Education, 2002
External Reviewer (3), Ph.D. Dissertation, Indian Institute of Technology
American Society of Civil Engineers, Best Practices Paper Award, 2002.
American Society of Civil Engineers, Best Research Paper Award, 2003.
American Society of Agricultural Engineers, Technical Reviewer Special Recognition, 2001, 2002
Distinguished Alumnus Award, Utah State University, College of Engineering (BIE), 2004

MEMBERSHIP ON COMMITTEES AND EDITORIAL BOARDS

Editor, Soil and Water Division, American Society of Agricultural Engineers, 2004-present
Associate Editor, Soil and Water Division, American Society of Agricultural Engineers, Developed and implemented procedures for an electronic journal, 1991-present

Member, Advisory Board, International Journal of Water Resources Engineering, 1991-present
Member, Editorial Board, Irrigation Science, 1994-present
Member, Editorial Board, Brazilian Journal of Irrigation and Drainage, 2002-present
Member, Technical Advisory Committee on Forest Geology, State of California Mining and Geology Board, 2002-present
Member, Challenge Program Consortium, Global Challenge Program on Food and Water, Consultative Group on International Agricultural Research, 2001-2
Member, Integrated Basin Water Management Systems (Research) Workgroup, Global Challenge Program on Food and Water, Consultative Group on International Agricultural Research, 2001-2

SELECTED RECENT REFEREED PUBLICATIONS

Wallender, W.W. and M.E. Grismer. 2002. Irrigation hydrology-Crossing scales. J. of Irrigation and Drainage Engineering ASCE 128(4):203-211.

Young, C.A. and W. W. Wallender. 2002. Spatially distributed irrigation hydrology: water balance. Transactions of the American Society of Agricultural Engineer 45(3):609-618.

Angermann, T., W.W. Wallender, B.W. Wilson, I. Werner, D.E. Hinton, M.N. Oliver, F. G. Zalom, J.D. Henderson, G.H. Oliveira, L.A. Deanovic, P. Osterli, W. Krueger. 2002. Runoff from orchard floors -- micro-plot field experiments and modeling. Journal of Hydrology 265(2002):178-194.

Tarboton, K.C., W.W. Wallender and N.S. Raghuwanshi. 2002. 2-D Saturated-unsaturated zone irrigation and drainage model: part I theory. Transactions of the American Society of Agricultural Engineer 45(5):1353-1363.

Tarboton, K.C., N.S. Raghuwanshi and W.W. Wallender. 2002. 2-D Saturated-unsaturated zone irrigation and drainage model: part II Sensitivity analysis. Transactions of the American Society of Agricultural Engineer 45(5):1365-1373.

Wallender, W.W., J. Rhoades, M. Weinberg, S. Lee and C. Uptain. 2002. Irrigated land retirement. Irrigation and Drainage Systems 16:311-326.

Joyce, Brian, W. W. Wallender, T. Angermann, B.W. Wilson, I. Werner, M.N. Oliver, F.G. Zalom, and J.D. Henderson. 2004. Using infiltration enhancement and soil water management to reduce Diazinon in runoff. Journal of the American Water Resources Association. August: 1063 – 1070.

Sivakumar, B., W.W. Wallender, C.E. Puente, and M.N. Islam. 2004. Streamflow disaggregation: a nonlinear deterministic approach. Nonlinear Processes in Geophysics. 11: 383-392

Vrugt, J.A., G. Schoups, J.W. Hopmans, C.A. Young, W.W. Wallender, T.A. Harter and W. Bouten. 2004. Inverse modeling of large-scale distributed vadose zone properties using global optimization. Water Resources Research, Vol. 40: 1-20.

Purkey, D.R. W.W. Wallender, G.E. Fogg, and B. Sivakumar. 2004. Describing near surface, transient flow processes in unconfined aquifers below irrigated lands: model application in the western San Joaquin valley, California. Journal of Irrigation and Drainage Engineering 130:451-459.

Daniel H. Putnam, PhD
Extension Agronomist - Alfalfa and Forage Crops
Agronomy & Range Science Department, UC Davis

Address: Department of Agronomy and Range Science
University of California
Davis, CA 95616-8515
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E-mail:

Website: *http://alfalfa.ucdavis.edu*

Education:
1986 Ph.D. (Plant and Soil Sciences), University of Massachusetts, Amherst
1983 M.S. (Plant and Soil Sciences), University of Massachusetts, Amherst
1977 B.S. (Agronomy), Wilmington College, Wilmington, Ohio

Employment History:
1993-present Cooperative Extension Specialist and Agronomist in the Agriculture Experiment Station–Alfalfa and forage crops, University of California, Davis, California
1986-1993 Assistant Professor, University of Minnesota, St. Paul, Minnesota. Specialist in New and Alternative Crops.
1985-1986 Research Associate, University of Massachusetts, Amherst, Massachusetts.

Current Position Description: ***Cooperative Extension Specialist and Experiment Station Scientist*** at UC Davis for alfalfa and forage cropping systems.This position entails statewide responsibility for extension and research activities related to alfalfa and forage crops. Currently chair of the California Alfalfa Symposium, and UC California Alfalfa Workgroup. Other interests include introduction of new crop species, crop ecology, and forage quality analysis methods, introduction of unique traits in alfalfa.

Research Interests: Alfalfa cultivar interactions with agronomic practices, introduction of unique traits in alfalfa, economics of the yield-quality tradeoff in alfalfa, forage quality analysis methods, irrigation techniques, alternative forage crops, interactions of alfalfa and the environment.

Honors, Awards:
1984-85 - Fulbright Scholarship for overseas study (India).
1999 - Hilgaard Award for Outstanding Teaching - Extension Specialist. California Association of Farm Advisors and Specialists.
2000 - Award for Excellence - American Society of Agronomy Extension Publications Award - Newsletter category, (California Alfalfa & Forage Review, candidate is editor)
2000 - Extension Education Award - National Association of Farm Advisors and Specialists
2000 - Achievement Award - California Associations of Farm Advisors and Specialists

Industry, Professional Memberships Chair, UC California Alfalfa Workgroup; Chair, California Hay Testing Consortium; Chair, California Alfalfa Symposium; Past President, and board member, National Forage Testing Association; California Alfalfa & Forage Association founding board member and Secretary; Member, American Society of Agronomy; Crop Science Society of

America; California Farm Bureau Federation, Hay Advisory Committee; Alfalfa Council (national), Advisory Board; National Alfalfa Intensive Training Seminar Instructor

Consulting: USDA oversees development projects, World Bank Oilseed Project, with private parties in Egypt, Saudi Arabia, Pakistan, China, and India, subjects related to forage production, hay storage and marketing, spontaneous combustion of hay, hay quality, and the use of forages for mitigation of pollution including applications of effluent and industrial wastes. Scientific exchanges and consultancies to Chile, Russia, India, Poland, Australia, New Zealand, and Egypt.

Five relevant publications:

Putnam, D.H. and M. Ottman. Emerging Issues with Alfalfa in the Desert and Mediterranean Regions of the Western United States. In Proceedings, Western Alfalfa and Forage Conference, 11-12 December, 2002, Reno, NV. UC Cooperative Extension, University of California, Davis.

Putnam, D.H. Producing Quality Alfalfa in the Western United States. Published In China International Grasslands Symposium Proceedings. 20-23 May, 2002 Bejing, China.

Long, R.F., M. Nett, D.H. Putnam, G. Shan, J. Schmierer, B. Reed. Insecticide Choice for Alfalfa may Protect Water Quality. California Agriculture 56(5):163:169.

Putnam, D.H., M. Russelle, S. Orloff, J. Kuhn, L. Fitzhugh, L. Godfrey, A. Kiess, and R. Long. Alfalfa, Wildlife and the Environment The importance and Benefits of Alfalfa in the 21st Century. 24 pages. California Alfalfa and Forage Association, Novato, CA.

Blank, S.C, S. Orloff, and D. H. Putnam. Sequential Stochastic Production Decisions for a Perennial Crop: The Yield/Quality Tradeoff for Alfalfa Hay. Journal of Agricultural and Resource Economics 26(2001): 195-211.

Mark E. Grismer, Ph.D. Agricultural Engineer/Hydrologist, U.C. Davis, Dept. of LAWR

Education:

Ph.D. – Agricultural Engineering, Colorado State University (1984)
Study Emphasis: Groundwater Hydrology
M.S. – Environmental Engineering, Oregon State University (1981)
Study Emphasis: Hydrology and Water Quality
B.S. – Agricultural Engineering, Oregon State University (1980)
Study Emphasis: Soil and Water Science

Teaching and Research:

Dr. Grismer is a Professor at U.C. Davis in the Department of Land, Air, and Water Resources, (LAWR) and in Biological & Agricultural Engineering. His teaching area includes general hydrology, and soil erosion/restoration courses. A key area of his current research interest and expertise is in soil erosion and runoff processes on agricultural lands, characterizing these processes through numerical modeling, determining the effects of these processes on water quality, and developing management solutions. Dr. Grismer also has interests in groundwater management, especially the influence of agricultural irrigation and drainage on shallow groundwater and salinity in a regional context.

Relevant Publications (of 104):

Bali, K.M., Grismer M. E., and R. L. Snyder. 2001. Alfalfa water use pinpointed in saline, shallow water tables of Imperial Valley. California Agriculture 55(4):38-43.

Bali K. M., M. E. Grismer and I. C. Tod. 2001. Reduced-Runoff Irrigation of alfalfa in Imperial Valley, California. ASCE J. Irrig. & Drain. Engr. 127(3):123-130.

Grismer, M. E. 2001. Regional alfalfa yield, ET_c, and water value in the western states. ASCE J. Irrig. & Drain. Engr. 127(3):131-139.

Grismer M. E. and Bali K. M. 2001. Reduced-Runoff Irrigation of Sudangrass Hay, Imperial Valley, California. ASCE J. Irrig. & Drain. Engr. 127(5):319-324.

Grismer, M. E. 2001. Sudangrass hay uses water at rates similar to alfalfa, depending on location. California Agriculture. 55(4):44-48.

Grismer, M.E., Orang, M. and S. Matyac. 2001. Evaluation of pan evaporation to evapo-transpiration conversion methods. ASCE J. of Irrig. & Drain. Engr. 128(3):180-185.

Grismer, M. E. 2001. Regional cotton lint yield, ET_c and water value in Arizona and California. Agricult. Water Mgmt. 1710:1-16.

Wallender, W. W. and M.E. Grismer. 2002. Irrigation hydrology: Crossing scales. ASCE J. of Irrig. & Drain. Engr. 128(4):203-211.

Snyder, R.L., Orang, M., Matyac, S. and M.E. Grismer. 2004. Simplified estimation of ET_o from pan evaporation data. ASCE J. of Irrig. & Drain. Engr. In-Press.

Khaled M. Bali, Ph.D.

Irrigation/Water Management Advisor
University of California Desert Research & Extension Center
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http://tmdl.ucdavis.edu

EDUCATION:

Ph.D. (Soil Science; Soil Physics), University of California, Davis. 1992.
Dissertation: *Error Corrections for Gamma-attenuation Measurements of Multi-phase Flow in Porous Media.*

M.S. (Water Science; Irrigation and Drainage), University of California, Davis. 1987. Thesis: *Water Application Under Varying Infiltration and Time.*

B.S. (Soils and Irrigation), University of Jordan, Amman. 1984

POSITIONS:

Assistant, Associate, and Full Title Cooperative Extension Advisor-Irrigation/Water Management, University of California- Division of Agriculture and Natural Resources, UC Desert Research & Extension Center (1992-present).

Engineering Technician: City of Davis, Davis, CA (1990-1991).

Research and Teaching Assistant: University of California, Davis, CA (1985-1991).

AWARDS:

- Khaled Bali Xeriscape Demonstration Garden. Yuma Crossing State Historic Park. Dedicated on April 22, 2004. USBR & Yuma Crossing State Park.
- 2003 Water Conservation Award. USBR- Lower Colorado Region Regional Award- Yuma Area Office October 2003.
- 2003 American Society of Civil Engineers/Environmental & Water Resources Institute Best Practice Paper Award for our ASCE Journal of Irrigation and Drainage paper "Model for Estimating Evaporation and Transpiration from Row Crops. Journal of Irrigation and Drainage Engineering, Nov/Dec 2001".
- University of California-Office of the Vice President: 2002 Agricultural and Natural Resources Distinguished Service Award for Outstanding Teamwork
- University of California Outstanding Research Award .UC Academic Assembly Council. July 1997.
- Volunteers in Overseas Cooperative Assistance (VOCA)- Outstanding Contribution to VOCA. August, 1996.
- Outstanding Student of the College of Agriculture. University of Jordan. Awarded by the late King Hussein of Jordan. June 1984.
- Practical training scholarship at the University of Stuttgart, Germany. Awarded by DADD, Germany. June-September 1984.

FIVE RELEVANT PUBLICATIONS:

Bali, K. M., M. E. Grismer, M. E. and R. L. Snyder. 2001. Alfalfa Water Use Pinpointed in Saline, Shallow Water Tables of Imperial Valley. *California Agriculture*, Vo. 55, No. 4, 38-43.

Bali, K. M., M. E. Grismer, and I. C. Tod. 2001. Reduced-Runoff Irrigation of Alfalfa in Imperial Valley,

California. American Society of Civil Engineers, Journal of Irrig. & Drain. Engr. Vol. 127, No. 3, 123-130.

Grismer M. E. and Bali, K. M. 2001. Reduced-Runoff Irrigation of Sudan Grass Hay, Imperial Valley,

California. American Society of Civil Engineers, Journal of Irrig. & Drain. Engr. Vol. 127, No. 5, 319-323.

Bali, K. M. 2003. Saline Water. Pages 829-831. *Encyclopedia of Water Science.* New York. Marcel Dekker, Inc.

Bali, K. M., I. C. Tod and M. E. Grismer. 2004. Reducing Drainage Requirement in Alfalfa Production. Proceedings of the Eighth International Drainage Symposium. Sacramento, CA. March 21-24, 2004. Pages 99-104.

David C. Slaughter, Professor
Biological and Agricultural Engineering
University of California, Davis 95616
(530) 752-5553

Education

1987 - Ph.D. awarded in Agricultural Engineering, University of Florida. Dissertation title "Color Vision for Robotic Orange Harvesting".

1984 - M.S. awarded in Biological and Agricultural Engineering, North Carolina State University.

1982 - B.S. awarded with high honors in Agricultural Engineering, University of California, Davis.

Employment

1996 - Present	Associate Professor, Department of Biological and Agricultural Engineering, University of California, Davis.
1990 - 1996	Assistant Professor, Department of Biological and Agricultural Engineering, University of California, Davis.
1987-1990	Research Scientist, Instrumentation and Sensing Laboratory, USDA - Agricultural Research Service, Beltsville, MD.
1984-1987	Research Scientist, Insect Attractants, Behavior, and Basic Biology Research Laboratory, USDA - Agricultural Research Service, Gainesville, FL.

Honors and Awards

1998 - American Society of Agricultural Engineers Paper Award for publication titled "Precision band spraying with machine vision guidance and adjustable yaw nozzles".
1997 - American Society of Agricultural Engineers Paper Award for publication titled "Machine vision detection of early split pistachio nuts".
1990 - American Society of Agricultural Engineers Paper Award for publication titled "Discriminating fruit for robotic harvest using color in natural outdoor scenes."
1989 - USDA Certificate of Merit.
1986 - USDA Certificate of Merit and Quality Increase.
1984 - USDA Engineering Traineeship
1982 - American Society of Engineers Student Honor Award.
1981 - Robert Row Owen Academic Scholarship.
1979 - Ben L. Hagglund Academic Scholarship.

Professional and Honorary Societies

Alpha Epsilon - Agricultural Engineering Honor Society.
American Society of Agricultural Engineers.
Council for Near Infrared Spectroscopy.
Phi Kappa Phi - National Interdisciplinary Honor Society.

Pi Mu Epsilon - National Honorary Mathematics Fraternity.
Sigma Xi - Scientific Research Society
Tau Beta Pi - National Engineering Honor Society

Patents

Slaughter, D.C., R. Curley, P. Chen, and D.K. Giles. 1995. Robotic Cultivator. U.S. Patent No. 5,442,552.

Giles, D. K., and D. C. Slaughter. 1996. Adjustable spray system and assembly method. U.S. Patent No. 5,544,813. August 13, 1996. (Similar Canadian Patent Pending). Licensed to Capstan Ag Systems, Inc., Topeka, KS.

Selected Publications:

Giles, D.K., and D.C. Slaughter. 1997. Precision band spraying with machine-vision guidance and adjustable yaw nozzles. Transactions of the ASAE 40(1):29-36.

Tian, L., D.C. Slaughter, and R.F. Norris. 1997. Outdoor field machine vision identification of tomato seedlings for automated weed control. Transactions of the ASAE 40(6):1761-1768.

Li, M., D.C. Slaughter, and J.F. Thompson. 1997. Optical chlorophyll sensing system for banana ripening. Postharvest Biology and Technology 12:273-283.

Sebben, E., D.C. Slaughter, and R.P. Singh. 1998. Optical assessment of corn oil deterioration during frying. J. of Food Processing and Preservation 22(4):265-282.

Tian, L.F., and D.C. Slaughter. 1998. Environmentally adaptive segmentation algorithm for outdoor image segmentation. Computers and Electronics in Agriculture. 21:153-168.

Slaughter, D.C., M.G. Pelletier, and S.K. Upadhyaya. 2001. Sensing soil moisture using NIR spectroscopy. Applied Engineering in Ag. 17(2): 241–247

Slaughter, D.C., and J.A. Abbott. 2004. Analysis of Fruits and Vegetables. In Near-Infrared Spectroscopy in Agriculture. Agronomy Monograph No. 44. Am. Soc. of Agronomy, Crop Sci. Soc. of Am. Soil Sci. Soc. of Am. Madison, WI, USA.

Downey, D., D.K. Giles and D.C. Slaughter. 2004. Mapping weeds using DGPS and ground based vision identification. California Agriculture. 58(4):218-221.

M. Nielsen, H. J. Andersen, D. C. Slaughter, D. K. Giles 2004. Detecting leaf features for automatic weed control using trinocular stereo vision. Proc. 7th International Conference on Precision Agriculture and Other Precision Resources Management. Minneapolis.

Haff, R.P., and D.C. Slaughter. 2004. Real-time x-ray inspection of wheat for infestation by the granary weevil, *Sitophilus Granarius* (L.). Trans. of the ASAE. Vol. 47(2): 531-537.

Giles, D.C. Slaughter, D. Downey, J.C. Brevis-Acuna, W.T. Lanini. 2004. Application design for machine vision guided selective spraying of weeds in high value crops. Aspects of Applied Biology. 71(1): 75-81.

2. Role of Cooperators

Dr. Upadhyaya will be overall in charge of the project. He will supervise the graduate student (GSR), development engineer (DE), and the undergraduate researcher (UGR). He is responsible for the design and development of the sensors and communication systems, experimental design, analysis of the data, demonstration of the cutoff management system to end users, and completion of all reports.

Dr. Wallender will assist the PI and GSR, DE, and UGR in designing experiments, and analyzing and interpreting the data. Drs. Upadhyaya and Wallender have collaborated successfully on projects funded by the Water Resource Board in the past as described in #3 below. Dr. Wallender's expertise in surface irrigation techniques will be particularly helpful to this project.

Dr. Putnam is the agronomist on the team. He will advise the team on all aspects of the alfalfa production system including irrigation management. Dr. Putnam worked with us closely on our previous project on network of wireless sensors. He identified growers in Woodland and Davis for us where we could conduct our field work. His expertise in alfalfa production system and familiarity with growers will be very helpful in all phases of this project.

Drs. Grismer and Bali bring us a wealth of experience with irrigation and drainage issues related to alfalfa production. They will assist the team in planning the field experiments, and analyzing and interpreting the data. Dr. Bali will also assist the team in demonstrating our cutoff irrigation scheme to farmers, farm advisors, and extension specialists in the Imperial Valley.

Dr. Slaughter is an expert in sensors and instrumentation. He will provide assistance to the team in designing and developing rope type sensors and implementing a cell phone communication technique to alert the irrigator. Drs. Upadhyaya and Slaughter have collaborated extensively in the past on several projects – nitrate sensor development, moisture sensor development, imaging a furrow irrigated field to track the wetting front.

The research team will meet frequently (once a month when necessary, but no less than once a quarter) to discuss the project progress and plan future activities. Dr. Bali will participate through videoconferencing. In addition, the GSR and DE will seek out the assistance of the PI and Co-PIs as and when needed.

3. Performance in Previous Water Use Efficiency Projects:

Drs. Upadhyaya, Slaughter, and Wallender were involved in two different projects supported by the Water Resources Board over the last two years. One of the projects was

headed by Dr. Wallender and involved using digital imaging techniques to track the wetting front advance in a furrow irrigated field. In this project, Dr. Slaughter successfully demonstrated the feasibility of tracking the wetting front in a furrow irrigated processing tomato field that used gated pipes to supply irrigation water. The project also demonstrated the feasibility of automatically controlling the inflow using solenoid actuated gate control devices.

In a second project headed by Dr. Upadhyaya, we demonstrated the feasibility of using a network of wireless sensors to track the wetting front advance in a furrow irrigated sedan grass field (Fig. 4). Although this system worked well in a furrow irrigated sedan grass field as well as flood irrigated alfalfa checks, it became clear that network of wireless sensors may not be the best method of sensing wetting front advance rate at this point in time as we explained earlier. However, our results clearly indicated that a network of sensors can accurately track wetting front advance rate and provide the most critical information needed, wetting font advance rate, for cutoff irrigation management in flood irrigated checks (Figure 1a to c). This proposal is based on the very successful and encouraging results obtained in this preliminary study.

Outreach, Community Involvement, and Acceptance

Objective #5 (task #7) aims at demonstrating this project to farmers, farm advisors, and extension specialists. We expect to draw a gathering of 50-100 people at these demonstrations. We are aware of no opposition to this project. When we contacted two different farmers in Woodland area during our preliminary study, they were very enthused about this project. In fact, one of those farms (Gnoss's farm) in Woodland was chosen for the preliminary study. We also hope to present our work at the alfalfa symposium. This symposium is usually attended by 300-500 people, mostly farmers, farm advisors, and extension specialists.

Innovations

Development of low cost, rope type water arrival sensors, determination of wetting front advance rate from sensor data, determining the irrigation cutoff time based on senor data and underlying model, and implementation of a voice communication technique to inform the irrigators are some of the innovative aspects of this study.

Applicant:Shrini K. Upadhyaya, Professor, Bio. and Agr. Eng., UC Davis

Project Title:Monitoring Wetting Front Advance Rate for Irrigation Management in Flood Irrigated Alfalfa Production Systems

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Section A projects must complete Life of investment, column VII and Capital Recovery Factor Column VIII. Do not use 0.

Table C-1: Project Costs (Year 1 Budget) in Dollars)

	Category (I)	Project Costs $ (II)	Contingency % (ex. 5 or 10) (III)	Project Cost + Contingency $ (IV)	Applicant Share $ (V)	State Share Grant $ (VI)	Life of investment (years) (VII	Capital Recovery Factor (VIII)	Annualized Costs $ (IX)
	Administration[1]								
	Salaries, wages	$52,294	5	$54,909	$0	$54,909	0	0.0000	$0
	Fringe benefits	$18,135	5	$19,042	$0	$19,042	0	0.0000	$0
	Supplies	$10,591	5	$11,121	$0	$11,121	0	0.0000	$0
	Equipment	$0	5	$0	$0	$0	0	0.0000	$0
	Consulting services	$0	5	$0	$0	$0	0	0.0000	$0
	Travel	$1,000	5	$1,050	$0	$1,050	0	0.0000	$0
	Other - UCD overhead (25% excludin	$18,213	5	$19,124	$0	$19,124	0	0.0000	$0
(a)	Total Administration Costs	$100,233		$105,245	$0	$105,245			$0
(b)	Planning/Design/Engineering	$0	0	$0	$0	$0	0	0.0000	$0
(c)	Equipment Purchases/Rentals/Rebates/Vouchers	$0	0	$0	$0	$0	10	0.0000	$0
(d)	Materials/Installation/Implementation	$0	0	$0	$0	$0	0	0.0000	$0
(e)	Implementation Verification	$0	0	$0	$0	$0	0	0.0000	$0
(f)	Project Legal/License Fees	$0	0	$0	$0	$0	0	0.0000	$0
(g)	Structures	$0	0	$0	$0	$0	0	0.0000	$0
(h)	Land Purchase/Easement	$0	0	$0	$0	$0	0	0.0000	$0
(i)	Environmental Compliance/Mitigation/Enhancement	$0	0	$0	$0	$0	0	0.0000	$0
(j)	Construction	$0	0	$0	$0	$0	0	0.0000	$0
(k)	Other (Specify)-Publications	$0	5	$0	$0	$0	0	0.0000	$0
(l)	Monitoring and Assessment	$0	0	$0	$0	$0	0	0.0000	$0
(m)	Report Preparation	$0	5	$0	$0	$0	0	0.0000	$0
(n)	**TOTAL**	$100,233		$105,245	$0	$105,245			$0
(o)	Cost Share -Percentage				0	100			

1- excludes administration O&M.

Applicant:Shrini K. Upadhyaya, Professor, Bio. and Agr. Eng., UC Davis

Project Title:Monitoring Wetting Front Advance Rate for Irrigation Management in Flood Irrigated Alfalfa Production Systems

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Section A projects must complete Life of investment, column VII and Capital Recovery Factor Column VIII. Do not use 0.

Table C-1: Project Costs (Year 2 Budget) in Dollars)

	Category (I)	Project Costs $ (II)	Contingency % (ex. 5 or 10) (III)	Project Cost + Contingency $ (IV)	Applicant Share $ (V)	State Share Grant $ (VI)	Life of investment (years) (VII	Capital Recovery Factor (VIII)	Annualized Costs $ (IX)
	Administration[1]								
	Salaries, wages	$54,677	5	$57,411	$0	$57,411	0	0.0000	$0
	Fringe benefits	$19,350	5	$20,318	$0	$20,318	0	0.0000	$0
	Supplies	$715	5	$751	$0	$751	0	0.0000	$0
	Equipment	$0	5	$0	$0	$0	0	0.0000	$0
	Consulting services	$0	5	$0	$0	$0	0	0.0000	$0
	Travel	$2,000	5	$2,100	$0	$2,100	0	0.0000	$0
	Other - UCD overhead (25% excludin	$16,927	5	$17,773	$0	$17,773	0	0.0000	$0
(a)	Total Administration Costs	$93,669		$98,352	$0	$98,352			$0
(b)	Planning/Design/Engineering	$0	0	$0	$0	$0	0	0.0000	$0
(c)	Equipment Purchases/Rentals/Rebates/Vouchers	$0	0	$0	$0	$0	10	0.0000	$0
(d)	Materials/Installation/Implementation	$0	0	$0	$0	$0	0	0.0000	$0
(e)	Implementation Verification	$0	0	$0	$0	$0	0	0.0000	$0
(f)	Project Legal/License Fees	$0	0	$0	$0	$0	0	0.0000	$0
(g)	Structures	$0	0	$0	$0	$0	0	0.0000	$0
(h)	Land Purchase/Easement	$0	0	$0	$0	$0	0	0.0000	$0
(i)	Environmental Compliance/Mitigation/Enhancement	$0	0	$0	$0	$0	0	0.0000	$0
(j)	Construction	$0	0	$0	$0	$0	0	0.0000	$0
(k)	Other (Specify)-Publications	$900	5	$945	$0	$945	0	0.0000	$0
(l)	Monitoring and Assessment	$0	0	$0	$0	$0	0	0.0000	$0
(m)	Report Preparation	$0	5	$0	$0	$0	0	0.0000	$0
(n)	**TOTAL**	$94,569		$99,297	$0	$99,297			$0
(o)	Cost Share -Percentage				0	100			

1- excludes administration O&M.

Applicant:Shrini K. Upadhyaya, Professor, Bio. and Agr. Eng., UC Davis

Project Title:Monitoring Wetting Front Advance Rate for Irrigation Management in Flood Irrigated Alfalfa Production Systems

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Section A projects must complete Life of investment, column VII and Capital Recovery Factor Column VIII. Do not use 0.

Table C-1: Project Costs (Year 3 Budget) in Dollars)

	Category (I)	Project Costs $ (II)	Contingency % (ex. 5 or 10) (III)	Project Cost + Contingency $ (IV)	Applicant Share $ (V)	State Share Grant $ (VI)	Life of investment (years) (VII	Capital Recovery Factor (VIII)	Annualized Costs $ (IX)
	Administration[1]								
	Salaries, wages	$57,180	5	$60,039	$0	$60,039	0	0.0000	$0
	Fringe benefits	$20,516	5	$21,542	$0	$21,542	0	0.0000	$0
	Supplies	$0	5	$0	$0	$0	0	0.0000	$0
	Equipment	$0	5	$0	$0	$0	0	0.0000	$0
	Consulting services	$0	5	$0	$0	$0	0	0.0000	$0
	Travel	$4,000	5	$4,200	$0	$4,200	0	0.0000	$0
	Other - UCD overhead (25% excludin	$18,117	5	$19,023	$0	$19,023	0	0.0000	$0
(a)	Total Administration Costs	$99,813		$104,804	$0	$104,804			$0
(b)	Planning/Design/Engineering	$0	0	$0	$0	$0	0	0.0000	$0
(c)	Equipment Purchases/Rentals/Rebates/Vouchers	$0	0	$0	$0	$0	10	0.0000	$0
(d)	Materials/Installation/Implementation	$0	0	$0	$0	$0	0	0.0000	$0
(e)	Implementation Verification	$0	0	$0	$0	$0	0	0.0000	$0
(f)	Project Legal/License Fees	$0	0	$0	$0	$0	0	0.0000	$0
(g)	Structures	$0	0	$0	$0	$0	0	0.0000	$0
(h)	Land Purchase/Easement	$0	0	$0	$0	$0	0	0.0000	$0
(i)	Environmental Compliance/Mitigation/Enhancement	$0	0	$0	$0	$0	0	0.0000	$0
(j)	Construction	$0	0	$0	$0	$0	0	0.0000	$0
(k)	Other (Specify)-Publications	$900	5	$945	$0	$945	0	0.0000	$0
(l)	Monitoring and Assessment	$0	0	$0	$0	$0	0	0.0000	$0
(m)	Report Preparation	$500	5	$525	$0	$525	0	0.0000	$0
(n)	**TOTAL**	$101,213		$106,274	$0	$106,274			$0
(o)	Cost Share -Percentage				0	100			

1- excludes administration O&M.

Applicant:Shrini K. Upadhyaya, Professor, Bio. and Agr. Eng., UC Davis

Project Title:Monitoring Wetting Front Advance Rate for Irrigation Management in Flood Irrigated Alfalfa Production Systems

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Section A projects must complete Life of investment, column VII and Capital Recovery Factor Column VIII. Do not use 0.

Table C-1: Project Costs (Total Budget) in Dollars)

	Category (I)	Project Costs $ (II)	Contingency % (ex. 5 or 10) (III)	Project Cost + Contingency $ (IV)	Applicant Share $ (V)	State Share Grant $ (VI)	Life of investment (years) (VII	Capital Recovery Factor (VIII)	Annualized Costs $ (IX)
	Administration[1]								
	Salaries, wages	$164,151	5	$172,359	$0	$172,359	0	0.0000	$0
	Fringe benefits	$58,001	5	$60,901	$0	$60,901	0	0.0000	$0
	Supplies	$11,306	5	$11,871	$0	$11,871	0	0.0000	$0
	Equipment	$0	5	$0	$0	$0	0	0.0000	$0
	Consulting services	$0	5	$0	$0	$0	0	0.0000	$0
	Travel	$7,000	5	$7,350	$0	$7,350	0	0.0000	$0
	Other - UCD overhead (25% excludin	$53,257	5	$55,920	$0	$55,920	0	0.0000	$0
(a)	Total Administration Costs	$293,715		$308,401	$0	$308,401			$0
(b)	Planning/Design/Engineering	$0	0	$0	$0	$0	0	0.0000	$0
(c)	Equipment Purchases/Rentals/Rebates/Vouchers	$0	0	$0	$0	$0	10	0.0000	$0
(d)	Materials/Installation/Implementation	$0	0	$0	$0	$0	0	0.0000	$0
(e)	Implementation Verification	$0	0	$0	$0	$0	0	0.0000	$0
(f)	Project Legal/License Fees	$0	0	$0	$0	$0	0	0.0000	$0
(g)	Structures	$0	0	$0	$0	$0	0	0.0000	$0
(h)	Land Purchase/Easement	$0	0	$0	$0	$0	0	0.0000	$0
(i)	Environmental Compliance/Mitigation/Enhancement	$0	0	$0	$0	$0	0	0.0000	$0
(j)	Construction	$0	0	$0	$0	$0	0	0.0000	$0
(k)	Other (Specify)-Publications	$1,800	5	$1,890	$0	$1,890	0	0.0000	$0
(l)	Monitoring and Assessment	$0	0	$0	$0	$0	0	0.0000	$0
(m)	Report Preparation	$500	5	$525	$0	$525	0	0.0000	$0
(n)	**TOTAL**	$296,015		$310,816	$0	$310,816			$0
(o)	Cost Share -Percentage				0	100			

1- excludes administration O&M.

Justification of the Budget:

Personnel:

Dr. Shrini K. Upadhyaya, 20% FTE. Overall in charge of the project. No cost to WRB.

Dr. Wes Wallender, 5% FTE. Advice on surface irrigation related issues, experimental design, and analysis and interpretation of the data. No cost to WRB.

Dr. Dan Putnam, 5% FTE. Advice on various alfalfa production aspects including irrigation, identification of growers to setup demonstration, and assist with actual demonstration activities. No cost to WRB.

Dr. Mark Grismer, 5% FTE. Advice on irrigation and drainage issues related to alfalfa production. Assist the team with experimental design, analysis and interpretation of data. No cost to WRB.

Dr. Khalid Bali, 5% FTE. Advice on irrigation and drainage issues related to alfalfa production. Assist with the field demonstration in the Imperial Valley. No cost to WRB.

Dr. David Slaughter, 5% FTE. Advice on rope type water arrival sensor development and cell phone based communication system to the irrigator. Also assist with the experimental design, data analysis, and interpretation.

Development Engineer (DE): 50 % FTE @ $4098/month. Design, develop, and test the rope sensor. Conduct field experiments, collect and analyze data. Develop cell phone based communication system. Carry out the demonstration.

Salary:

Yr1: $24, 588 Yr2: $25, 817[1] Yr3: $27, 108[1] Total: $77, 513

Benefits: 34.6% of the salary

Yr1: $8, 507 Yr2: $8, 933 Yr3: $9, 379 Total: $26, 819

Graduate Student Researcher (GSR): 50% FTE 9 months and full time summer @ $2438/month. Work closely with the PI and the DE to carry out all phases of the study. Model water arrival sensor data along with inflow to determine the wetting front advance rate. Use this information to determine water shutoff time. Develop necessary code to generate a call using the telephone modem with voice synthesizer. Test the technique in the field.

Salary:

Yr1: $18, 285 Yr2: $19, 199 Yr3: $20, 159 Total: $57, 643

Benefits: 1.3% during the academic year (9 months) and 3% during summer (3 months) – Effective rate is 1.725%

[1] Subsequent year rates include a 5% increase.

Yr1: $315	Yr2: $331	Yr3: $348	Total: $994

Fee Remission:

Yr1: $9, 169	Yr2: $9, 935	Yr3: $10, 630	Total: $29, 734

Undergraduate student: Three months during summer @$10/hr and 160 hrs/month. Assist DE and GSR with the filed experiments, data collection, and analysis.

Salary:

Yr1: $4, 800	Yr2: $5, 040	Yr3: $5, 292	Total: $15, 132

Benefits: 3% of the salary

Yr1: $144	Yr2: $151	Yr3: $159	Total: $454

Electronic Technician: 80hrs/yr at a recharge rate of $57.75/hr which includes benefits. Assist the DE and GSR with sensor fabrication and cell phone communication technique.

Yr1: $4, 621	Yr2: $4, 621	Yr3: $4, 621	Total: $13, 863

Supplies:

1. Supplies for fabricating 12 rope sensors.	$1, 800
2. Chemical analysis of tail water samples at the DANR lab. (about 120 samples)	$1, 200
3. One PDFM-IV portable Doppler flow meter from Greyline Instruments for measuring inflow ($3695+ tax and shipping):	$4, 013
4. One AVFM Area-Velocity flow meter to measure tail discharge from Greyline Instruments($3290+tax and shipping):	$3, 578
Yr 1 Total:	$10, 591
5. Com 310 Telephone modem Voice Synthesizer from Campbell Scientific ($620 + tax and shipping):	$715
Yr 2 Total:	$715

Travel cost:

Car rental to travel to test sites: $1000/yr during the first two years. $3000 during the third year due to increased travel related to field demonstrations. Moreover, during the second and third year we plan to present the results of our study at the California alfalfa symposium and national scientific meetings. The travel cost request for each year is $1000/ year.

Yr1: $1, 000 Yr2: $2, 000 Yr3: $4, 000 Total: $7, 000

Publication Cost:

$ 900/year during the second and third year of this study to cover page charges related to the publication of the results of this study in journals.

Report preparation cost:

We have requested $500 for preparation of the final report. We are not charging the WRB for quarterly report costs.

Indirect cost (25% of the direct cost excluding fee remission):

Yr1: $18, 213 Yr2: $16, 927 Yr3: $18, 117 Total: $53, 257

Benefits and Costs:

Following assumptions are made to estimate water savings as well as value of water saved for the Bay-delta region and the State of California.

- Alfalfa is grown over 1.1 million acres in California and 55.1 thousand acres in the Bay-delta region (WRB 2004a; Agricultural Statistics, 2003).
- The irrigation water applied to alfalfa is 20 to 27% of the water applied to California agriculture (Hanson and Putnam, 2000). The California Agriculture consumes 33.7 million acre-ft (WRB 2004b). Even if we use a conservative estimate of 20%, this amounts to 6.74 million acre-ft. On the other hand, Vargas et al. (2003) suggest the use of 4.5 ft of applied water per season. This amounts to *4.95 million acre-ft* for California's 1.1 million acres of alfalfa crop. We will use this lower number in our calculations. The amount of water applied to alfalfa in the Bay-Delta region is *298 thousand acre-ft* (WRB 2004a)
- Nearly 60% of the alfalfa production uses boarder strip irrigation (personal communication with K. Bali). This translates to *0.67 million acres* for California and *33.1 thousand acres* for the Bay-Delta region. In terms of water use, this amounts to *2.97 million acre-ft* for the State of California and *179 thousand acre-ft* for the Bay-Delta region.
- According to WRB 2004b irrigation water cost varies from $35 to $95 per acre-foot. However, Vargas et al. (2003) suggest the use of a more conservative value of $30/acre-foot. We will use this lower value of *$30/acre-ft* for irrigation water.
- Bali et al. (2001) reported a savings of 15% when a cutoff irrigation scheme is employed. We will use a more conservative number of *10%* in our calculations.

Using the above assumptions, we estimate following savings for the Bay-Delta region and California:

Bay-Delta Region:

Amount of water saved	:0.10*179,000 acre-ft
	= **17, 900 acre-ft**
Value of the water saved	:17, 900 acre-ft * $30 /acre-ft
	= **$537, 000**

State of California:

Amount of water saved	:0.10*2.97 million acre-ft
	= **0.297 million acre-ft**
Value of the Water saved	:0.297 million acre-ft * $30 /acre-ft
	= **$8.9 million**

Note that on a per acre basis the average value of water saved is **$13** for the State of California and **$16** for the Bay-delta region in flood irrigated alfalfa production systems.

Once established, alfalfa stand lasts about 3 to 4 years in warmer climates and even longer in the cooler intermountain region. Assuming a thee year stand, total value of water saved in *California is 26.7 million dollars* and in *Bay-delta region is 1.6 million dollars*. Given that project cost is $296, 015 for three years, the benefits far outweigh the cost. If you extend this technique to other crops that are flood irrigated, the magnitude of benefit will be even greater. The cost of the technology to farmers is difficult to estimate at this point in time. However, rope type contact sensors and the cell phone communication technique should be quite inexpensive when produced in large commercial scales. Moreover, environmental benefits of reducing tail drainage in itself might justify employing this type technology in alfalfa production. In view of the improvements in irrigation efficiency, water savings, and reduction in pollutant loading on the environment, we feel that this project will greatly benefit the Bay-delta region as well as the State of California.

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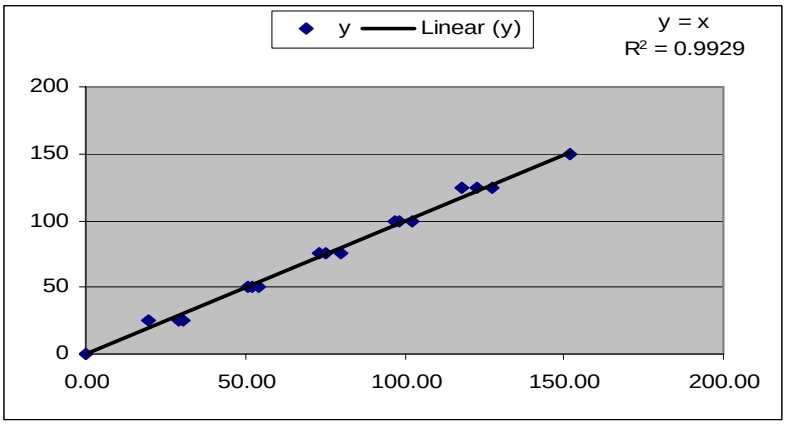
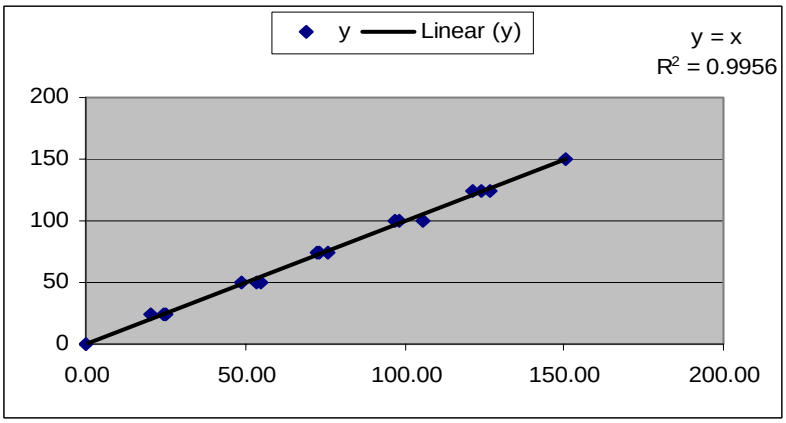


(a)



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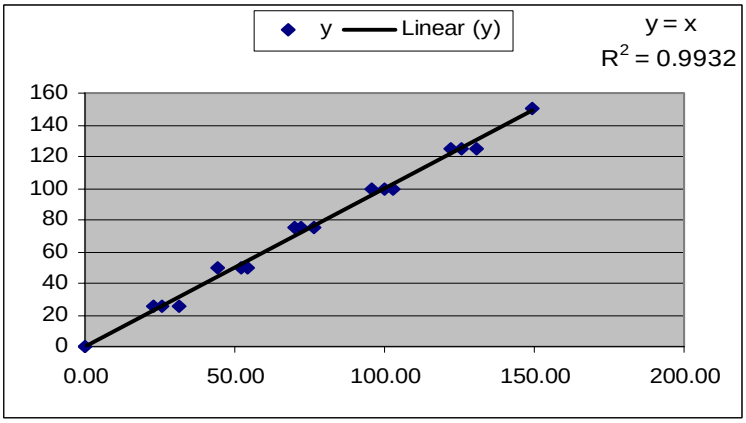

(c)

Figure 1. Predicted versus actual wetting front advance through (a) Check #1, Irrigation #1 (b) Check#2, Irrigation #2, and (c) Check#3, Irrigation #3 in flood irrigated alfalfa checks on UC Davis campus.

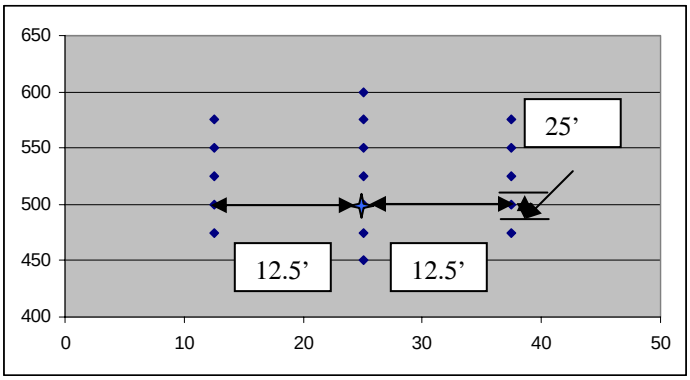

Figure 2. Locations of wetting front advance sensing units in checks.

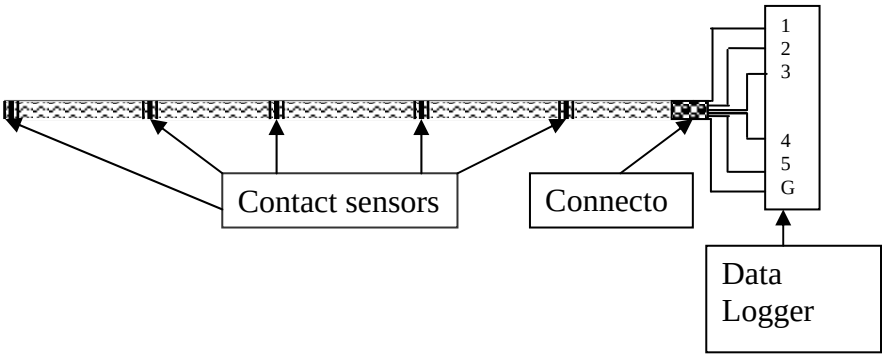

Figure 3. A schematic of a rope type of wetting front advance sensor containing five simple contact type sensors spaced 15 ft. apart and connected to a data logger. Numbers 1 to 5 are the sensor connections to the data logger and G is the ground terminal. In operation the sensor will be buried about 3 to 4 in deep across an alfalfa check.

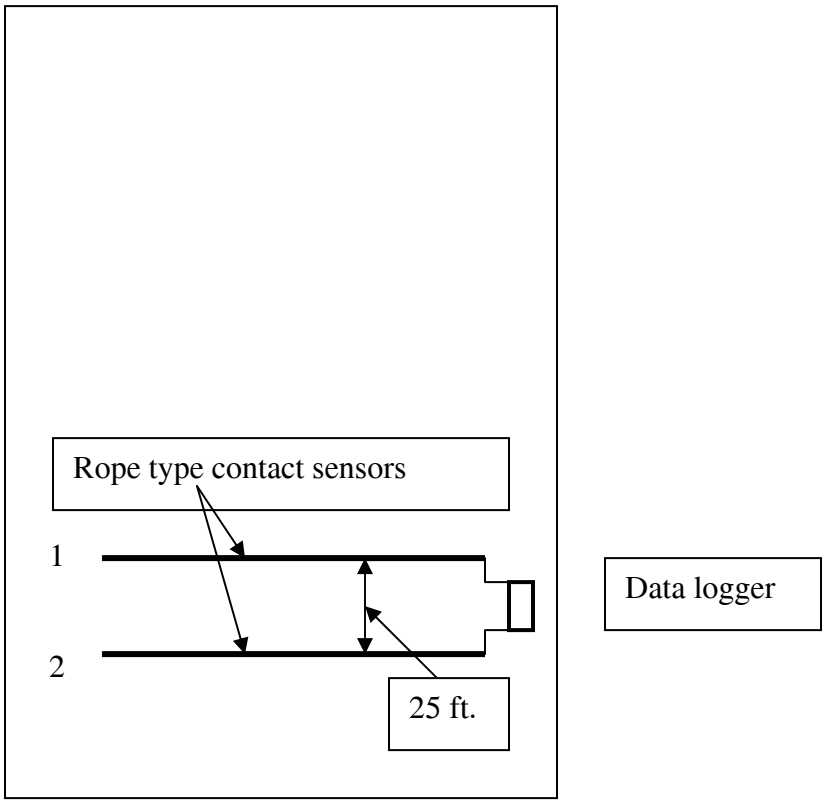

Figure 3. Installation of rope type sensors in an alfalfa check. The first sensor (#1) is located at 50 or 75% of the check length as per experimental design.

Figure 4. A network of simple contact type wireless sensors in a furrow irrigated Sedan grass field.