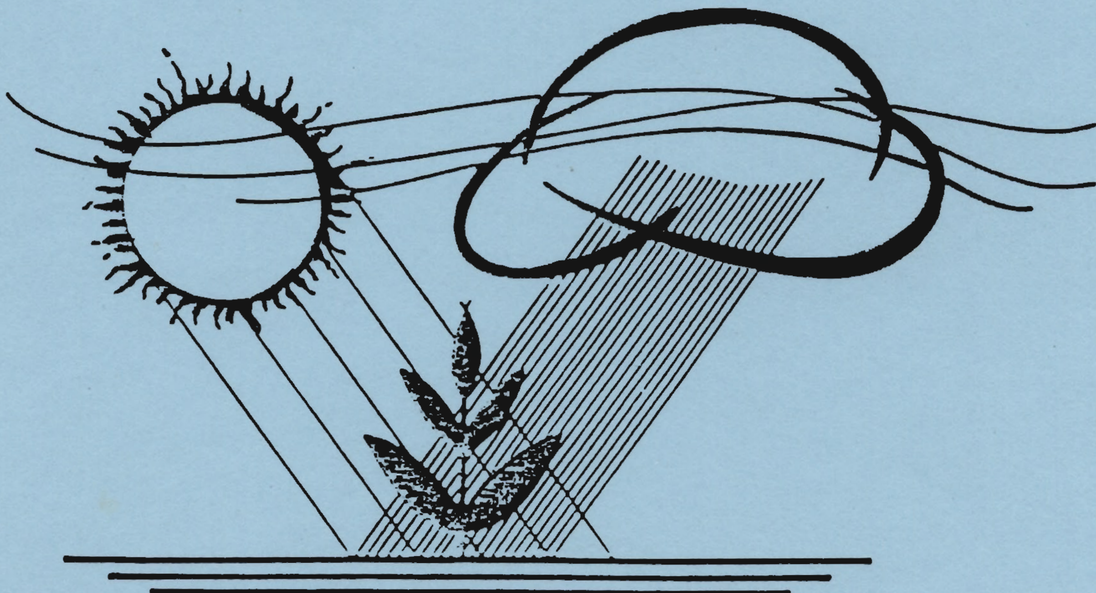
Proceedings

1986 CALIFORNIA PLANT AND SOIL CONFERENCE

Sustaining California's Agriculture



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CALIFORNIA CHAPTER

AMERICAN SOCIETY OF AGRONOMY

January 28-30, 1986

Sacramento Inn

Sacramento, California

Includes

Proposed Amendment to the Constitution & By-laws

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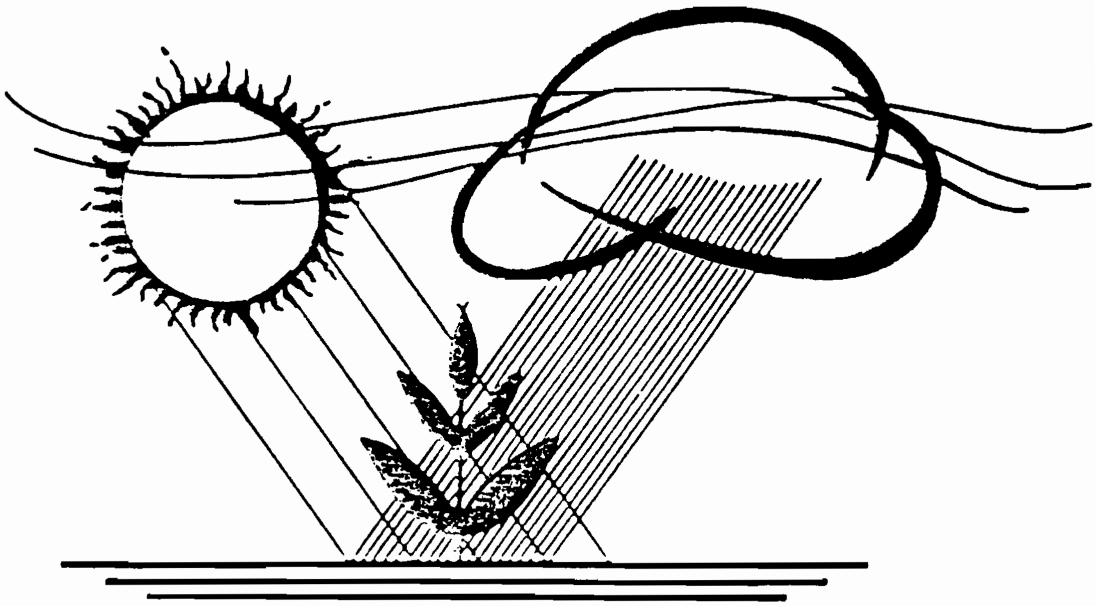

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PROGRESS WITH PHYSIOLOGICAL MODELS

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Progress in agronomy is based largely on traditional empirical approaches involving "same-level" and "reductionist" experiments. Same-level experiments are typified by field experiments in which we try to relate yield to an independent variable such as density or moisture supply. Efforts in bioclimatology, for example, have centered on multivariate statistical approaches in which yield variations over years and locations are equated with variations in rainfall, temperature, radiation and other factors. A response pattern is defined but the explanation for that response may remain unclear. Same-level experiments are not unique to field research -- they are also found at whole-plant to molecular levels. A serious problem with same-level work is that it is usually situation specific. If we change cultivars, soil history, location or weather, we may have to repeat the experiments to obtain a new empirical answer.

Reductionist research aims at providing explanations. Given that yield varies with moisture supply, we may find "explanation" in root distribution, xylem or leaf conductance or osmotic adjustment or in a direct effect of low plant water potentials on an enzyme system or on turgor-driven cell expansion. Our expectation is that behavior of the crop or whole plant will be explained by the sum of its operating parts, e.g., that enzymes or cells fully explain whole plants.

One serious problem with reductionist research is that qualitative integrations are often difficult (e.g., is the nitrate reductase system really the controlling step in plant use of nitrogen?) and we have had no good means for quantitative integration (e.g., if cell division rate in leaves at low temperature is increased by x%, how will crop yield respond?). Another problem is that the behavior of cells and enzymes are strongly controlled by the whole-plant/crop situation. For example, we find that the level and activity of the nitrate reduction system in the plant is really explained by the soil supply of nitrogen and the effectiveness of roots in acquiring it and by the rate at which reduced nitrogen is used in growth.

Clearly we need a additional approach aimed at quantitative integration if we are to make much use of advances in physiology for understanding and predicting crop behavior. Simulation of crop behavior with dynamic, integrative models is gradually emerging as an answer to that problem. Advanced models now exist for all major crops.

Integrative Crop Models

Structure

Most integrative models are based on the "state-variable" concepts pioneered in the early 1960s by J. W. Forrester of MIT. A complex system can be described at any point in time by state variables corresponding to things which we can see in a "snapshot." For a crop, the number, mass and area of leaves, mass of grain and mass, length and distribution of fibrous roots would be among the state variables which would describe the crop. These parts change in time through growth and through the initiation of new organs or activities. They also carry out important functions such as photosynthesis, respiration, transpiration and uptake of water and nutrients.

The trick in integrative models is to calculate the rates of these processes dependent upon the current state variables (e.g., photosynthesis as a function of leaf area) and weather (photosynthesis rate depends upon radiation and temperature). The state variables are then advanced in time, rates are calculated again and the states are further updated in an iterative fashion. In this way we create a moving picture of crop growth controlled by crop "rules" (in essence, genetic rules) and environment.

The central features of a typical crop model are illustrated in Figure 1. When we are interested in yield, the accumulation and partitioning of dry matter becomes the central theme. To simulate that properly, a model needs to give nearly as much detail to the morphogenesis of different plant parts as it does to their activities in photosynthesis or water uptake. One of the nice things about such models is that they force our attention to the first law of thermodynamics (matter

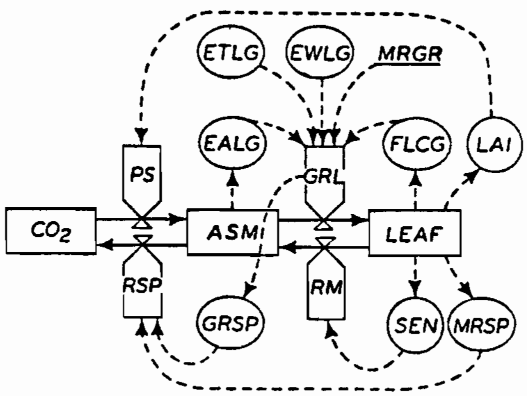

Figure 1. Relational diagram for the production (PS) and loss (RSP) of new assimilate (ASM) and its use in the growth (GRL) of leaves and recovery during senesence (RM). Control variables such as the effect of assimilate supply on leaf growth (EALG) and feedback loops are shown.

can be neither created nor destroyed). Dry matter (or carbon), water and nutrient balances are included in the models and the fluxes of these materials to and from all sources and sinks are balanced at each iteration of the model.

The Time Problem

A daily time advance is certainly adequate for defining the course of the main features of a crop over a 100- to 200-day period. However, daily time advance requires certain compromises in physiological detail which may limit the utility of the model. In real plants, the rates of physiological processes vary from minute to minute or hour to hour as temperature, radiation and water status change. The growth of leaves, for example, might be limited at night by low temperature or substrate depletion and during the day by low plant water potential. With a daily advance, we must restrict the potential growth rate by a factor which represents the average of those interacting factors. A shorter time step allows one to simulate those interactions using simple single-factor response functions for the "most limiting" factor at each time of day. A 1-hour time advance has proven practical for most features of crop systems but shorter steps are required to represent stomatal control. That of course requires more interations and the model will run more slowly on the computer.

The choice of time step also influences how one looks at developmental rate (e.g., the rate at which new leaves are produced or the rate at which a plant advances from one phenological stage to the next). Developmental rates are strongly influenced by temperature (Fig. 2) in roughly the same manner as are growth rates. As is seen in Figure 2,

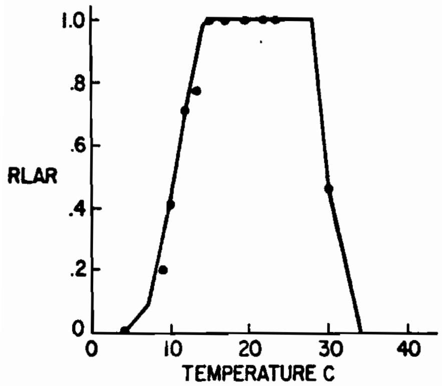

Figure 2. The relative effect of temperature on developmental rate of sugarbeet. The solid line is the function used in a sugarbeet model (1); points represent experimental observations in controlled environments.

developmental rate usually increases with temperature to an maximum and then declines. As long as the plant experiences only temperatures below the optimum (in this case, between 6 and 14°C), the time between developmental events can be correlated fairly well with temperature-time summations such as "degree-days" and many daily time advance models use temperature summations as a basis for physiological time. However, simple sums from daily mean temperature minus some base temperature overlook the plateau and the negative effects of high temperature. The total associated with a particular phenological event will also differ with different diurnal amplitudes of temperature (different locations or years). One can circumvent these problems by calculating the temperature sum in different ways (2) or by using an hourly model. The hourly temperature can be simulated from daily maximum and minimum and the hourly developmental rate then extrapolated directly from a curve such as that in Figure 2.

Accuracy vs. Realism and Explanation

It has not proved difficult to achieve reasonable accuracy (±10%) in crop simulations and accuracy can be improved by tuning and fitting model parameters to the local situation (e.g., by varying the temperature sums for phenological stages). However, if a model must be fitted to each situation, it loses some of its utility. In addition, considerable experimental work may be required to do that, but our main concern is that the model then may lose explanatory ability -- the right answers are found but for the wrong reasons. One alternative is to direct the model towards realism so that obtaining the correct behavior for the right reasons is given priority over accuracy. This can be achieved by adding more detail including appropriate feed back control to the model. Done properly, accuracy will follow but again we have made a larger model and hence increased the cost of simulation.

Whether simple or detailed, it is very important that users look beyond the simple output of yield in evaluating the behavior of a model. Look closely at secondary variables such as leaf area index and crop water status to see if these offer correct explanations for the observed behavior. Performance of a model at different plant density, for example, provides a severe test of its partitioning rules.

Simplicity and Validation

Most modelers follow the tenent of "Occam's Razor" -- build the simplest possible model for the objectives at hand. Irrigation scheduling, for example, can be accomplished with a simple model dealing with crop cover, energy balance and advection. Model performance can then be compared with real situations so that we are satisfied that it yields valid predictions. However, that model would probably be too simple for the simulation of yield components of a grain crop, development of a foliar disease, or competition by weeds. Strict obedience to Occam's principle could easily lead us to a dozen different, special-purpose wheat models. Model development and validation are very time-consuming and costly activities. While special-purpose models may be easily understood and thus individually "user friendly," an array of a dozen partially validated models becomes very confusing.

I am increasingly convinced that we should concentrate on only a few, highly versatile models for each crop. Inevitably this means more structure and slower running time but even the largest crop models can now be run on IBM PC/AT equivalent computers. Understanding large models requires more time and commitment by users but that is offset by their much greater utility and thus greater amount of user experience. Large models are best written with separate sections for root growth, water balance, photosynthesis, and so on. Each can be easily understood by itself. As in backcross breeding, each section can be improved as defects or better opinions arise so that the model grows in competence and versatility over time.

Applications

A great diversity of objectives underlie existing physiological models. They have proved effective in research on integrative physiology both for analysis of how the parts of plants work together and in identifying deficiencies in our knowledge (1,5,7). The most common stumbling blocks lay in morphogenesis and respiration.

Since physiological models at the same time predict and explain crop response to weather they are rapidly displacing statistical approaches in bioclimatology (6). The models can be run with specific weather sets, long term averages, and with various types of perturbation (a week of hot weather at emergence or flowering, for example). Relatively few models have yet achieved realistic treatment of nutrient deficiencies. Nutrient budgets for well nourished crops are easily simulated but broader objectives in nitrogen management have not been achieved. Evapotranspiration is simulated well by many models. Coupled with a layered soil and fibrous root model, performance under rainfed conditions and with variations in irrigation is possible. By running many simulations over years and locations the variability and risk of farming can be evaluated.

Physiological models offer considerable potential as an aid to management. The most important uses there include comparisons of effects of planting date and prediction of potential performance with current weather. That leads directly to assessments of losses due to weather, pests and other causes (3). Considerable progress has been made with coupled host-pest models for predicting the time course and severity of insect and disease attack (4). The hope is that such models will serve as an effective basis for integrative pest management.

Conclusion

Crop modeling is still a young field. The first pioneering efforts were launched less than 20 years ago and we have yet to see any truly finished first-rate models and we are only now beginning to realize some of their potential as powerful tools in research and management.

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OBJECTIVES AND PROGRESS OF CROP GROWTH MODELS SPONSORED BY THE CALIFORNIA IPM PROJECT

H. Ferris

The commodity groups funded by the UC/IPM Project have placed considerable emphasis on the development of models of crop production systems and their associated pests. Models, in any sense of the word, are simplifications of larger, more complex systems, structures, or events. They promote understanding of the form and function of the system they represent. However, They are limited by simplification and by the modeler's understanding of the system.

Part of the complexity of crop management is the understanding of how individual pest populations interact with the crop and with each other. Such understanding would allow prediction of repercussions throughout the system resulting from perturbation of one population or of one part of the system. The interaction among the individual populations is primarily integrated by the plant, and the effect of this integration from a practical standpoint is reflected in yield and quality of the crop. Central to the UC/IPM Project modeling activities is the development of plant models. These models describe the important plant growth processes involved in crop production. They vary in their complexity, but generally simulate the production of photosynthates under given conditions of temperature and sunlight, and the partitioning of that energy into respiration or production of leaves, stems, roots, and fruit over time. More complex models may account for varying supplies of water and nitrogen, impact of pruning, soil type, or other factors.

Each commodity group and researcher has a somewhat different approach to model development, but basic strategies are similar. The first step is to determine the objectives of the model, the type of model, and the level of complexity necessary to describe the system adequately. Relevant components are selected within the designated boundaries of the system. The next step is to describe the model in mathematical terms. The parameters of the mathematical model are estimated through experimentation, analysis of data sets from collaborators, review of available literature, or from the opinions of experienced specialists. Completing this step may take several years if new experiments are necessary to collect the appropriate data. Once the parameters are estimated, the model is installed on a computer system in a form accessible to users. Last, the model is validated by comparing its simulations to field biology observations. Sometimes this process will reveal the importance of factors heretofore not considered of consequence for determining timing of event, yields, or population increase; such factors might include chilling requirements, day length, or natural enemies. The validation process may take several seasons if adequate historical data are not available.

Although an initial model structure may be completed, the model development process is never really finished. As research provides more detailed information about how a crop grows or how pests damage the plant, the model can be developed into a more accurate predictor of events in the field. A model can only reflect the current state of knowledge about the factors affecting plant growth, and there will always be room for improvement. However, modeling activities can effectively and efficiently direct research programs toward the prescribed goal of describing a crop or pest community. In the process, they provide a forum for integrating information, identifying critical data gaps, and for promoting interdisciplinary research.

Several types of models are useful for crop and pest management purposes. Phenology models predict the timing of developmental events. They are frequently based on temperature, or on units of heat summation called degree-days. The events predicted might include bud break, flowering, vegetative growth, fruit growth, or the appearance of various life stages of pest populations. Some phenological models account for factors other than temperature, including humidity, chilling requirements, and other environmental conditions. Models at this level are useful for timing crop protection activities, or for timing monitoring efforts for the detection of pest species.

More complex than phenological models are population models, which predict not only the timing of the events, but also their magnitude. For example, a pest population model would predict not only the occurrence, but also the magnitude of the pest outbreak. When sufficient data are available on the impact of the pest on crop growth, the population model can be used to estimate the expected crop damage. Such models provide a basis for economic threshold considerations, and ultimately for optimization of returns from the system, either in the short term or over a multi-year cropping sequence.

Other models fall under the category of management decision models. They include predictors of the relationship between the intensity of the monitoring or sampling effort and the associated precision of the pest population estimate. These models allow assessment of the risk involved in acceptance or rejection of a management decision. Management decision models may also project the efficacy of a management strategy given the current size of the pest population, the current development of the crop, and the current environmental conditions. Once again, the accuracy of the predictions and projections from such models is limited by understanding of the complexities of the system, and by necessary definition of a restricted boundary to the system. The models are extremely useful, however, in promoting rigorous statements about understanding of the structure of the systems, thereby revealing gaps in knowledge and appropriately directing research activities.

Plant modeling activities undertaken by the University of California Integrated Pest Management Project are at various levels of resolution and stages of development.

Alfalfa

A physiologically-based plant growth model has been developed which tracks photosynthetic productivity, and respiratory and growth demands on an hourly basis. The model allows specification of management inputs such as cutting height, regrowth potential and cutting frequency. Efforts are currently underway to improve the "user friendliness" of the model and to couple pest models into the system. The pest models will include Egyptian alfalfa weevil and models of the impact of phytopathogenic fungi.

Almond

A phenology model is in the final stages of development for almond. The model predicts hull-split and susceptibility of almonds to navel orange worm attack.

Cereals

There has been considerable modeling activity in cereals in various parts of the world. Rather than redevelop a cereals model, personnel in the UC/IPM Project are evaluating and modifying models from The Netherlands and Australia to determine their usefulness. Some experimentation is ongoing to determine appropriate parameter values for these models under California conditions.

Citrus

A physiologically based crop growth model is being developed which will deal with photosynthetic production, and respiratory and growth demands. The model will have both below-ground and above-ground components to allow coupling of important pest organisms. Considerable data have been collected by the IPM Project for derivation of parameter values for the model and there is wealth of historical information on citrus physiology and growth available in California. Separate phenology models predicting timing and rates of fruit development have also been developed and are considered important for the management of spray schedules.

Cotton

Several cotton models have been developed both in California and elsewhere. The UC/IPM Project is in the process of evaluating existing models for their suitability for management purposes and their applicability to California conditions. An expert systems protocol is being developed to allow management selections for mites, *Lygus* and *Verticillium* in cotton.

Grape

A physiologically based plant model has been developed in grape similar to that under development in citrus. Data have been collected to generalize the parameter values of the model for various grape cultivars, and two years of validation trials have been conducted in various regions of the Central Valley. Pest models currently linked to the grape model include grape leaf hopper, powdery mildew and root-knot nematodes.

Walnut

A phenology model based upon day-degrees has been developed in walnut to predict various stages of nut development. This model allows projection of spray schedules for crop protection at vulnerable periods.

Rice

A phenology model is under development for rice which predicts timing of various growth stages in rice development and prediction of vulnerable periods to pest damage.

Tomato

A very sophisticated tomato plant model is in the final stages of development. The model deals not only with photosynthate supply and demand as with the grape model, but also incorporates nutrient, moisture and heat stress factors, and their impact on growth rates and productivity. The model is linked to tomato fruitworm and beet armyworm models, and ultimately will formulate the basis of a management decision model.

Some of the models discussed have immediate utility as a basis for management decisions. Others are very much in the research phase, aiding and testing the understanding of researchers of the crop systems in question. Hopefully, when suitably explanatory, they will allow research and formulation of management decisions. Little progress has yet been made on structuring the models into an operations research framework to allow solution of optimal management strategies for a given system. However, the investigation of the underlying biological concepts will allow such developments.

EFFECT OF WEATHER VARIATION ON SEASONAL PRODUCTION OF CALIFORNIA ANNUAL GRASSLAND -- A SIMULATION AND REGRESSION APPROACH

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A dynamic simulation model of the annual grassland ecosystem of California has been developed through the adaptation of ELM, a compartment/flow computer model constructed in the US/IBP Grassland Biome (Pendleton et al., 1983). The general objective was to simulate the seasonal dynamics of biomass in the annual grassland on a daily basis. The components of the grassland ecosystem -- weather factors, primary producers, decomposers, nutrients, and mammalian consumers -- are described in linked submodels. Process mechanisms in each of the submodels control flow rates of carbon (biomass), nutrients, and water through the simulated system. Driving variables are temperature, precipitation, relative humidity, wind speed, and cloud cover. Primary data from the San Joaquin Experimental Range and other information from published and unpublished sources were used in developing the model.

Multiple regression and correlation analyses were done to relate simulated seasonal biomass production to weather variables, including max-min temperatures, heat sums, effective precipitation, and time between rainfall events. The results were used to test hypotheses explaining weather effects on fall, winter and spring grassland productivity and species composition. Ninety-nine simulations of production at three long-term, regional range field stations (San Joaquin Experimental Range, Hopland, and Sierra Foothill Range) were compared with field data to validate model predictions. Traces of cumulative biomass, degree-days, and precipitation were examined to classify fall, winter and spring growing conditions.

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DEVELOPMENT OF A MANAGEMENT ORIENTED COTTON CROP SIMULATION MODEL AT THE TEXAS AGRICULTURAL EXPERIMENT STATION

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A cotton crop simulation model (COTTAM) is currently being developed at the Texas Agricultural Experiment Station (TAES) at Temple, Texas. This presentation includes: 1. historical information on this cotton modeling effort, 2. an overview of the model structure with emphasis on the subroutines dealing with abscission of fruiting forms, and 3. a discussion of plans for current and future research and implementation.

Historical Background

The objective of this model building project has been to develop a management tool for cotton. Dr Gerald Arkin (TAES) and Brian Hearn (CSIRO, Australia) formulated the original structure and approach. It should be noted that Hearn is involved in the SIRATAC model in Australia so that SIRATAC (Hearn and da Roza, 1984) and COTTAM are fundamentally very similar. In fact, originally the submodels were developed so that they could be used in either model. Over the last few years, however, work has progressed independently so that this modularity has probably been lost.

In the last few years the model has progressed through various stages of submodel improvement and refinement. This was done primarily by Bruce Jackson and Arkin at TAES. During 1983 and 1984 the author was responsible for development of algorithms for simulating the abscission of fruiting forms (bolls and squares). During this time Hearn also joined the team for one year. As a result, there was a surge in model development, bringing the model to a stage where it simulates cotton crop growth and fruiting development adequately. The first version, accompanied by a users guide, will be available in 1986.

Model Structure

The objectives of this project are to develop a management tool for cotton growers. Existing modeling projects were surveyed to determine which aspects would be suitable for inclusion in a management type model. Previous modeling projects at TAES suggested that a complete physiologically based carbon budget model, (i.e., tracing the fate of every carbon molecule assimilated into the plant), would be so complex that the resulting micro computer simulation would be too slow and cumbersome for use as a management tool. At the same time, the model was to retain the flexibility of being able to respond validly to a large variety of environmental conditions with variables which consist of entities observable by the grower.

A model was assembled which predicts the morphological development of the plant using empirical, process-oriented submodels. This is done by simulating the pattern in which the cotton plant produces nodes on the main stem and branches (Jackson et al., 1984). Furthermore, the concept of "boll carrying capacity" is defined to represent the carbohydrate status of the crop. This variable varies with population density, irradiance, and nutritional factors and reflects the number of fruiting forms which can be maintained by the plant. In the model it is a key factor in controlling cutout and abscission of reproductive organs.

Abscission of fruiting forms occurs even in well managed stands of cotton. Shedding is usually light early in the season but becomes heavier as the number of fruit increases. This observation has led model builders to postulate that shedding is a response to metabolic stress associated with increasingly severe competition for nutrients. External stresses, such as reduced light or water supply increase the proportion of fruit shedding.

There are two theories regarding abscission of fruiting forms in cotton: 1. nutritional and 2. hormonal. The nutritional theory is based on the carbohydrate status of the plant. It states that fruiting forms shed in response to the shortage of carbohydrates in the plant resulting from competition among plant parts. The hormonal theory is based on observations of concentrations of various compounds such as abscisic acid, ethylene and cytokinins. Of these ABA was found to be most closely correlated with percent abscission. In this theory various stimuli affect the concentrations of these hormones - exceeding certain threshold levels initiates the abscission process.

These two theories are, in general, compatible. The hormonal theory suggests a pattern for abscission with respect to organ age while the nutritional theory explains the overall volume of abscission. A model was constructed to simulate the probability of abscission based on observed patterns of frequencies of shedding of fruiting forms of various ages. This resulted in a model with high abscission probabilities for young squares, decreasing to moderately low levels prior to flowering, high levels for young bolls and extremely low levels (near zero) for older, mature bolls (Lieth et al., 1984). While the pattern remains the same regardless of environmental conditions, the magnitude varies with the boll carrying capacity.

Simulations were run with these submodels built into COTTAM using environmental data collected at three separate locations in California, Arizona and

Texas. The simulated numbers of squares, and green and open bolls were compared with those observed in each of the studies. The simulation showed good agreement with observed fruiting form counts. Also the distribution of occurrences of abscission with respect to fruiting form age agreed with that reported in the literature (Lieth et al., 1986).

Current and Future Work

The current short-term goal is to produce a "first version" accompanied by a user manual. This version is not yet likely to be useful as a management tool but rather as a vehicle for demonstrating to researchers what exactly is being done and what questions have arisen. Dr. Arkin's estimate for utility in that it would probably be suitable for dissemination to Extension within five years and to on-farm use within the next five years so that actual management applications are probably still 5 to 10 years away.

Presently COTTAM is among various models chosen for integration into an expert system for cotton in development at Texas A&M University. Here it will be interfaced with other models which deal with other aspects of cotton management such as pest control.

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COMAX - A Cotton Management Expert System Incorporating GOSSYM

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Much of what I present here today is taken from a paper, by Hal Lemmon (1986), to be published soon in Science. That paper describes a type of expert system which we believe is new to the field of artificial intelligence. This expert system (COMAX) exercises a dynamic simulation model (GOSSYM) for purposes of system optimization. Here we describe the system and provide one example of its use in a farm management situation.

The elements of COMAX are shown in Figure 1. A weather station in the cotton field is connected via phone link to the IBM PC (AT or XT with extended memory) in the farmer's office. The computer contains an inference engine and a knowledge base, written in LISP, a crop simulation model (GOSSYM) written in FORTRAN, and a data base.

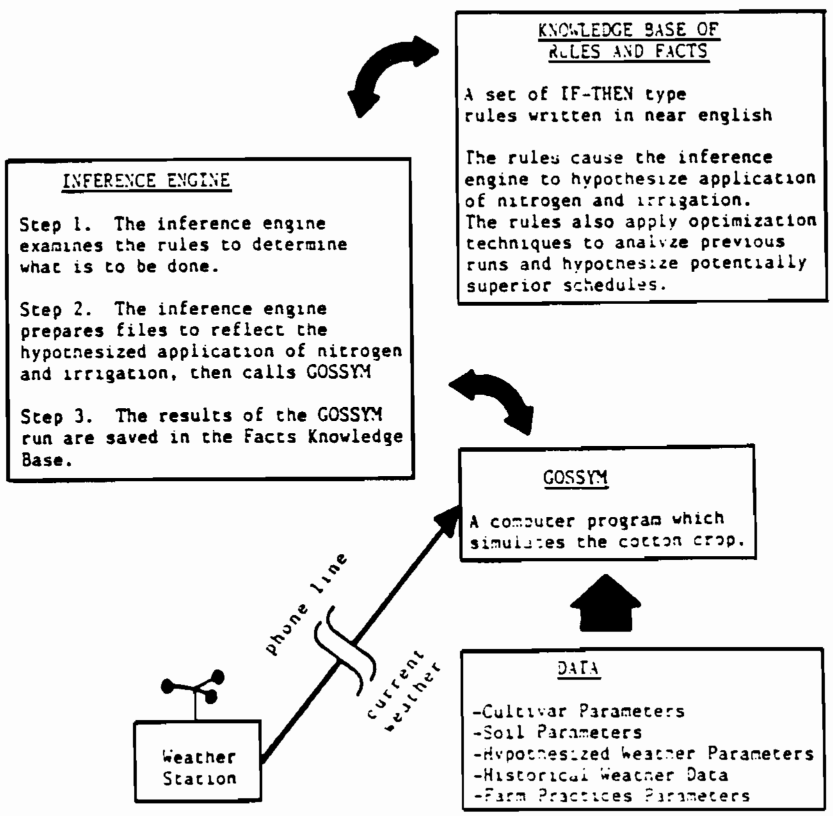

Figure 1.

The inference engine performs Steps 1 through 3 iteratively until the optimum management program is determined. What constitutes optimum is partly determined by the rules and differs with the circumstances. For example secondary growth of the plant after the bolls have matured may be desirable in Arizona and undesirable in Mississippi.

In Figure 1, the rules considered pertain to irrigation and fertilizer scheduling. Other rules pertain to other cultural operations including cultivation, pest management, harvest, etc. In practice this system operates continuously during the growing season archiving input data and searching for optimum management options. Economic factors including operations costs, commodity prices and the risk capability of the farmer are now being incorporated in the system.

Rules and facts in the knowledge base are readily changed, so all elements of the system, except the simulation model are applicable to any row crop. GOSSYM is one of a class of structurally isomorphic models. This structure (c.f. Figure 2) is designed broadly along disciplinary lines to simulate the crop wherever it is grown, and to accomodate new research information continuously as it becomes available with minimum disturbance to the end user. These are process based materials balance models which iterate on daily or hourly time steps.

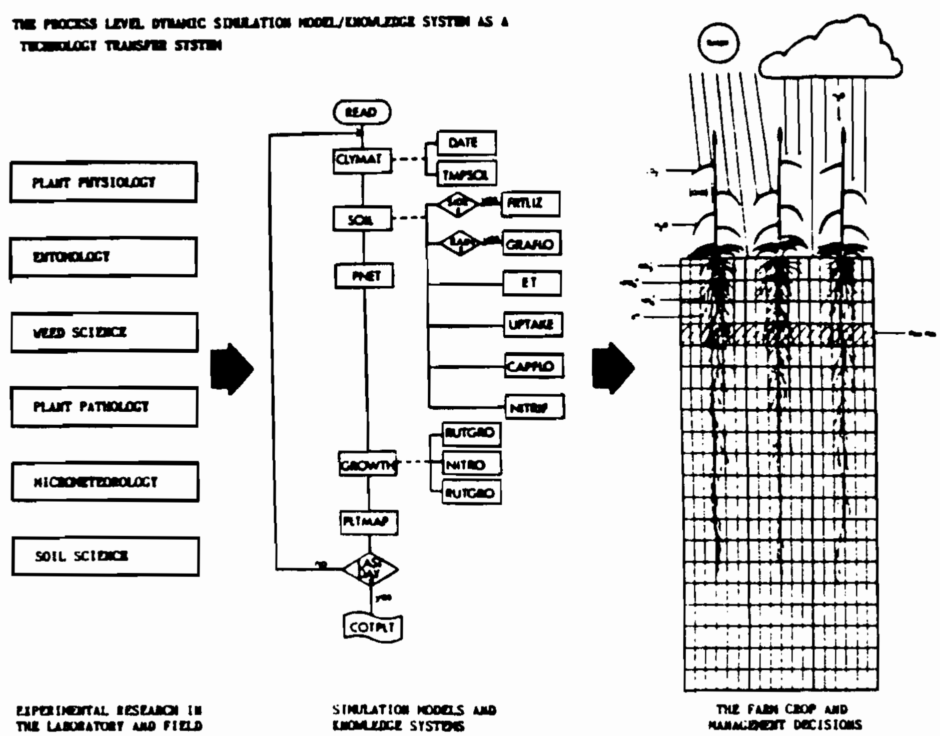

Figure 2.

Briefly they operate as follows: Climate, fertilizer, irrigation and other data are read in. Water and fertilizer inputs are distributed appropriately within a two-dimensional soil matrix. Increments of evaporation and transpiration are calculated. The resulting amounts of water and nutrient uptake are imposed on the system and distributed considering mass and age structure of roots in the various cells in the matrix. Soluble nutrients are assumed to be entrained in the transpiration stream. The remaining water and soluble nutrients are redistributed within the matrix via Darcy flows. Soil nitrogen transformations are estimated depending on temperature and water content of each cell. The water content in the rooted portion of the soil profile along with the climate information are used to calculate plant water potential. Plant water potential, canopy light interception and temperature are used to calculate canopy photosynthesis and respiration. The resulting dry matter increment is distributed to the growing points in the plant as follows: First, the potential dry matter accretion increment of each organ is calculated from temperature, tissue turgor and age. Additionally, root growth depends on soil strength, soil oxygen, the presence of certain herbicides and the water content of the soil cell. The amount of mineral nutrient required to elaborate the new tissue in each organ is calculated. A nitrogen supply:demand ratio is formed and (if less than one) used to reduce the potential dry matter accretion increment. A dry matter supply:demand ratio is calculated and used to partition photosynthate to the various organs. Finally, the appearance of new organs is simulated considering running average temperatures and developmental delays indexed via the metabolite supply:demand ratios. Fruit abortion is also indexed via these ratios. The model was structured from the outset to accept insect damage and to provide insect models with plant geometry and feeding substrate quality information. Comparable pest models are now being developed.

A specially designed controlled environment installation (SPAR) is used to provide data bases for process rate functions in these models over the environmental range of interest.

GOSSYM(SJ-2) has been validated with data sets representing fifty-seven crop years including a wide range of climate and soil conditions in Israel (Marani, et al., 1985). We have published papers describing the use of GOSSYM in evaluating the impact of changing climate, increasing atmospheric CO_2, soil erosion, soil compaction and herbicide injury on cotton growth and yield. In two papers (Landivar, et al., 1983a and b) we correctly predicted yield responses to genetic manipulations of cotton (leaf shape and stomatal response to water stress) which were subsequently verified in breeding efforts (Meredith, 1984 and Quisenberry, et al., 1985).

Figures 3 through 9 demonstrate a COMAX analysis from a farm in the Mississippi Delta in 1985. The analysis was done about 70 days after emergence.

In the first graph of Figure 3, the circles represent the amounts of nitrogen applied and the day of application. On this farm the grower applied 55, 60 and 30 lbs. of nitrogen per acre at planting, and at 33 and 63 days after emergence respectively. The line shows the nitrogen stress; the ratio of nitrogen taken up to nitrogen needed by the plant for full growth of all organs. In the second graph the jagged line represents a measure of water stress in the plant, and the vertical bars show the amount of water applied by either rain or irrigation. The third graph shows the height of the plant, the number of squares (unpollinated flower buds) and the number of bolls. The number of squares increases with time, then decreases as some are shed (due to stress) and others turn to bolls. The fourth graph shows the development of the predicted yield. Final yield, in bales per acre, is printed numerically above the curve. The crop was forecast to be fully mature on September 1. Later analyses confirmed this estimate of maturity date, and this information alone has been enormously valuable to participating farmers in the past two years.

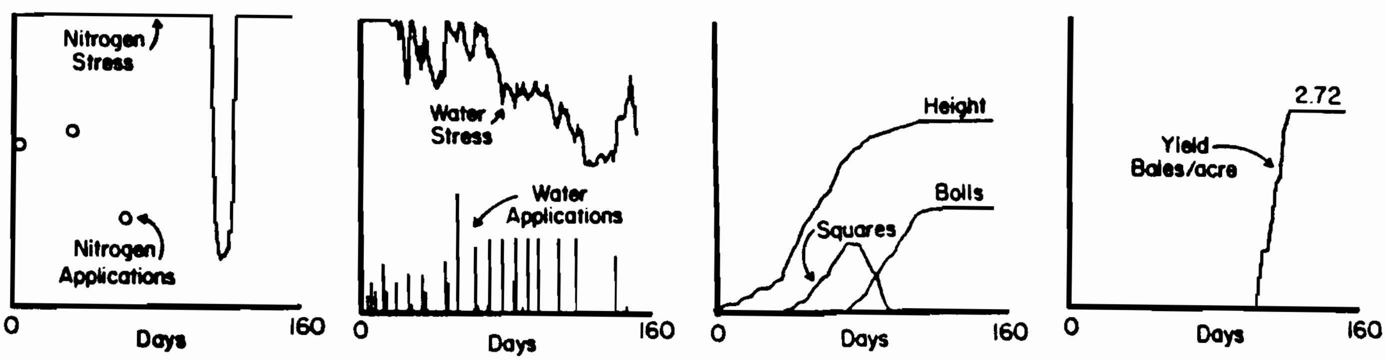

Figure 3.

In Figure 4 COMAX has hypothesized an application of 20 lbs. of nitrogen 10 days prior to the time it would have gone into stress. Nitrogen stress, while still present, has decreased and there is a corresponding increase in the yield.

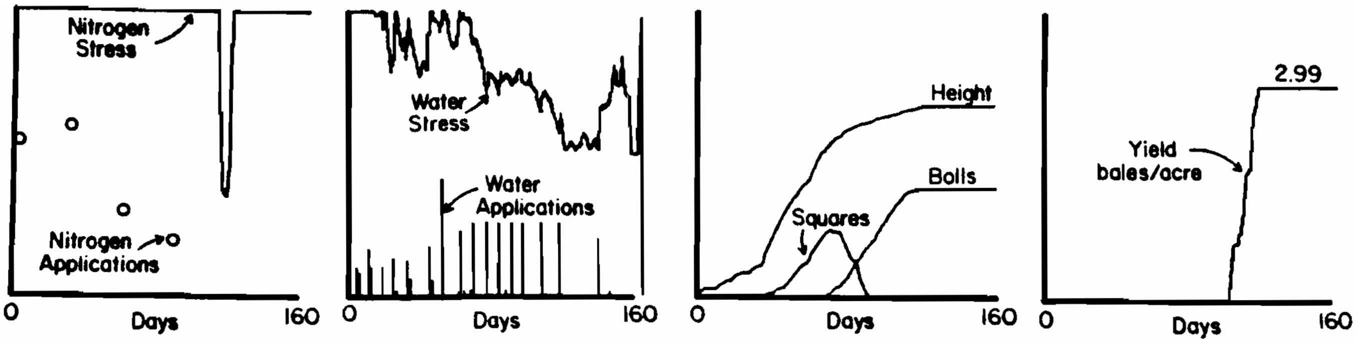

Figure 4.

In Figure 5 COMAX has hypothesized an application of 40 lbs. of nitrogen. The nitrogen stress has nearly disappeared and the yield increased again. However, there is a deleterious aspect. The third graph shows that after the bolls have all matured, the cotton plant has had a spurt of new growth and started adding squares. At the point where the yield levels off the crop should be harvested since no more cotton can be expected and there is a risk that delay will encounter devastating rain. To harvest cotton with modern equipment it is first necessary to apply a defoliant to cause the leaves to drop off. However, this plant is now so healthy that the defoliant may not be as effective as it should be. The rules in COMAX will cause this selection to be rejected.

Another "run" predicted that nearly all of the yield increase projected for 40 lbs. additional nitrogen could be obtained with 30 lb. This was field tested in a replicated experiment with 0.6 acre plots. Data from hand picked subplots indicated that a 0.36 bale per acre yield increase was achieved. The machine picked plots produced an average 0.23 bales per acre. This increased profit amounted to $55.00 per acre. It appears that some of the gain in late developing boll growth was more susceptible to harvest loss (hard lock).

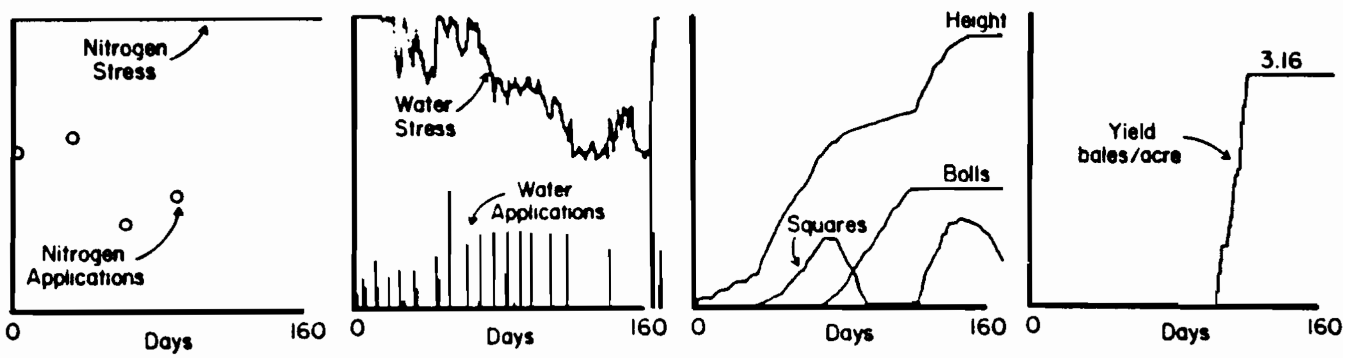

Figure 5.

In Figure 6 COMAX has turned it's attention towards the water stress problem and hypothesized a heavier irrigation schedule with no additional nitrogen. The second graph shows that increased irrigation resulted in reduced water stress, but the nitrogen stress has intensified. With increased water the plant has the capacity of increased growth, and therefore needs even more nitrogen. Notice that even with increased irrigation there is no increased yield over Figure 3.

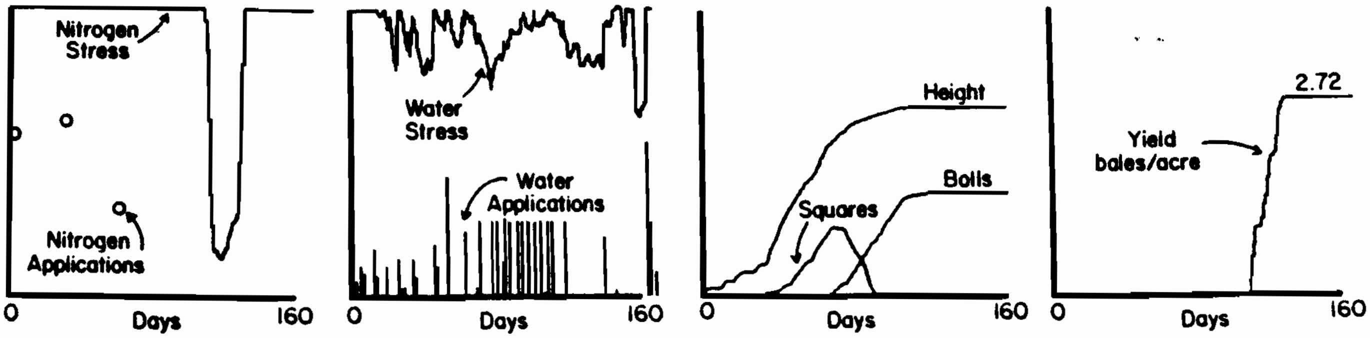

Figure 6.

In Figure 7 COMAX has hypothesized an additional 40 lbs of nitrogen with the increased irrigation; the nitrogen stress has decreased and the yield increased correspondingly.

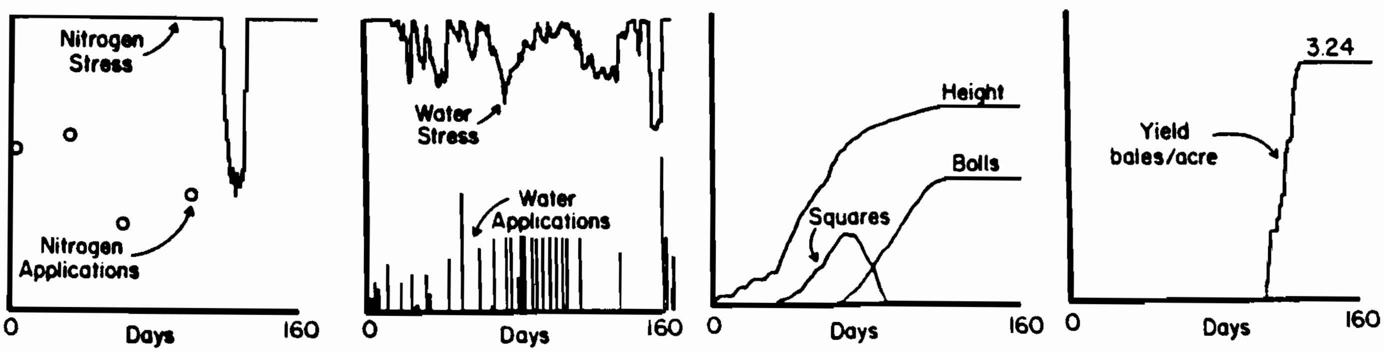

Figure 7.

In Figure 8 COMAX has hypothesized an additional 60 lbs. of nitrogen, the nitrogen stress is gone and the yield has increased correspondingly. However the third graph shows the plant has begun to re-grow rapidly after the bolls have all matured and it has initiated new squares which will never mature, and which will be difficult to defoliate for harvesting.

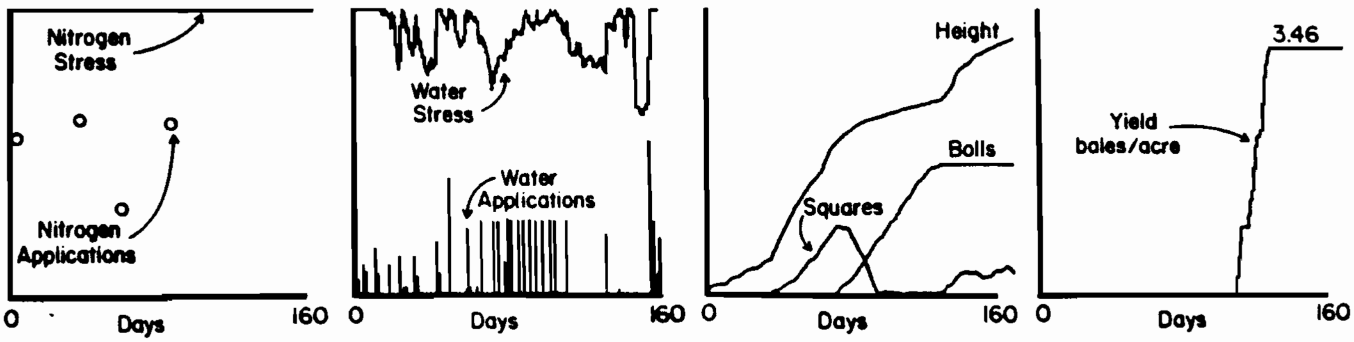

Figure 8.

In Figure 9 COMAX has selected 50 lbs of nitrogen per acre in conjunction with the indicated irrigation applications for the maximum yield subject to the constraint of no secondary growth.

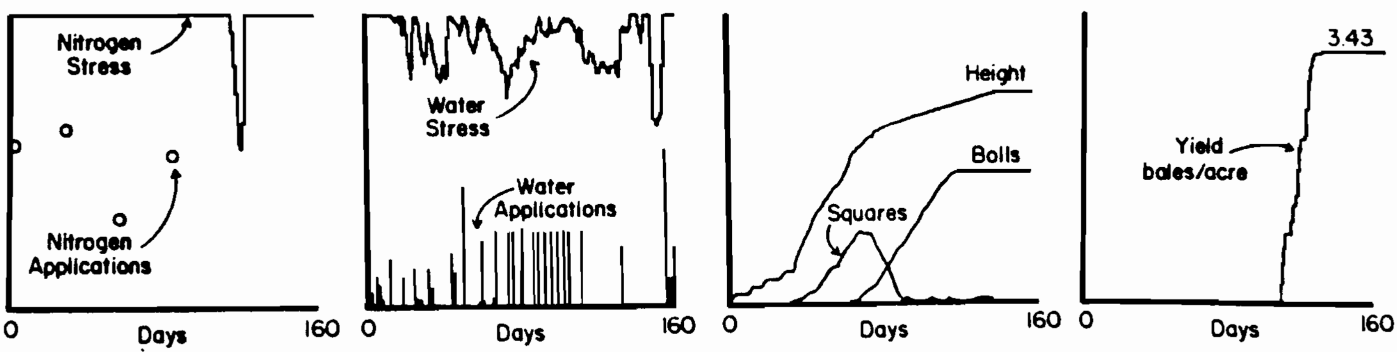

Figure 9.

SUMMARY

A rule based crop managment expert system (COMAX) has been built which archives real time weather data and exercises process level dynamic simulation models using steepest ascent procedures, etc. to optimize operator inputs. The crop simulation models are based on process rate data from especially designed and equipped controlled environment installations. The cotton model GOSSYM (SJ-2) has been extensively validated, although validation work is continuing here in California. COMAX including GOSSYM are structured to continuously accomodate new basic research information and convey it to the farmer and to other users. Initial farm trials in South Carolina and Mississippi have shown

COMAX has significantly contributed to increases in profit by improved fertilizer, irrigation, and harvest managment.

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Title: SIRATAC, an Australian Cotton Management Tool

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Introduction

Cotton crop systems are inherently complex. During the course of a season, a farmer or his manager is faced with a myriad of decisions. Some decisions are made only once a year or less often, such as what to buy as the next piece of farm equipment, however most are tactical in nature, repeating themselves at varying intervals through the course of a season. This latter group of decisions includes scheduling irrigations, determining when next to side dress or aerially fertilize a field, or when to initiate a control action to prevent a pest species from reaching a damaging level. With reference to pest management, Ellington et al. (1985) identified no fewer than 95 arthropod, disease, and weed pests of cotton in the western region of the U.S.. As could be expected, data are only available for objectively managing but a few of these. When considered within the context of the whole management picture, as impinged upon and regulated by the abiotic environment, information is rarely available for addressing the multiplicity of interactions which come into play.

As a focus for developing a better understanding of crop systems, a considerable emphasis has been placed upon the development of pest and crop models. Systems approaches such as these provide a focus for addressing the complex interactions inherent to biological systems. With foresight they can be used to identify the major factors regulating a crops growth, development, and profitability and be used to formulate and plan appropriate experiments which are necessary for development of a biological model which mimics reality at the desired level of resolution.

With few exceptions, most crop and pest models are primarily research oriented, and as such are not structured to be used in commercial crop management. Table 1 lists some of the more common cotton models and associated pest models. Several of these models have proven valuable when addressing crop production or pest management related hypotheses. SIMCOT I (Baker et al. 1969, 1972, Duncan 1971, Duncan et al. 1971, Hesketh et al. 1971, 1972), SIMCOT II (McKinion et al. 1974), and GOSSYM (Baker et al. 1976) from Mississippi, have largely addressed the physiological details inherent to a population of cotton plants, with a smaller effort directed to the agronomics of crop production. COTCROP (Jones et al. 1980) a spin off of SIMCOT II has been used to address agronomic management questions, and to a degree the management of the cotton bollworm and tobacco budworm in both Mississippi and Arkansas (Brown et al. 1976, Brown and McClendon 1982). At the other extreme different versions of COTSIM (Gutierrez et al. 1975) have been used in California, Texas, Mexico, Nicaragua, Brazil, and Australia (Blood and Wilson 1978, Gutierrez et al. 1975, 1977a, 1977b, 1979a, 1979b, 1981, 1983, Wang et al. 1977) to address the interaction of a range of pest species with the cotton crop, from the strategic management level and from an ecosystems perspective.

Table 1. Cotton crop models and associated pest models

Crop Model	Pest models	References
COTCROP		Jones et al. 1980
	Heliothis zea	Brown et al. 1976, Brown & McClendon 1982
	Heliothis virescens	same same
COTSIM		Gutierrez et al. 1975
	Anthonomus grandis	Gutierrez et al. 1979a, 1981
	Heliothis virescens	Wilson & Gutierrez 1980
	Heliothis zea	Gutierrez et al. 1981, Wilson & Gutierrez 1980
	Heliothis armigera	Blood & Wilson 1978
	Heliothis punctigera	same
	Lygus hesperus	Gutierrez et al. 1977b, 1979b
	Pectinophora gossypiella	Gutierrez et al. 1977a
	Spodoptera exigua	Gutierrez et al. 1975
	Tetranychus spp.	Wilson & Corbet unpub. ms.
	Trichoplusia ni	Gutierrez et al. 1975
	Verticillium dahliae	Gutierrez et al. 1983
GOSSYM		Baker et al. 1976
Isreali model		Wallach 1980
	Heliothis armigera	same
	Heliothis punctigera	same
SIMCOT I		Baker et al. 1969
SIMCOT II		McKinion et al. 1974
SIRATAC		Hearn & Room 1979, Room 1979
	For pests see Table 2.	Hearn et al. 1981, Ives et al. 1984, Room 1979
Australian model		Wilson et al. 1972
	Heliothis armigera	same
	Heliothis punctigera	same

These modelling efforts have considerably advanced our current understanding of crop production and pest management, however, none truly transcend into the tactical management sphere, to be used on a day to day basis by farm managers. In general, the reason why these and most research models have not taken that last step is due to several factors, not least is the lack of an incentive for rewarding U.S. scientists for promoting development of commercial crop management packages. To date only two computerized cotton crop production and pest management programs have been developed which are commercially used on a broad scale. Not surprisingly, both of these have been developed in countries which strongly promote collaboration with industry, recognize the importance of such efforts by their scientists, and also provide the necessary level of funding for such development. An Isreali model (Wallach 1980) is still very much in its infancy. To date, this model allows for management of water and for management of one of their key cotton pest, the cotton bollworm, Heliothis armigera. An Autralian cotton management program (Hearn and Room 1979, Hearn et al. 1981, Ives et al. 1984, Room 1979, and Wilson et al. 1983), which I will focus on for the remainder of this paper, is on the other hand used to manage a wide range of arthropod pests, and is rapidly becoming the defacto standard for cotton management in that country.

Australian Cotton Management

SIRATAC, an acronym for CSIRO and New South Wales Department of Agriculture Tactic for growing cotton, was as the name implies jointly developed as a cooperative effort between these two organizations, and has evolved from an initial research program to a commercial on-farm on-line computer-based management system (Brook and Hearn 1983). SIRATAC was developed to assist growers in the day to day or tactical aspects of cotton production and pest management. The initial impetus for its development was a concern over insecticide resistance. In Australia, during any stage of the crops development, a particular field will have one or more pests any of which are likely to reach damaging levels (Table 2). For this reason cotton can not be grown commercially in Australia without the use of insecticides. Excessive spraying, however, resulted in the total demise of the cotton industry in North-Western Australia due to the development of high levels of insecticide resistance, leading to real concerns over the likelihood of the same situation developing in the remaining eastern cotton regions. A recent increase in the levels of resistance by Heliothis armigera to pyrethroids in the eastern cotton growing region of Australia has given further credence to this concern (Fitt 1984, Forrester and Cahill 1984).

Table 2. Species addressed during each stage of crop growth in SIRATAC (modified from Anonymous 1985).

Arthropod Category	Crop Growth Stage: Pre - Squaring	Crop Growth Stage: Squaring - Boll Setting	Crop Growth Stage: Boll Maturation
Heliothis spp.	+	+	+
Predators	+	+	+
Aphids	+	+	+
Rough bollworm	+	+	+
Mites		+	+
Loopers		+	+
Thrips	+		
Green vegetable bug		+	+
Tipworm	+	+	
Other sucking pests	+	+	
Whitefly		+	+

An underlying pest management philosophy has been maintained since SIRATAC'S initiation and has been discussed in some detail (Hearn and Room 1979, Room 1979, Brook and Hearn 1983). In summary, SIRATAC attempts to

1. Use selective insecticides whenever possible, and only when needed.

2. Only protect fruiting structures which can mature, taking into account that an increasing proportion of squares and young bolls will abort as fruit load increases. During the course of a season, up to 80 % of

the fruiting structures will shed as squares or small bolls in the absence of pest attack even under ideal growing conditions (Gutierrez et al. 1977b, 1979b). During certain crop stages, the probability that a square or young boll will survive to maturity is even lower.

3. Use economic thresholds so that control is only recommended when the incremental (marginal) benefit equals the incremental cost. Headley (1972, 1982), Stern (1970), and others cover in detail the merits of using economic thresholds when making management decisions.

Evolution from research to implementation

The initial research for development of SIRATAC was provide by the combined efforts of two CSIRO research scientists (Room 1979, Hearn and Room 1979). Both of these individuals started from somewhat different backgrounds, Room being an insect population ecologist with a a strong interest in multitrophic community level processes, while Hearn is an agronomist with a physiological modelling bent. Subsequently, six other research scientists have participated in the programing of SIRATAC code (Brook and Hearn 1983), incorporating their expertise in the process.

SIRATAC has progressed through essentually three stages during its development.

1. Research trials (1976-79)

2. Commercial trials (1979-81)

3. Commercial implementation (1981-present)

Figure 1 shows a generalized flow diagram of the SIRATAC program. The program consists of a series of submodels together used to assess the abundance of pest species, predict their abundance to the next sampling date, estimate whether the pests are above their economic threshold, and make a recommendation as to which insecticide to apply if necessary; taking into account age class specific developmental rates and mortality. Initially the crop component of the program was represented by a Yield Development Threshold (YDT) for squares and one for bolls, based on a target yield (Hearn and Room 1979), somewhat analogous to but the reverse of an economic threshold (Fig. 2). If the number of squares or bolls drop below their respective YDT, there is a risk that the yield will be less than the selected. The selected YDT's and target yield are based on the growth characteristics of the crop and the environmental conditions inherent to a particular geographical area. A short season growing area would necessarily have a greater restriction on the upper limit of the YDT's and the target yield, while a farmer who consistently manages his water or nitrogen at a near optimal level will have higher YDT's and target yield.

Although the initial rationale for using a simplified crop model was to avoid the complexities inherent to a more detailed physiologically based crop simulation model and the inevitable time delay in field testing and validating multi state-variable models, by the beginning of the commercial trial period the need to incorporate a greater degree of biological realism was evident. The next stage of crop model development was to include a function to predict the survival of the counted squares and young bolls to harvest (Hearn et al. 1981, Eq. [1]). Once the bolls exceed ca. 10 days age the rarely abort.

$$\text{Surv} = 0.8 - 0.008 * \text{bolls} / m^2 \qquad [1]$$

In 1980/81 a further function was included to predict subsequent fruit production as a function of boll load and as a function of the total number of fruiting points (FP) currently on the crop (Hearn 1981, Eq. [2]). These functions were more recently modified, incorporating square and boll load based on estimated growth demands for 10 different cultivars of cotton (Anonymous 1985).

$$\Delta FP / m^2 = 0.063 * FP / m^2 - 0.0137 * \text{bolls} / m^2 \qquad [2]$$

As Wilson et al. (1983) state, "these improvements allowed for better estimation of the number of squares (flower buds) and bolls of different ages for use in estimating feeding by Heliothis larvae".

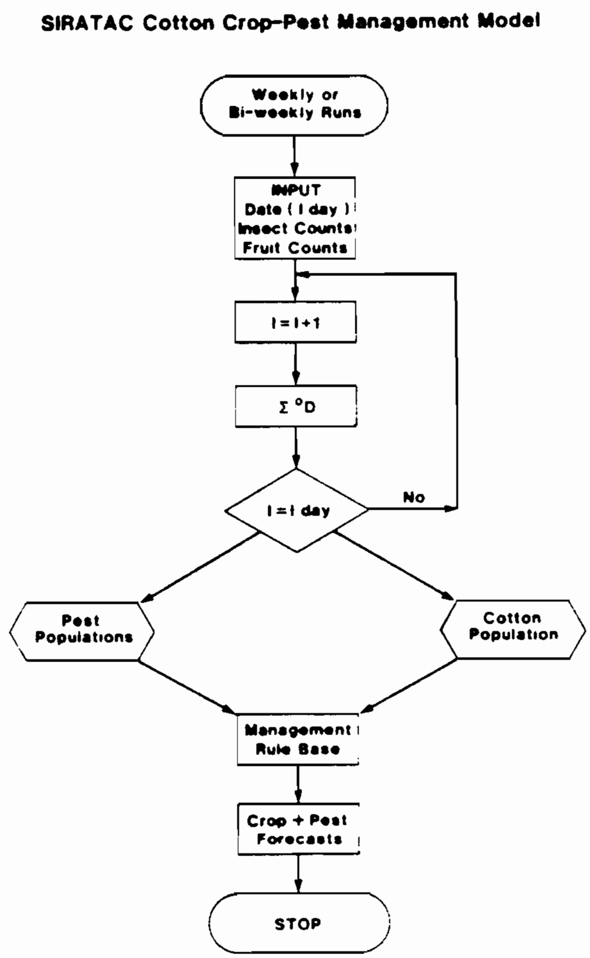

Fig. 1. Generalized flow diagram for SIRATAC cotton management program.

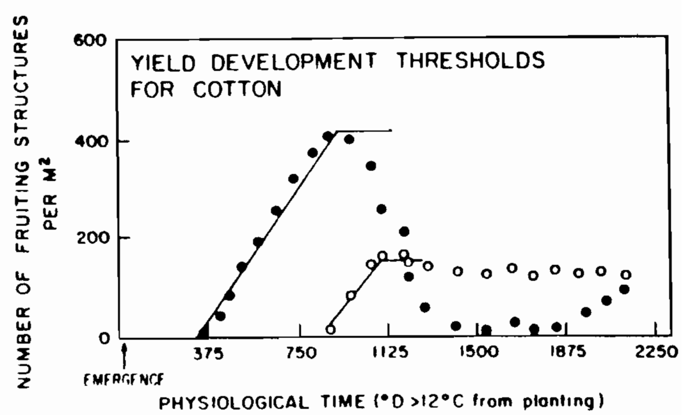

Fig. 2. SIRATAC yield development thresholds for cotton squares and bolls compared with observed data.

In the later part of the 'commercial trial' period an irrigation submodel was incorporated, and more recently, a nitrogen submodel has been developed and is being incorporated (Hearn pers. com. 1985). Interestingly, the result of these later developments has been a reversal of the initial decision not to use a simulation approach to management, and to instead use a fairly simple but powerful crop simulation model that can be recalibrated as relevant data become available (Brook and Hearn 1983).

The remaining components of the management model evolved through similar stages of development. An intensive daily research oriented sampling procedure was replaced with a less frequent presence-absence sampling procedure (Wilson and Room 1983), while terminal sampling replaced whole plant sampling (Wilson and Room 1982). Together these improvements allowed for arthropod densities to be accurately and reliably estimated in a fraction of the time previously possible. Other additions include development of a Heliothis submodel (Wilson and Gutierrez 1980, Wilson and Waite 1982) enabling more accurate estimation of damage by this key pest, which when linked to the crop model, enabled estimation of potential impact on yield, thereby adding a large degree of dynamism to the previously fairly static economic thresholds. Lastly, the ever increasingly cumbersome insecticide decision tree was replaced with an approach which enabled sequential simulation of management options from the softest (most selective) to the hardest (broad spectrum), with the most economical option recommended (Brook and Hearn 1983). This approach fits in well with the Heliothis damage model making use of the information on damage prevented by each spray in determining the appropriateness of each spray. This newer expert systems rule base approach is also much more easily modified for future updates than the previous procedure.

Figure 3 shows the usage of SIRATAC through time. By the 1980/81 season, the demand expressed by Australian cotton growers to use SIRATAC far exceeded the ability of the research team. Furthermore the legal liabilities associated with the use of this program necessitated a major change.

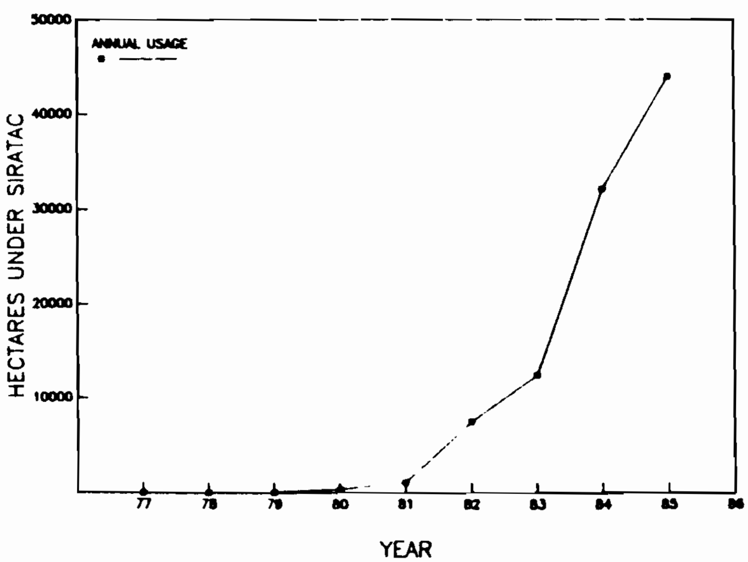

Fig. 3. Usage of SIRATAC through time.

In 1980, a private, non-profit, tax-free company modelled after the Australian Cotton Seed Distributors Party Ltd. was established. SIRATAC Ltd. is now jointly run by growers and by CSIRO, essentually as a cooperative, with CSIRO responsible for the computer system and for subsequent program modifications to more accurately mimic crop and pest population development. Farmers who used the SIRATAC program are charged a usage fee, which currently has a $ 6.10 / ha base price (Brook and Hearn 1983), with field scouting available through SIRATAC at an additional cost. In turn a contracted grower receives access to the following services (modified from Anonymous 1985).

1. SIRATAC pest management program

   a. Sampling decision forms and density estimation algorithm.

   b. Pest predictions.

   c. Crop development predictions.

   d. Yield and crop maturity predictions.

   e. Pest damage predictions.

   f. Insecticide recommendations - timing, chemical, rate, cost.

   g. Irrigation scheduling.

   h. Nitrogen fertilization recommendations.

2. DEMONSTRATION program - a facility available for demonstrations, testing, experimenting, and dummy runs.

3. COMPARE program - allows a user to compare his fruiting with the average for all SIRATAC users in the region.

4. PROBE program - a program which facilitates the calibration of neutron probes.

5. INFORMATION DATABASE - a library containing information on active ingredients and trade names of cotton chemicals, insect pests of cotton, pyrethroid strategy and pheromone trap locations.

6. AUSTPAC - a data transmission facility to reduce transmission costs to users.

7. METINFO - historical and current meterological data for most cotton growing regions.

8. MOTHINFO - moth counts from the Myall Vale Research Station light trap.

9. BATCH MODE - a facility available to reduce data transmission charges for users.

10. MAIL - a facility which allows users to send and receive messages through the SIRATAC system.

Commercial Acceptance of SIRATAC

The commercial success of SIRATAC can be evaluated based upon the area overwhich it is used, by the % of total Australia cotton area using SIRATAC, and by some of the economic benefits which have resulted from its use. SIRATAC's usage increased from 10 ha during its initial research testing in 1976, to an estimated 44,000 ha in 1985 (Fig. 3). When compared with California cotton growing region this quantity is relatively minor and could not be considered a success. However, on a proportionate basis, SIRATAC is now used on ca. one-fourth of Australia's cotton. When considered in light of growers having to pay for the use of SIRATAC, this degree of usage is considerable. It is becoming unacceptably common to read in the literature or hear researchers say that this or that model is commercially implemented when in fact the model is only being field tested and often not very extensively. Continued use of SIRATAC by growers who are willing to pay for these services is a sure sign of acceptance.

An equally important reason for the success of this program is the demonstration that SIRATAC can be easily used to economically grow a cotton crop over a wide geographical area, covering a range of pest pressures and crop growth conditions. Although most research crop and pest simulation models take a considerable amount of time to run, SIRATAC takes ca. 3 minutes per run on a VAX 11/750, and in the process is very user friendly (Brooks pers. com. 1985). The economic benefit to SIRATAC users is demonstrated by insecticide usage having been reduced by ca. 40 % or more, yields on average slightly greater, and net profits having been increased compared with growers not using SIRATAC (Hearn et al. 1981, Hearn pers. com. 1985, Ives et al. 1984, Room 1979).

Lastly, an important reason for success has been the ability of research scientists to work closely with industry to rapidly address new problems, and to rapidly improve weakness in the SIRATAC program as they become apparent. The responsiveness of the CSIRO cotton research unit to growers needs, and the inclusion of growers in the decision making process has been instrumental in the longer term effectiveness of this research program.

SIRATAC's Benefit to Cotton Research

As with most modelling effort, SIRATAC has proven useful by serving as a focus for researchers with vastly different backgrounds. Possibly more important, SIRATAC also provides data previously not available. Normally a hypothesis that is being tested by a researcher is limited in the number of factors which can be addressed and in the number of geographical areas over which it is tested; by limits imposed upon the resources available to a researcher. Because of SIRATAC's large scale acceptance, it has provided a data base on crop and pest management from which researchers can test various and sundry hypotheses. The longer that SIRATAC is used, and greater the number of conditions with which it is used, greater the amount of data available. Because the data gathered by field scouts working for the various farmers is stored within the SIRATAC data base and is cross referenced with respect to date, location, pesticide usage and timing, irrigation scheduling, pest abundance, crop development, and respective pest and crop forecasts, subsequent hypothesis testing using multifactoral type analyses are straight forward. During my visit to Australia this past January and February, a subset of ca. 300 cotton fields was analyzed, showing that early season applications of pyrethroid insecticides induce mites outbreaks. While researchers in California have been able to demonstrate and quantify the same problem (Wilson and Gonzalez unp. data, Leigh unp. data), through SIRATAC the

Australian have been able to do so much more extensively, over a much wider set of environmental and management conditions (Brook pers. com., 1985). They have also been able to do so without the cost of additional field research.

The following is a partial list of hypotheses which are currently being addressed or will likely be addresses using the SIRATAC data base. This data base is also self serving in its providing a means to fine tune various components of SIRATAC, as indicated in the parentheses.

1. Impact of timing of sprays and insecticide type on the development of resistance.

2. The impact of timing and level of insect damage (different species) on crop yield (used to fine tune the existing economic thresholds).

3. The impact of insecticide sprays on insect survival (fine tune mortality algorithm).

4. Impact of water and nitrogen management on the crops growth and development (fine tune respective subroutines).

5. The interaction between planting date and crop attractiveness to pest.

6. The impact of insecticide sprays on the likelihood of secondary outbreaks of normally innocuous pests.

7. The accuracy of the forecasting subroutine at predicting subsequent development of pest populations, and subsequent crop development and yield.

8. The regional development of pest pressures (species specific).

9. Optimal planting dates for maximizing net profit (with respect to crop yield and control costs).

SIRATAC's Future

During the course of its relatively short existence, SIRATAC has experienced a large degree of industry acceptance. During a recent tour of Australia's cotton regions three points were repeatedly brought up when discussing whether SIRATAC will become more widely used in Australia. Because insecticide usage has decreased for those growers using SIRATAC, segments of the insecticide sector has welcomed SIRATAC with less than open arms. This sector will eventually be convinced of the merits of SIRATAC; for without a reduction in the usage of insecticides brought about through SIRATAC, the long term economic viability of the Australian cotton industry is questionable. There is a belief that SIRATAC may end up promoting the diversification of the services provided by insecticide companies, a move that has recently become apparent in California following the fairly rapid spread of fairly simple day-degree phenology models. Some commercial crop consultants have also reacted negatively to SIRATAC, in this case reflecting the perception of competition. SIRATAC's use is predicated upon experienced scouts or consultants who can work as intermediaries between growers and SIRATAC. Considerable flexibility appears to exist for developing a working relationship between these three groups. Lastly, some growers perceive a need to have a copy of SIRATAC on their own micro or mini-computer. Part of this is an innate fear of 'big brother' looking over their shoulder (Brook and Hearn 1983). In the forseeable future, revisions to SIRATAC to improve identified weaknesses will remain common. Until micro-computers become powerful enough to rapidly handle a program the size of SIRATAC, and until a protocol is developed to enable updates of 'outdated' versions, implementation of SIRATAC's will likely continue through a centralized computer network. It is presently possible however to place components of SIRATAC on micros, such as the irrigation or nitrogen submodels, since these appear less likely to change substantially through time. It is also currently possible to access SIRATAC with micros serving as dumb terminals; this feature enabling growers to have access to financial ledger programs and other business packages available for micros.

Cotton managment modelling in the U.S.

From 1976 to the present SIRATAC has evolved from a research program to a commercially implemented cotton management program. Its success is apparent by its wide usage and its further success is likely. Development of a similar programs in the United States, or in a specific region such as California is likely to occur, but is dependent upon greater industry support. At present cotton research in the U.S. is poorly funded. In comparison, although Australia grows only ca. 14 % of California's total cotton acreage, the amount of research support provided by the Australian cotton industry is ca. $ 250,000, compared to less than $ 100,000 provided by the cotton industry for research in California's San Joaquin Valley (ca. 97 % of California's cotton. The California cotton industry is often quick to point out that ca. $ 5,000,000 is spent under the pink bollworm program. However, nearly 100 % of these funds are being used to release sterilized pink bollworm or to conducted research in the lower desert valleys of California. A quick economic analysis indicates that for every research dollar spent by industry per acre of cotton in the San Joaquin Valley, Australia spends ca. $ 17.5. Furthermore, if the number of Australian researchers working on cotton per acre of Australian cotton is taken into account, compared to similar figures for California, this value is at least quadrupled.

The blame for lack of adequate support for cotton research in California can also be blamed in part on researchers focussing on problems which are of little short term relevant to industry. A better balance between the basic and the applied, fostered by a substantial increase in industry funding, and by a greater recognition by university administrators of the importance of a balance research approach would go a long way to solving this problem.

The development of a SIRATAC type program for California, is highly feasible, most of the necessary experiments have been conducted and many of the necessary parameter estimates for factors affecting the crops growth and development are available. Optimistically, I would like to think that such a project would be imbraced by industry and that the researchers and extension personnel involved would be able to overcome some of the problems mentioned above. It is only through a commercially practical approach such as used in developing SIRATAC that similar gains can be expected to be forthcoming for California, or for that matter the remaining cotton growing regions of the United States. This is not to say that more basic research, including more detailed physiologically based crop and pest simulation modelling, is not necessary, only that it must be linked more tightly to the practical side of research to be useful to industry in the short term.

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Measurement of Soil Water by the Thermal Diffusion Method

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Soil matric potential (Ψ_m) (sometimes referred to as capillary potential, soil suction or soil tension) expresses the change in free energy of soil water resulting from adsorptive force fields in the soil matrix (or the negative amount of work that must be done to remove water from the soil pores). Knowledge of the matric potential of soil water over the range important in agriculture is essential for irrigation management. Several methods for determining matric potential of soil water are used, but none of them is completely satisfactory. Most of the present methods that are applicable throughout the range important in agriculture are based on measurement of properties related to the water content of soil or of some porous medium whose matric potential is at equilibrium with that of the surrounding soil (Phene et al, 1971)

The rate of heat dissipation in a porous medium of low heat diffusivity has been shown to be sensitive to water content. Basically, it depends on the fact that air is a good thermal insulator with respect to water, so that as water is replaced by air, the remaining water films become thinner and the path length for heat conduction increases. This requires a larger temperature gradient to dissipate a given quantity of heat. The water content of a porous material can, therefore, be measured by supplying a heat source at a point centered within the porous material and measuring the temperature rise at that point.

Previous studies (Shaw and Baver, 1939; Bloodworth and Page, 1957; DeJager and Charles-Edwards, 1969, and Phene et al, 1971) have demonstrated that heat dissipation in a porous medium can be used as an index of the amount of water present.

Shaw and Baver (1939) inserted the temperature sensor-heater units directly into the soil. This required a separate calibration for each soil. Bloodworth and Page (1957) used a nonlinear temperature sensor (thermistor) so that either a separate calibration or a correction curve was required for use at a different temperature.

Phene, Hoffman, and Rawlins (1971) mathematically modeled the system and outlined details for constructing a sensor that measures the matric potential (Ψ_m) component of soil water potential in situ. The performance of the instrument and its usefulness in the laboratory and in the field were evaluated in terms of four essential criteria:

1) The sensor should measure a wide range of soil matric potential more accurately or more simply than other available sensors.

2) It should respond quickly to changes in soil matric potential.

3) It should remain stable with time.

4) It should measure soil matric potential independently of soil texture, salinity, and soil temperature fluctuations.

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The basic theory of the soil matric potential sensor described by Phene et al. (1971a) has remained unchanged. The discrete temperature sensing element (RCA 1N2326, germanium P-N junction diode)* has been replaced by a two-terminal integrated circuit temperature transducer (Analog Devices, AD 590) which produces an output current proportional to temperature. The AD 590 can be used in any temperature sensing application below +150°C and is available in chip form making it suitable for fast temperature measurements required by the soil matric potential sensor.

The AD 590 is particularly useful in remote temperature measuring applications because it is insensitive to voltage drops over long lines due to its high impedence current output. Any well-insulated twisted pair of wires is sufficient for operation hundreds of feet from the receiving circuitry.

The original heating element which consisted of 200 cm of teflon-coated copper wire coiled around the diode (R=20 ohms) was replaced by a laser-trimmed hybrid resistor (R=1000 ohms). Increasing the heater resistance by a factor of 50 minimized the effect of long electrical lead resistance on the total voltage drop across the heater.

A new ceramic material developed by Agwatronics has a pore size distribution capable of providing a large soil matric potential sensitivity between -5 and -300 J/kg (1 J/kg = 1 centibar) and some measureable sensitivity between -300 and air dry (-3100 J/kg). This ceramic provides a stable matrix for the sensor as originally suggested by Phene et al. (1971) and a linear output between -5 and -150 J/kg.

The waterproofed micro-electronic components are imbedded into the ceramic block with thermal conductive polyurethane. Micro-electronics allows the use of a cylindrical ceramic block smaller than that in previous units. The dimensions of the new sensor have thus been reduced to a diameter of 2.0 cm and a length of 2.0 cm. Laboratory and field evaluations have shown that these sensors have (a) a large measurement sensitivity in the soil matric potential range of interest for irrigation control (-10 to -70 J/kg) and a large voltage output, (b) independence of temperature changes encountered in soils, (c) independence of soil texture, (d) a rapid response to changes in soil matric potential and (e) are not effected by salinity.

Irrigation Scheduling Applications

Several experiments have been conducted using the original sensor in the field and laboratory by Phene et al. (1973); Phene and Beale (1976), and Phene et al. (1979) to demonstrate the validity of the concept of high-frequency irrigation control under extreme dynamic conditions. Shallow, layered sandy loam soils and potentially high rainfall had to be accounted for by the automatic irrigation scheduling system to prevent long periods of low aeration caused by water saturated soil. The control system satisfied the variable crop water requirement conditions as affected by rapidly changing external parameters (climate and soil) and the localized application of water by a drip system buried in the rootzone caused the soil between the beds to dry and provide storage for rainfall events of up to 2 cm (Phene and Beale, 1976).

* Trade names are used for identification purposes only and do not imply preference for this item by the US Department of Agriculture.

The modified electronic soil matric potential sensors were tested as input devices for an irrigation controller to schedule irrigation in several replicated experiments (Phene et al, 1981). The field plots were planted to processing tomatoes (Lycopersicon esculentum Mill, UC82B) and irrigated at three soil matric potential thresholds by subsurface trickle irrigation. Results demonstrated that high-frequency trickle irrigation can be controlled accurately by soil matric potential sensors in the root zone of row crops. Yields of processing tomatoes obtained by this irrigation scheduling method were comparable to yields obtained with irrigation scheduling based on calculated evapotranspiration. The sensors can be used in a feedback mode to maintain a portion of the root zone at nearly constant Ψ_m within an optimal Ψ_m range (Phene et al, 1984).

The objectives of this paper are to discuss the operational requirements and characteristics of the sensor and the strengths and weaknesses of the method.

Equipment Needed

The equipment needed to monitor soil matric potential manually consists of sensors, a battery power supply (± 18 Vdc), a wheatstone bridge with amplified output, and a timer. Figure 1 shows one of the sensors (Agwatronics, Model AGWA-II)[3]. The white portion of the sensor is the ceramic which should be in intimate contact with the soil to be sampled. The black portion of the sensor encapsulates the electrical connectors and provides strain relief for the electrical conductors.

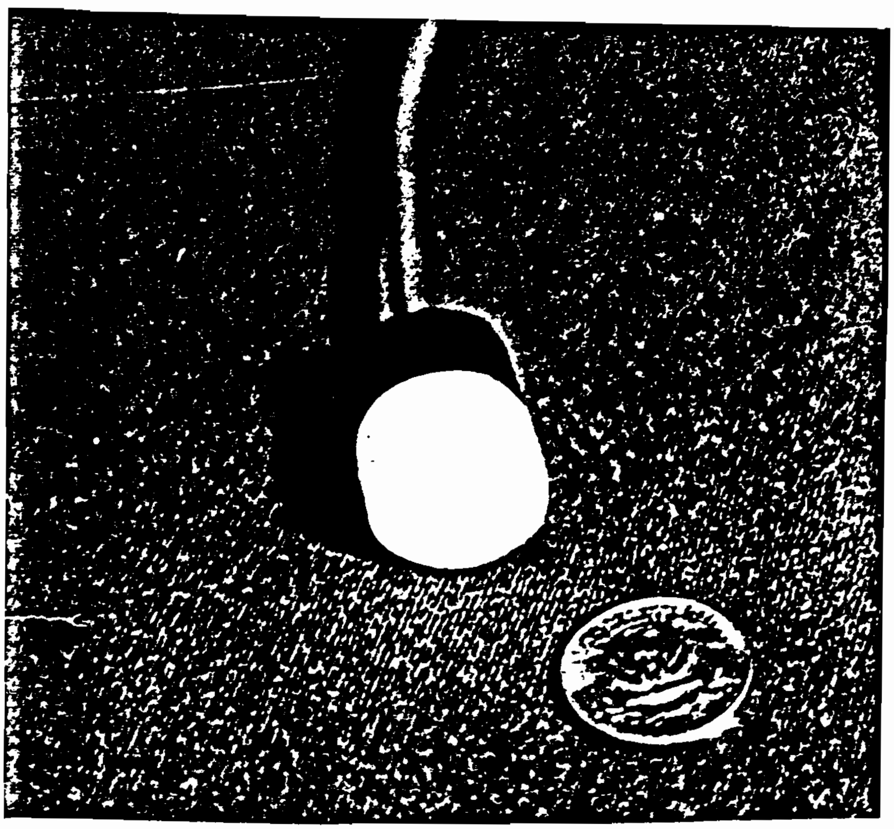

Fig. 1. Electronic soil matric potential sensor shown next to a US quarter coin (Agwatronic, model AGWA-II)*.

Figure 2 shows a portable electronic meter used for measuring one sensor at a time. To take a measurement, the sensor is plugged into the back of the meter, the start switch is activated and after one minute the final voltage reading is locked in the digital display until the start switch is activated again. The soil matric potential is obtained by inserting the voltage reading into the calibration equation for the specific sensor, usually a linear equation of the form $\Psi_m = mV + b$, where m is the slope of the line, V is the voltage reading obtained with the meter and b is the y-axis intercept. Figure 3 is a typical calibration curve showing the relationship between the sensor output voltage and the soil matric potential. The meter can be operated in the field with its internal batteries for at least twelve hours before recharging is needed. Where electrical power is available, the meter can remain plugged in to external 110 Vac electrical power. A trickle charger with voltage regulator maintains the batteries at full capacity.

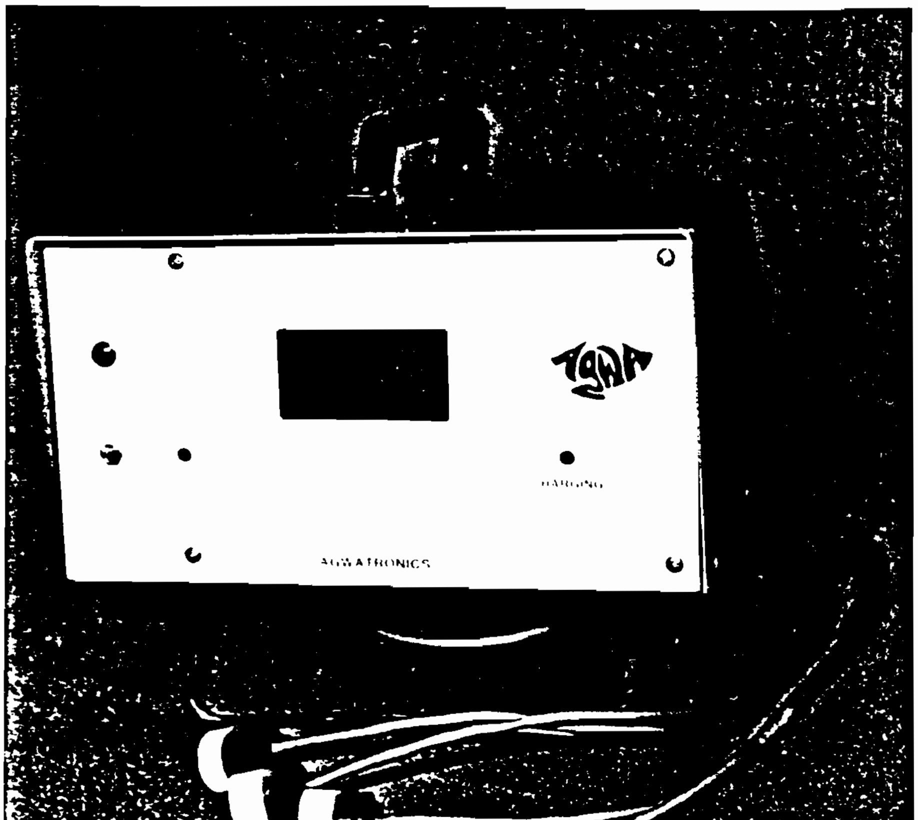

Fig. 2. Portable electronic meter (Agwatronics, model AGWAMETER)* for measuring soil matric potential manually.

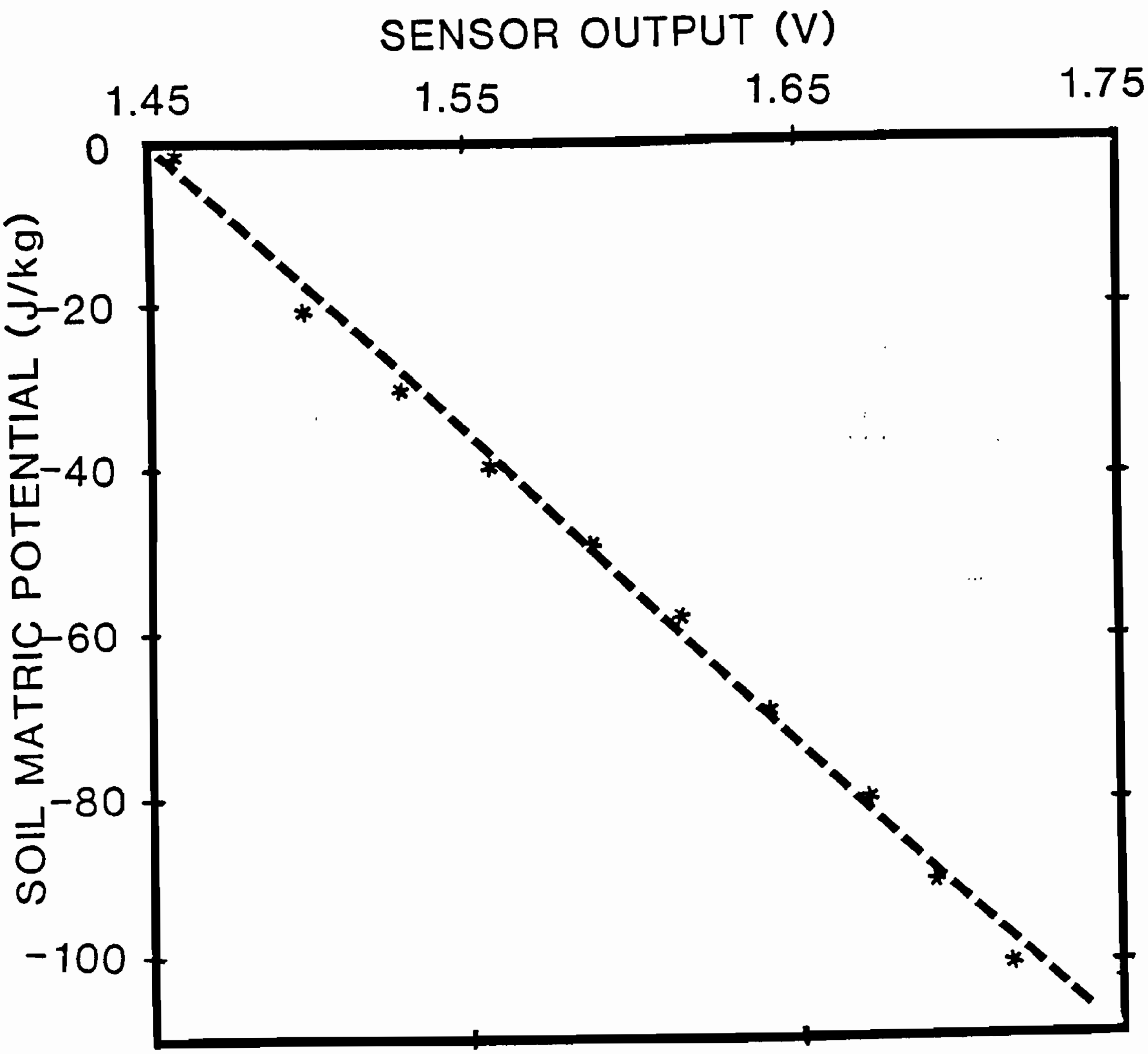

Fig. 3. Calibration curve showing relationship between voltage output of the sensor and soil matric potential (Ψ_m). This calibration procedure is usually carried out in a standard pressure plate apparatus as described by Phene et al, (1971).

An electronic circuit interface can also be used with micro-computers to automate the measurement and/or automatically control irrigation systems. The required electronics must be capable of (1) automatically sampling several sensors sequentially, (2) comparing each sensor output to the threshold soil matric potential at which irrigation is to start, and (3) having programmable outputs capable of starting a pump, switching electrical valves, and performing other electrical functions as needed. Desktop computers (Hewlett Packard, HP-85 with Data Acquisition System)[3/] and single board microprocessors (Intel, MCS 8085 with multiplexer and A/D converter) have been used to control irrigation systems automatically (Phene et al, 1981 and 1984).

Potential Applications of the Methodology

The soil matric potential sensor measurement and feedback technology may be used beneficially in many agricultural water management applications to improve yield, quality, and water use efficiency and to provide management flexibility. Examples of applications are as follows:

1. Irrigation Scheduling. Measurement of soil water as an index for irrigation scheduling is probably the most widely used method. Irrigation efficiency can be improved in many soils if the frequency of irrigation is increased and the volume of applied water is decreased. However, increasing irrigation frequency requires more frequent and precise measurements of the soil water in the root zone. Phene and Howell (1984) have shown that using frequent measurements of the Ψ_m can help maintain optimal soil water for good crop productivity and high water use efficiency.

2. Reduced Nitrate Leaching. Phene and Beale (1976) have shown that in shallow sandy soils, nitrate losses by leaching can be reduced if irrigation water is applied frequently by automatically scheduled trickle irrigation based on Ψ_m.

3. Labor and Safety Factors. In areas where labor is short and other cost-effective operations require automation, the soil sensor feedback technique can provide the simple means for fully automating the irrigation control systems and for remote monitoring operation (Phene, 1985).

4. Crops. Many perennial crops (fruit, nut trees, and vines) or semi-permanent crops (sugar cane, asparagus, and artichokes) are well suited for high frequency irrigation and therefore could benefit from soil sensor feedback irrigation scheduling. With permanently-installed subsurface trickle irrigation systems, the technology can be adapted for row crops (Phene et al, 1981).

Practical Strengths and Weaknesses of the Method

The thermal diffusion soil matric potential sensor can be used manually or as an input device to any programmable irrigation controller capable of interpreting an analog signal. Table 1 outlines and rates strengths and weaknesses of the method:

Range of Measurement. Theoretically, the range of the sensor can be changed to fit the soil texture and measurement requirements by using ceramic disks with different pore size distributions. Practically, precise laboratory calibration of sensors embedded in different ceramic materials have shown the theory to be valid at least to -1500 J/kg (Phene et al, 1971). For most applications where irrigation scheduling is the objective, a ceramic with a range of 0 to -100 J/kg will suffice.

Accuracy. Lack of uniformity in the pore size distribution of the ceramic and in the physical characteristics of the electronics requires that each sensor be calibrated in the pressure plate or against some known standard. Regardless of the calibration method used, the accuracy of the sensor is totally dependent on the calibration and most calibration procedures are time consuming and difficult to do precisely.

Sensitivity and Precision. The instrument has a typical sensitivity of 3 mV/J/kg and it can provide precise measurements of the soil matric potential within ± 2.5 J/kg in the range of interest for irrigation control. The instrument has a time response of less than one hour between Ψ_m of -10 and -40 J/kg, which is fast enough to detect small diurnal variations of the soil matric potential (Phene et al, 1981).

Maintenance. No maintenance is required after calibration and installation. The sensor can operate for many months and perhaps a few years without interruption. In case of failure a warning signal can be provided by computerized systems. The sensor is not affected by frost.

Automation. The irrigation system can be fully automated. Several control options can be used based on feedback from sensors and data can be transmitted by wire, telemetry or by telephone (Phene, C.J. 1985).

Cost. Costs of the commercial sensor and manual readout are approximately $110 and $1200 respectively. The cost of the computer controller and interface will vary based on the size of the system from $2000 to $8000.

Availability. Known commercial availability of the thermal diffusion sensors is presently limited to Agwatronics, Inc. In the past, sensors were also available from Moisture Control Systems, Inc. (MCS, Inc. Findlay, Ohio).

Table 1. Stength and weakness criteria for factors considered important to the performance of the thermal diffusion soil sensor.

FACTORS CONSIDERED	CRITERIA -- STRENGTH --								-- WEAKNESS --	
	1	2	3	4	5	6	7	8	9	10
RANGE OF MEASUREMENT		X								
ACCURACY								X		
SENSITIVITY & PRECISION			X							
MAINTENANCE		X								
AUTOMATION		X								
COST									X	
AVAILA-BILITY							X			
STABILITY				X						
FLEXIBILITY OF CONTROL	X									
SAFETY FROM VANDALISM			X							

Stability. Sensors obtained from MCS, Inc. were stable for at least one year in the laboratory. Agwa-II sensors have been recalibrated in the laboratory four times over a six month period and all calibrations were within ± 2.5 J/kg between 0 and -70 J/kg.

Flexibility of Control. The measurement will rapidly sense the crop water use in response to change in weather, soil water movement (drainage), and can potentially be used to manage leaching fraction. With the automated systems, the sensors measure the soil matric potential hourly and sense changes in soil matric potential resulting from crop evapotranspiration; hence, the feedback system can provide the flexibility needed to schedule hourly irrigations to match the varying crop evapotranspiration. Irrigation threshold levels can also be adjusted to provide irrigation to fit specific management conditions.

Safety from Vandalism. The instrument and wires can be buried entirely and thus are less subject to vandalism or accident during cultivation practices.

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Simultaneous Measurement of Soil Water Content and Soil Salinity Using Time Domain Reflectometry Technique

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Development work is being done at the U. S. Salinity Laboratory on the use of time-domain reflectometry (TDR) for the simultaneous measurement of soil water content and soil salinity. Measurements are being taken with a tektronix S-52 pulse generator, a 7S12 sampling unit, a S-6 sampling head and a 7603 oscilloscope or with a Tektronix 1502 cable tester*.

WATER CONTENT

TDR was first used by Fellner-Feldegg (1969) to measure the frequency dependence of the dielectric constant of organic liquids. This system obtains the soil dielectric constant by measuring the transit time of an electromagnetic pulse launmched along a pair of metallic parallel rods of known length embedded in the soil (Figure 1). Topp et al. (1980) used this technique to measure the dielectric constant of wet soils and found that a unique relationship exists between water content and the dielectric constant for many soil types.

An ultra fast rise time voltage pulse is applied to the parallel rods and a reflected voltage caused by changes in probe impedance is superimposed on the constant initially applied voltage. The path length for the voltage pulse is twice the length of the parallel rods (L). Measuring the transit time (t) yields the propagation velocity (v) of the pulse.

$$v = 2L/t \qquad 1$$

* Names of products are included for benefit of the reader and do not imply endorsement or preferential treatment by USDA.

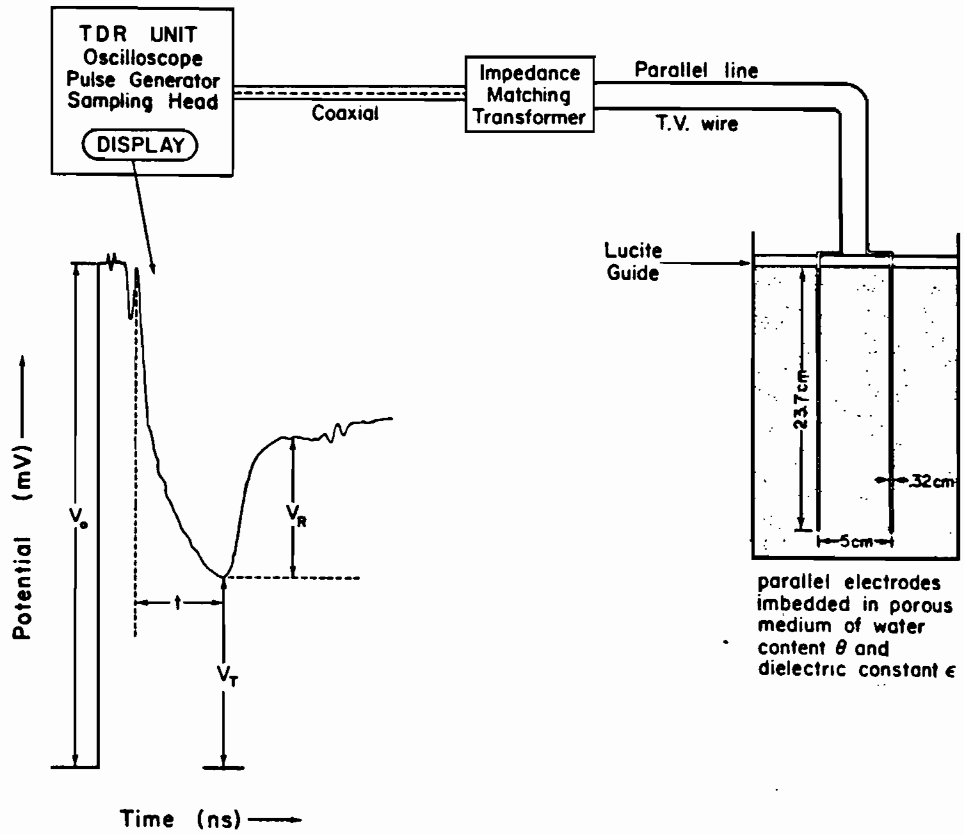

Figure 1. Schematic diagram of time-domain reflectometry system for measuring soil water content and electrical conductivity (after Dalton et al., 1984.

Electromagnetic theory shows that the velocity can be expressed in terms of the dielectric constant of the medium (ε) and the velocity of light in free space, c ($3x10^8$ m/s):

$$v = c/\sqrt{\varepsilon} \qquad 2$$

Combining these two equations yields to a first approximation the dielectric constant in terms of transit time, path length and velocity of light in free space:

$$\varepsilon = (ct/2L)^2. \qquad 3$$

Figure 1 shows the schematic of a time domain reflectometry system with a typical TDR output signal. The signal is analyzed to obtain the transit time of the launched voltage pulse. For a typical electrode length of 30 cm the transit time varies from approximately 4 ns for dry soils and 10 ns for saturated soils. The relative dielectric constant of distilled water is about 81; ε for a dry soil is approximately 3, while ε for a saturated soil is about 25.

The apparent dielectric constant obtained by equation 3 is now correlated with the volumetric water content of a soil. An emperical relationship between ε and θ obtained by Topp et al. (1980) is

$$\theta = (-530 + 29\varepsilon - 5.5\,\varepsilon^2 + 0.043\,\varepsilon^3) \times 10^{-4} \qquad 4$$

This equation was found to be nearly independent of soil texture, soil density, temperature and soil salinity. The standard error of estimate was reported to be 1.3% for all soils considered and could be reduced by calibrating for a specific soil. This method for water content measurement compares favorably with conventional methods (Topp and Davis, 1985 and Dasberg and Dalton, 1985). The method is also more adaptable to special applications, such as those involving undisturbed laboratory soil columns. In most cases the use of equation (4) obviates the need for special calibration.

Figure 2a shows a comparison between TDR and gravimetrically determined water contents obtained from subsamples taken while installing the (TDR) probes and neutron access tubes. Figure 2b shows the relationship between two sets of neutron probe readings and the same gravimetric water content as above. The calculated regression equations for the 102 data points are as follows:

$\theta(TDR) = 1.02\theta(grav) - 0.023 \quad r^2 = 0.84$

$\theta(Neut) = 0.86\theta(grav) + 0.03 \quad r^2 = 0.82$

These data show the correlation between TDR and gravimetric determinations is similar to that between neutron and gravimetric determinations.

Dalton et al. (1984) showed the potential use of the TDR technique for the simultaneous measurement of water content and electrical conductivity. Using transmission line theory, he showed that the bulk electrical conductivity σ, is given by:

$$\sigma = \varepsilon/120\pi \ \ln(V_T/V_R) \qquad 5$$

Where V_T and V_R are obtained from the signal trace (Figure 1). The signal trace contains information for both water content and electrical conductivity. Therefore, salinity measurements can be made on the same sampling volume as water content measurements.

The relationship between bulk soil electrical conductivity σ, and pore water electrical conductivity σ_w, is used to determine the soil water electrical conductivity. Salinity determinations are then made on the basis of a known general relationship between salt concentration and solution electrical conductivity (U.S. Salinity Lab, Handbook 60, 1954). This is identical to the four-electrode probe method.

The relationship between σ, σ_w, and θ was investigated by Rhoades et al., (1976) in their development of the four-electrode measurement of σ, and is give as:

$$\sigma = \sigma_w \theta(\theta) + \sigma_s \qquad 6$$

where σ_s is the solid phase electrical conductivity and T is a transmission coefficient that depends linearly on water content.

Since the TDR method simultaneously yields water content and bulk electricial conductivity on the same sampling volume, equation (6) can be used for salinity measurements over a wide range of water contents. Field measurements need not be limited due to changing water contents.

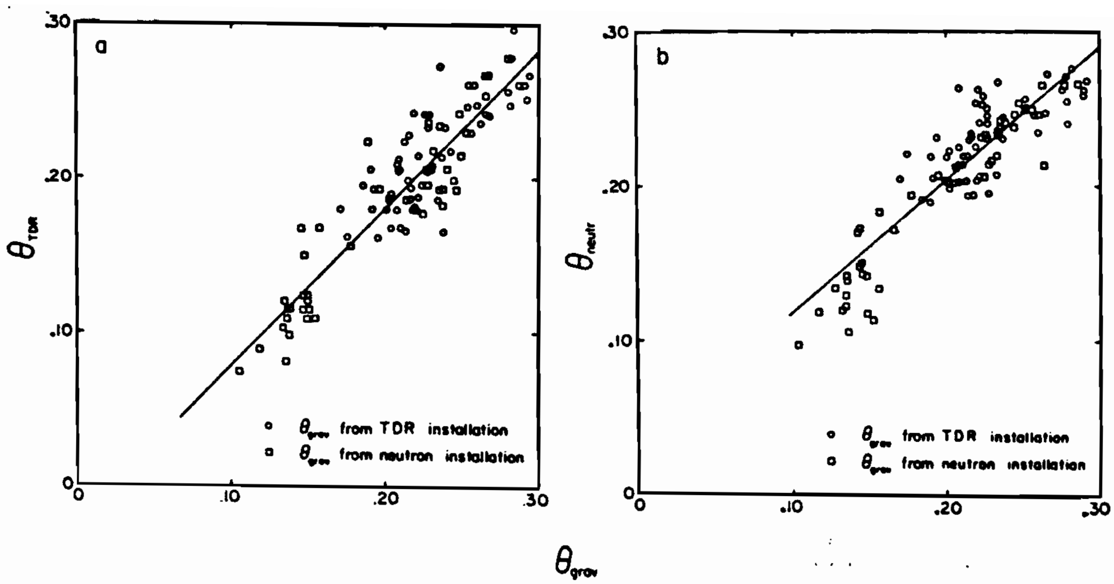

Figure 2 (a) Soil water content as measured by TDR vs. gravimetric determination and (b) water content measured by neutron scatering vs. gravimetric determination (after Dasberg and Dalton, 1985)

Figure 3 is a comparison between σ(TDR) and σ(4-prb). These are two independent measurements of the same physical property based on completely different measurement principles. Although the correlation between the two is high (r^2=.68, 102 data pts) many points are not near the 1:1 line. Further research comparing these two methods is planned.

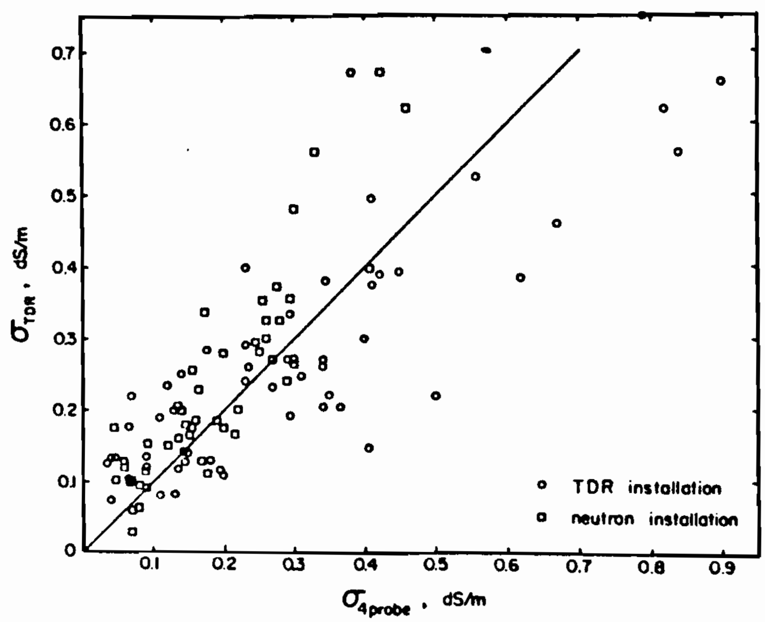

Figure 3. Bulk soil electrical conductivity measured by TDR vs. measurement with four-electrode probe and 1:1 line.

Presently, few methods exist for measuring water content and salinity simultaneously in a non-destructive fashion and over identical sampling volumes. This method becomes especially attractive for spatial variability studies involving heterogeneous soils. TDR techniques also have potential for non-destructive, in-situ measurements of the soil solution concentration during unsaturated flow and may be very useful for calibration and verification of theoretical flow and transport models.

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RAPID FIELD-WIDE ASSESSMENT OF SOIL SALINITY

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Increased irrigation efficiency and saline drain water use for irrigation in the high water table areas of the San Joaquin Valley can increase soil salinity with time. Field-wide monitoring of soil salinity may be necessary to prevent excessive salinity levels. Traditional sampling methods are too costly for field-wide sampling, thus we evaluated the four-electrode salinity probe (4P), the Wenner array (WA), and an electromagnetic induction device (EM) as methods for field-wide sampling. Responses of these instruments to changes in soil salinity along a transect were compared using both classical and time-series statistics.

Measurements along an 800 meter transect at the Duty site showed fairly constant salinity for the first 300 meters and increasing salinity thereafter for the 30 cm depth for the 4P and WA. Measurements at the deeper depths (60, 90 cm) showed similar behavior except between 200 and 300 meters, relatively low salinity occurred. Salinity generally increased with depth. For the shallow and deep configurations, data of the EM device showed a similar response as that of the deeper readings of the 4P and WA. For all instruments, a large dip in salinity occurred at about 770 meters.

Statistics of these data, in Table 1, show both the mean and standard deviation increasing with depth, thus the variance increases as the salinity increases. A fairly constant coefficient of variation with depth occurred for the 4P and WA. The CV's were similar for the 4P and WA but were lower for the EM device.

Histograms showed generally normal distributions but bimodal behavior occurred at the 60 and 90 cm depths in the WA data and at the 90 cm depth in the 4P data. The histogram of the 30 cm depth of the WA showed about 36 percent of the readings to be between 0.5 and 1.0 dS/m which was also the minimum range of the data.

The trend in the data accounted for about 90 percent of the data variance of the EM measurements and between 60 to 70 percent for the other instruments. Patterns in the random component of the variance were analyzed with residuals of a moving average used to describe the trend. Data of all instruments at all depths showed considerable variance in the residuals occurred over a 50 to 70 meter interval. Some variance was also occurred at a 20 meter interval for the 4P and WA.

We also investigated the effect of changes in soil moisture on the 4P measurements by comparing 4P measurements with water content and soil salinity of soil samples. Almost all of the variance in the 4P data was caused by soil salinity differences ($r^2 = 0.93$). Response of the instrument appeared unaffected by soil moisture, which is contrary to theory. Reasons for this lack of response are unknown.

Our results show all instruments to respond adequately to changes in soil salinity along the transect. Data of the 30 cm depth showed a slightly different pattern than that of 60 and 90 cm for the 4P and WA. The EM device responded similarly for both shallow and deep configurations. Larger CVs occurred for the 4P than for the EM device which was expected because of the larger volume of soil sampled by the EM device. Although the WA also samples a larger volume than the 4P, CV's were about equal. The relatively higher variance of the WA (compared to the EM) may be caused by poor electrical continuity between the electrodes of the WA and the soil.

Our conclusions are:

1. The EM device provides a method for rapid field-wide assessment of salinity. Its resolution of salinity with depth is limited, however.
2. The 4P and WA provide adequate resolution with depth. However, problems of electrical continuity may occur with the WA.

Table 1. Statistics for transect at Duty site (length = 800 meters).

Depth (cm)	$\bar{X}$ (dS/m)	s (dS/m)	CV (%)
Four - Electrode Probe			
30	2.09	0.90	43.2
60	2.97	1.31	44.0
90	4.13	1.84	44.5
Wenner Array			
30	1.41	0.60	42.6
60	3.29	1.30	39.6
90	4.80	2.04	42.6
Electromagnetic			
Shallow	2.77	0.90	32.6
Deep	3.64	1.07	29.3

USE OF THE BOWEN RATIO TO ESTIMATE CROP ET

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Accurate estimates of evapotranspiration (ET) in the field are essential for scheduling irrigations effectively. Various methods exist for estimating crop water use. One popular approach of estimating ET requires monitoring temporal changes in soil moisture. Unfortunately, the accuracy of this method depends upon the number of measurements in various locations within the field to account for the spatial variability.

Since climatic conditions largely influence the rate of ET, some methods have been developed that estimate ET based upon the weather. Water loss from pans or tubs are the oldest of these methods. Evaporation from pans is similar to water loss from soils and growing plants and can provide resonable accuracy if corrected for weather and siting conditions.. A more complex but generally more accurate method for estimating ET involves the use of various meteorological parameters such as net radiation, wind speed, humidity and temperature. The modified Penman equation is an example of an equation that uses these parameters to estimate water loss of a short, uniform, and healthy growing grass that is adequately watered (Doorenbos and Pruitt, 1977). Both of these methods, evaporation from pans and the modified Penman equation, require crop coefficients that relate estimated ET (commonly symbolized Epan and ETo, respectively) to ET of the crop.

Lysimeters, if well designed and maintained, provide good estimates of ET and do not require coefficients. However, lysimeters are expensive and are located permanently in a small section of the field that is allegedly representative of the entire field.

Two relatively accurate methods, eddy correlation and Bowen ratio, are currently being tested at the University of California at Davis. Both devices are advantageous because they are portable and therefore can be easily transported to various fields.

Although various methods exist for estimating ET, this paper will limit its discussion to the Bowen ratio method. Hereinafter, this method will be referred to as the Bowen Ratio - Energy Balance (BREB) method.

Principal of Operation

The balance of vertical energy fluxes may be expressed by the following relationship.

$$R_n = S + H + LE \quad (1)$$

where R_n is the net radiation, S is the soil heat flux, H is the sensible heat flux, E is the evaporation rate and L is the latent heat of evaporation. The Bowen ratio is the ratio of sensible heat flux to latent heat flux.

$$\beta = H/LE \quad (2)$$

Initially developed by Bowen (1926) to estimate evaporation from free water surfaces, this ratio was eventually applied to cropped surfaces by Tanner (1960) and others.

The Bowen ratio is determined by measuring temperature and vapor pressure at two heights above the crop canopy. Equation (2) may be expanded to yield

$$\beta = \frac{PC_p}{.622L} \; \frac{K_h}{K_v} \; \frac{\delta T/\delta z}{\delta e/\delta z} \qquad (3)$$

where P is the atmospheric pressure (mb), C_p is the specific heat of water at constant pressure (cal/g ^oC), L is the latent heat of vaporization (cal/g), δT is the difference in temperture (^oC) from each height, and K_h and K_v are exchange coefficients for sensible heat and water vapor, respectfully. These exchange coefficients are assumed equal under non-advective conditions (Brutsaert, 1982) $\delta T/\delta z$ and $\delta e/\delta z$ are the temperature and vapor pressure gradients, respectively, for a standard height differential (δz). By combining equation (1) and (2), the following relationship may be algebraically obtained.

$$LE = \frac{R_n + S}{1 + \beta} \qquad (4)$$

BREB Instrumental Design

A diagrammatic representation of the BREB apparatus for determining β is shown in Figure 1 (George et al., 1985). The apparatus consists of a support mechanism for the measurement of air and dew point temperatures at two heights above a crop canopy. A wooden base (1) supports a steel pole (2). A steel pipe (3) is attached to this pole using a "t" type bracket which can be adjusted along the length of the pole. This allows for the adjustment of the intake heights to account for variation in

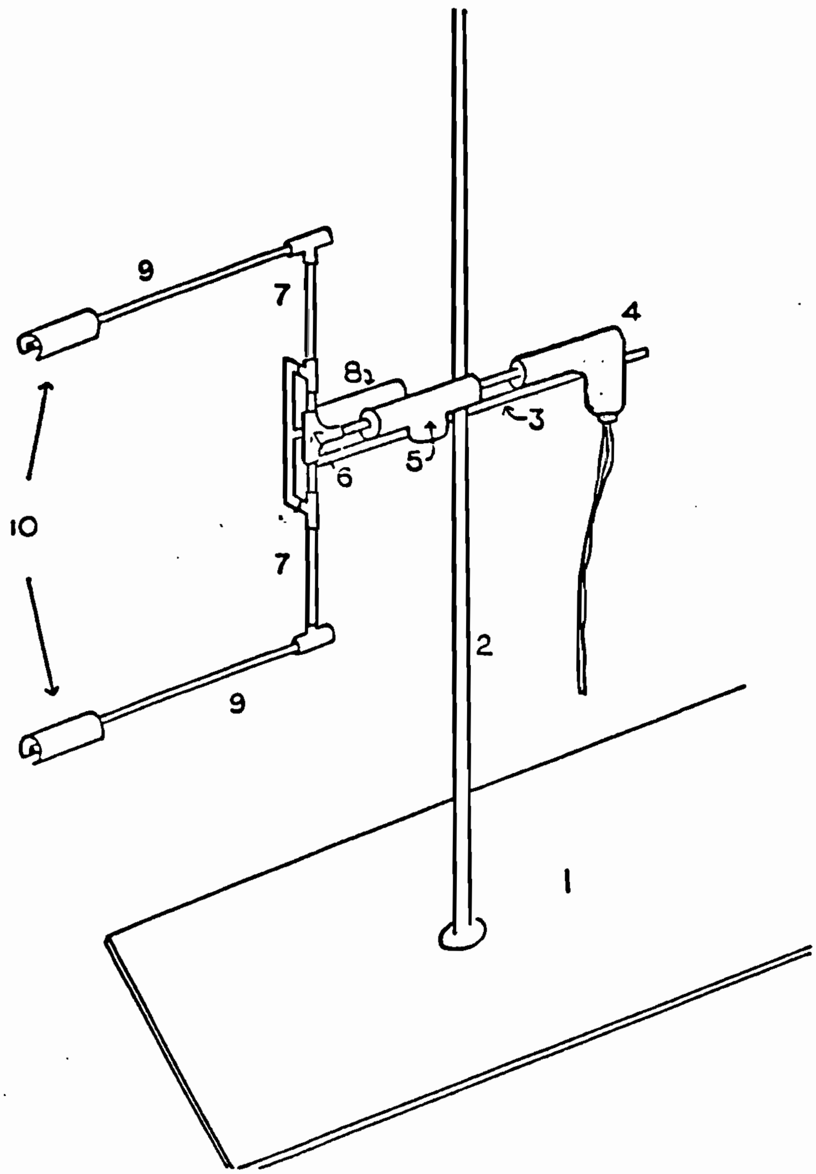

Figure 1. Diagram of the BREB instrument (from George et al., 1985)

crop heights. A chilled mirror hygrometer (4) (Dew 10, manufactured by General Eastern[1]) is attached to one end of the horizontal pipe. A PVC tube containing an enclosed intake fan (5) is fitted over the Dew 10's sensor end. This fan is attached to a switchable valve (6) that is controlled by a small electric motor and allows air samples to be taken from alternate heights.

Two PVC extensions (7) separated by a 0.8 m distance are attached to the switchable valve for drawing air from the two heights. An exhaust fan (8) is provided to maintain a continuous airflow through the intake arms (9) for purging. One platinum resistance temperature sensor is inserted approximately 7 cm from the intake end of each arm.

Double shields are attached at the two intake ends (10) to avoid solar heating of the air that surrounds the temperature sensors. A triple shield surrounds the Dew 10 sensor (not shown). The entire intake fan-Dew 10 system is then wrapped in a white cloth to assure total darkness within the chilled mirror chamber necessary in the proper operation of the Dew 10.

Measured values of soil heat flux are determined as the mean value of three soil heat flux plates. Net radiation values are determined using a net radiometer secured to a 0.7 m standoff attached to a vertical support rod that is separate from the main instrument system. All sensors are connected to a common sensor board which is secured to the vertical support pole. DC

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[1] Mention of company names is for the benefit of the reader and does not imply endorsement or guarantee by the University of California or its agents.

power supplied by two deep cycle lead acid batteries is connected to the sensor board through in-line fuses and supply 24 v to the Dew 10 and 12 v to the fans and switch motor. A variable resistor is contained in the board and is used to regulate the fan speed. A parallel interface is also available for connecting a data logger that controls the recording of data and calculation of both the Bowen ratio (β) and ET.

Field Tests

BREB instruments were located in uniform fields of cotton and sorghum at Davis during the summer of 1985. The instruments were situated next to lysimeters so that ET estimates of each method could be compared. As expected with new instrumentation, ET estimates from both methods were in close agreement with each other only on some days. Figure 2 shows data when the BREB device and lysimeters were all in satisfactory operating condition.

Potential Use of BREB Instruments for Estimating Field ET

Although BREB instruments have limitations and various problems associated with them, when working properly they may provide accurate estimates of field ET.

ET estimates at sunrise and sunset may be suspect due to β approaching -1. In these cases, as β approaches -1, the denominator (1 + β) approaches 0 and therefore LE approaches infinity. Furthermore, ET estimates under advective conditions are suspect since no advection term is included in the energy balance equation to estimate ET. Errors approaching 10 percent have been noted in previous investigations (Blad and Rosenberg, 1974).

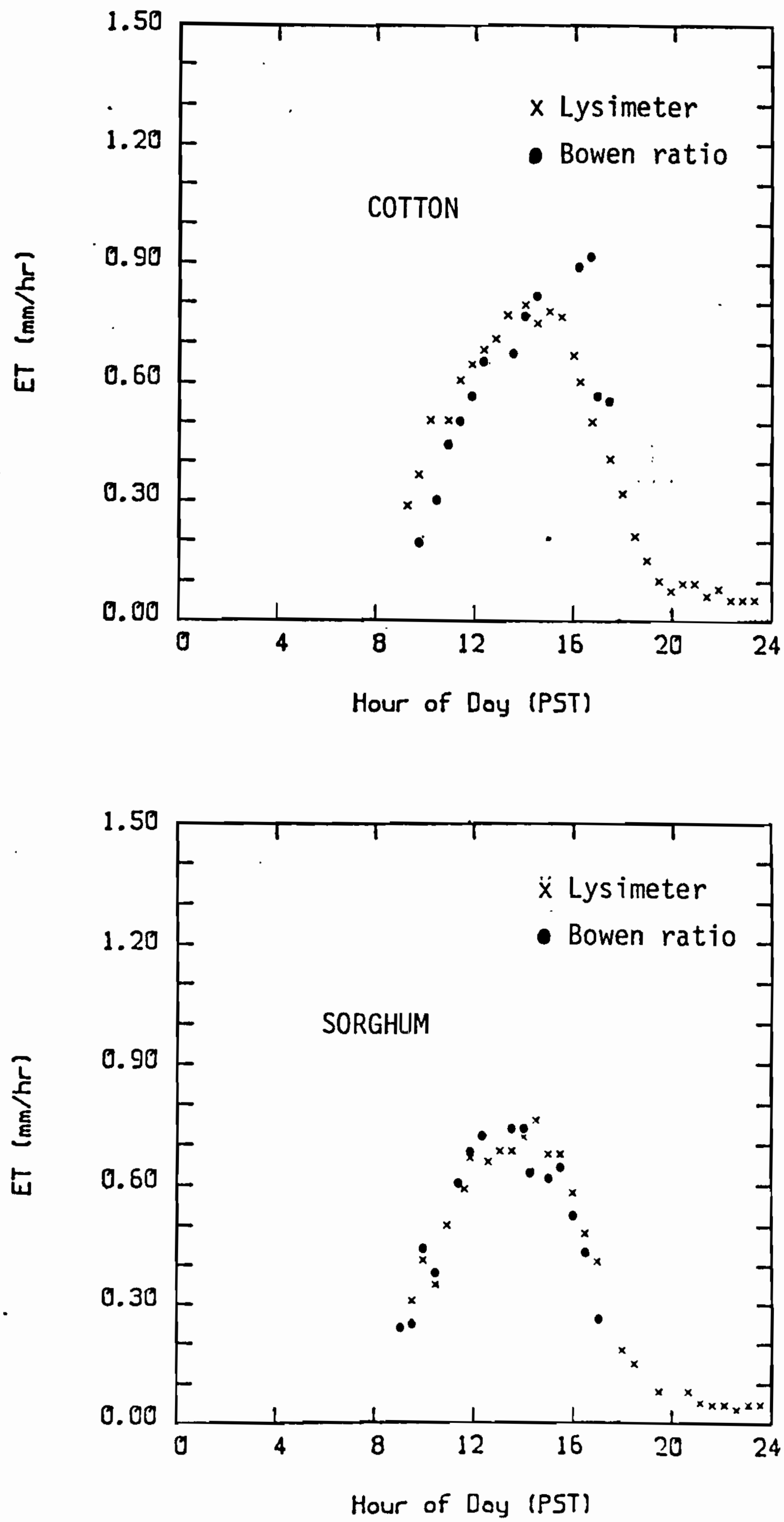

Figure 2. Evapotranspiration (ET) rate in cotton and sorghum fields as determined by lysimeters (x) and BREB Instruments (●).

Since simultaneous measurements of dewpoint temperature at both heights are not possible with the present design, errors are possible in the e term. The error is minimized by calculating 30 min means at each height. Position of the intake arms are important to maximize instrument sensitivity and accuracy. Maximum gradients are obtained when the lower arm is situated near the top of the canopy. Care must be taken so that the lower arm does not sample air from within the crop canopy. This air is generally cooler and more humid and will overestimate ET. Care must also be taken to insure that there is adequate fetch and that both measurements are taken within the boundary layer.

Further tests with the BREB instruments are necessary to gain confidence with their ET estimates. With slight modifications of the instruments, accurate ET estimates can become possible, especially during daylight hours when the rate of ET is largest.

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New Approaches to Control of Virus Diseases in Plants.

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Virus diseases remain the one major group of plant diseases for which no effective interventionary methods are available for control. Genetic resistance made available by plant breeding has been quite successful in some crops, but it is a long term effort that may or may not provide long term solutions. Vector control has been successful in some cases as has management to avoid or reduce disease incidence. In many crops and in many situations, most plant pathologists and growers would agree that new or improved methods for virus disease control could contribute significantly to reducing crop losses or risks of crop production.

Molecular biology technology, and in particular recombinant DNA methods, may provide new ways to solve plant virus disease control problems. In this talk I shall briefly review four strategies employing recombinant DNA methods that could result in improved disease control in the next 2 to 5 years. These strategies involve manipulation of the natural phenomena of cross protection and of satellite viruses, the development of powerful new diagnostic technology, and an approach to making plants resistant to virus infections that exploits a naturally occurring method used in other organisms and perhaps plants to regulate gene expression.

MONOCLONAL ANTIBODY TECHNOLOGY : APPLICATIONS IN PRODUCTION AGRICULTURE.

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AGRI- DIAGNOSTICS Associates, 2611 Branch Pike, Cinnaminson, NJ 08077

BIOTECHNOLOGY

Recent advances in basic understanding of biological systems has provided the basis for the rapid utilization of that knowledge for the benefit of society. The outstanding achievements of scientists in genetics, molecular biology, and immunology in particular have been recognized over the past decade through Nobel Prizes and other honors.

The astounding fact, however, is that these great discoveries have not lead just to academic honors, but they have been exploited commercially to produce useful products and services that benefit many people. These applications of basic research discoveries have come to be popularly refered to as "biotechnology".

Within biotechnology two main areas are being developed most rapidly:

1. **Genetic Engineering**
2. **Monoclonal Antibodies**

Genetic engineering is being applied to improving crop plants, economic animals, industrial microorganisms, and in the future may even be applied to humans directly. Monoclonal antibody technology has arisen out of reseach into the functioning of the immune systems of vertebrates. While genetic engineering is being applied initially to industrial microbiology and agriculture, monoclonal antibody technology is being used primarily in medicine where new applications are being developed almost daily.

MONOCLONAL ANTIBODY TECHNOLOGY

Vertbrate animals produce specific proteins in response to invasion by foreign organisms or substances. Antibody proteins are produced by specific populations of white blood cells circulating in the animal's body. When these cells encounter a foreign substance they begin to produce antibodies. The key features of the immune system are:

1. Antibodies' ability to recognize a specific target

2. Antibodies' ability to bind tightly to the specific organism or substance

3. The ability of white blood cells to produce antibodies when the animal is challenged by foreign materials

Analytical techniques which employ the specificity of antibodies are called "immunoassays". Immunoassays are used commonly in medical laboratories to diagnose diseases and various other conditions of patients. Such assays have been widely used in clinical laboratories for over a decade.

Over the past 2-3 years test kits based on immunoassays have been developed for the home health care market. Most noteable are home pregnancy test kits which are available at all pharmacies. These kits contain antibodies which bind specifically to a hormone whose level rises when a woman becomes pregnant. Increased levels of the hormone in urine and blood usually indicate pregnancy.

The first commercial immunoassay products were based on mixtures of antibodies obtained from the blood serum of experimental animals. While these reagents were and are very useful, they do have some limitations. Many of the limitations can be eliminated through the use of monoclonal antibodies.

Monoclonal antibodies are antibodies which are produced by a single white blood cell and its offspring as opposed to traditional or "polyclonal" antibodies which are obtained from experimental animals. The desired cells are cultured or "cloned" in the laboratory and antibodies are harvested for the intended use. The more traditional method of obtaining antibodies for use in tests was to harvest blood serum from experimental animals and separate out the desired antibodies. This resulted in mixtures of antibodies which varied over time and frequently gave non-specific cross reactivity.

Monoclonal antibodies are produced by injecting mice with minute samples of the target substance or a mixture that contains the material to be detected. The antibody-producing cells are carefully removed later and combined in the laboratory with another type of cell that allows the antibody-producing cells to be cultured. The cells are then carefully screened to find those which produce antibodies that will be useful in detecting the targeted material.

For example, if the target is a pathogen such as a plant virus, mice will immunized with purified virus. White blood cells will be removed from the mice 2-3 months later and combined with hybridoma cells. At this point, a great deal of testing is conducted to find the cell clones that make antibodies against the desired virus. The virus that was used for the immunization, related viruses, and plant extracts must all be tested to assure that the antibodies that are finally selected will react only with the target virus.

IMMUNOASSAY PROCEDURES

A specific antibody is the key to these analytical procedures. However, one must also have a way to detect the specific binding of the antibody to the target material. The methods used to visualize and measure the binding are called "immunoassays" and form the basis for the practical application of this powerful technology.

Medical laboratories often utilize antibodies which have been labeled with a radioactive tag. These "radioimmunoassay" procedures (RIA) are extremely sensitive and can be automated to allow hundreds of samples to analyzed each day. RIA tests, however, are limited to sophisticated laboratories due to the radioactive materials involved as a result, RIA procedures are unacceptable for general agricultural use.

Antibodies can be labeled with substances other than radioactive materials. A common procedure is to couple an enzyme protein to the antibody protein. The enzymes used will produce a visible color when they are present. This type assay is called "enzyme linked immunosorbent assay" or **ELISA**. ELISA tests are quite sensitive but eliminate the hazards of the RIA tests. Several of the home pregnancy tests and many clinical tests are based on ELISA.

Several other variations of immunoassay are used in medical test kits. Some of these are based on the ability of antibodies to form aggregates with proteins or particles. These assays produce a precipitate or ring which can be observed and rated. ELISA tests can be evaluated either visually or quantitatively with an instrument while most of the precipitating assays are difficult to read quantitatively.

AGRICULTURAL APPLICATIONS

The specific antibody-based assays have many potential uses within agriculture. Some of the leading targets include:

Plant Pathogens - Detection in plants, soil, seed, planting stocks

Plant Components - Detection of specific substances such as plant hormones, flavor components, and proteins.

Genetic Markers - Detection of proteins and other cell products which are correlated with the presence of a desirable gene in breeding stocks.

Fertility Indicators - Antibody assays can be used to detect substances which indicate the fertility status of the plant.

PRACTICAL APPLICATIONS IN AGRICULTURE

Until very recently agricultural immunoassays were used only in research laboratories. Commercial test kits are now available for a range of materials of interest including:

Plant viruses

Pesticides

Plant Hormones

Limonine (a bitter material in citrus juices)

Monoclonal antibodies to a variety of other materials and organisms of potential interest to agriculture have been reported as well. These include:

Plant Pathogenic Fungi

Plant Pathogenic Bacteria

Nitrogen-fixing Bacteria

Isoenzymes

Nitrate Reductase

Parasitic Nematodes

These research discoveries suggest that in the coming years crop management professionals will have an increasing array of tools available to assist them in making management decisions.

The test kits that are currently available are based on the ELISA technology discussed previously. They are primarily for use in a laboratory setting where equipment, instruments, and trained personnel are readily available.

Over the next few years, however, we can expect to see agricultural test kits designed for easy use directly by those individuals responsible for making crop management recommendations and decisions. These tests will be self-contained, simple to use, and easy to interpret. Some will produce a Yes/No reading that will be evaluated visually. Other tests will utilize inexpensive hand-held electronic instruments to provide a more quantitative reading.

TEST KIT USE

How will such test kits be used? As an example we will outline a procedure envisioned for the early detection of a plant disease caused by a fungus.

1. The crop manager purchases a test kit for a specific disease such as Grape Powdery Mildew.

2. After reading the directions, the user collects samples and brings them to a convenient work area. This might be the tailgate of a pickup truck or a desk in an office.

3. The user will prepare the sample and conduct the test using materials and reagents provided in the test kit.

4. The results may be a color change in a tube of liquid or the development of a color on a test strip or "dipstick".

5. In this instance we will assume the user gets a color change on an indicator paper and reads the intensity of the color with a hand-held meter.

6. The reading from the meter may indicate the presence of low levels of powdery mildew in the samples.

7. The manager could then take a number of actions depending on the stage of development of the crop, weather conditions, and crop value. For example, the user could continue to monitor a regular intervals to determine whether the pathogen level is increasing. When the levels warrant, a fungicide may be applied to protect the developing crop at the most appropriate time. Reapplications can be scheduled similarly, based on the prevalence and rate of increase of the pathogen. In any instance, the test results can be kept as a record of the recommendations made.

CONCLUSIONS

The specificity of antibodies coupled with assay technology adapted from medical sciences and electronic devices are being combined to make on-farm testing a practical reality. Routine questions about plant diseases, pests, fertility, and crop condition will be answered rapidly, allowing timely and accurate crop management decisions. The same technology will also be available to testing laboratories and extension personnel, providing cost-effective analysis and permitting highly trained specialists to focus their efforts on solving unusual problems.

Intellectual Property Protection for Plants and Plant Biotechnology

Robert E. Fissell
Manager of Plant Patents
Patent, Trademark
& Copyright Office
Office of the President
University of California
Berkeley, California

Intellectual property is intangible property and consists of rights under patents, trademarks, copyrights and trade secrets. In the case of patents and copyrights, rights are granted by the Federal government. Both Federal and state laws govern trademark rights. Rights under trade secrets are the provenance of the individual states. My talk will cover the four types of intellectual property, but focus primarily on patent or patent type protection for plant material and lower plant life forms useful in agriculture.

The legal basis for intellectual property in the United States stems from the Constitution. Article 1, Section 8 states the following: "The Congress shall have the power ... To promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." The various federal and state laws implementing this section of the constitution can be referred to collectively as intellectual property laws and the protection obtained thereunder as intellectual property protection.

The utilization of intellectual property protection by commercial firms is well established and, in an increasingly competitive world, vital in many cases to their continued economic success. Utilization of such protection by public research agencies is becoming more common and is necessary in certain situations to get publically funded technology development to the marketplace for the ultimate benefit of the general public.

As new ideas and methods in biotechnology are being applied rigorously in the realm of agricultural research, and as new and useful plant varieties are now reaching growers via both new and traditional plant breeding techniques, a presentation and discussion of available intellectual property protection for plants and plant biotechnology should be timely and prove of interest to those involved in plant or plant related research.

The talk will follow the general outline of topics listed below. Though the presentation will be informal and not a verbatim recitation of the various laws, it might be helpful to have certain portions of the applicable laws at hand or for later reference. They have been included for that reason. The addresses of certain administrative agencies have also been included for your information and possible future reference.

I. Trade Secrets

II. Copyrights

Copyright Statute, Title 17 U.S. Code:

Section 102 - "Subject matter of copyright: In general

(a) Copyright protection subsists ... in original works of authorship fixed in any tangible medium of expression, now known or later developed, from which they can be perceived, reproduced, or otherwise communicated, either directly or with the aid of a machine or device. . . .

(b) In no case does copyright protection for an original work of authorship extend to any idea, procedure, process, system, method of operation, concept, principle, or discovery, regardless of the form in which it is described, explained, illustrated, or embodied in such work."

Copyrights are administered by:

Copyright Office
Library of Congress
Washington, D.C. 20559

III. Trademarks

Trademarks registered with the Federal Government are administered by:

The Commisioner of Patents and Trademarks
Washington, D.C. 20231

Trademarks registered with the State of California are administered by:

State of California

Office of the Secretary of State

Corporate Filing Division

1230 J Street

Sacramento, California 95814

IV. Patent and patent like protection

A. Patents

Title 35 U.S. Code

Section 161 - Patents for Plants (From the 1930 Plant Patent Act)

"Whoever invents or discovers and asexually reproduces any distinct and new variety of plant, including cultivated sports, mutants, hybrids, and newly found seedlings, other than a tuber propagated plant or a plant found in an uncultivated state, may obtain a patent therefor subject to the conditions and requirements of title."

Section 101 - Inventions patentable

"Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title."

Patents are administered by:

The Commisioner of Patents and Trademarks
Washington, D.C. 20231

B. The Plant Variety Protection Act of December 24, 1970

Public Law 91-577

Chapter 4 - Protectability of Plant Varieties

Section 42. Right to Plant Variety Protection; Plant Varieties Protectable

(a) "The breeder of any novel variety of sexually reproduced plant (other than fungi, bacteria, or first generation hybrids) who has so reproduced the variety, or his successor in interest, shall be entitled to plant variety protection therefor, subject to the conditions and requirements of this title unless one of the following bars exists: . . ."

The Plant Variety Protection Act is administered by:

Plant Variety Protection Office
Livestock, Meat, Grain and Seed Division, AMS
United States Department of Agriculture
National Agaricultural Library Building
Beltsville, Maryland 20705

C. Supreme Court Chakrabarty Decision - Diamond v. Chakrabarty, 447 U.S. 303 (1980)

D. Board of Patent Appeals and Interferences Decision on an appeal (Appeal No. 645-91) heard on August 9, 1985 relative to a Section 101 patent application (S.N. 647,008) on Tryptophan Overproducer Mutants of Cereal Crops

E. International Convention for the Protection of New Varieties of Plants (UPOV) of October 23, 1978 Acceded to by the United States on November 8, 1981

UPOV administrative headquarters:

34, chemin des Colobettes
1211 Geneva 20
SWITZERLAND

UPOV member Countries:

Belgium, Canada, Switzerland, Federal Republic of Germany, Denmark, Spain, France, United Kingdom, Ireland, Israel, Italy, Japan, Mexico, Netherlands, New Zealand, Sweden, United States of America, South Africa.

Production Interactions for Maximum Economic Yield

Dr. A. E. Ludwick
Western Director
Potash & Phosphate Institute
Davis, California

Maximum economic yield is that point closest to maximum yield where the highest possible net return is achieved. It is reached, or at least approached, when a grower skillfully integrates crop and soil management decisions to maximize positive interactions (ie., synergistic benefits) among genetic, cultural, and environmental factors leading to high yields per acre. High yields are key to efficient production and essential for survival in today's agricultural economy because they typically reduce the cost per unit of production (bale, cwt, etc.) as illustrated in Figure 1. For example, from Cooperative Extension, Fresno Co., it is estimated that cotton production costs are $0.76 per lb of lint at 1,125 lb per acre production compared to only $0.60 per lb at 1,500 lb. (Dec. 1984, at $25 per acre-foot of water).

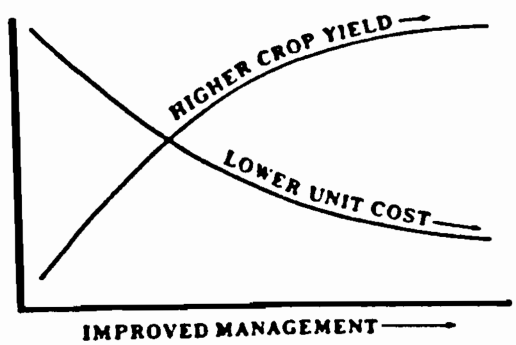

Figure 1. Improved crop management increases yield and reduces unit cost of production.

It may seem inconsistent to discuss the need for higher yields when crop prices are already low because of market surpluses. The fact is we operate in a world economy. Crops will sell (i.e., markets expand) when prices are competitive in the international market. Acreage restrictions (or lower yields) may reduce surpluses and raise prices in the U.S., but how do we compete internationally? And how long can we continue to subsidize agriculture? There are many marketing and political issues that greatly complicate food production and pricing. Regardless of how these issues are ultimately resolved, one point is clear -- THE MOST EFFICIENT FARMER IS THE ONE WHO WILL BE FARMING IN THE DECADES TO COME. Our role as agronomists is to help farmers become as efficient as possible.

Dr. John Marten, Staff Economist for the Farm Journal, strongly supports the concept of lower unit costs and emphasizes the role of fertilizer in producing high yields: "The sharp profit-oriented farmer is going to use adequate fertilizer as one of his main cost-cutting tools. To cut costs and increase efficiency, concentrate on lowering cost per unit, not cost per acre. High yields are still the key to efficient production."

We in the fertilizer industry tend to think mostly in terms of nutrient benefits -- added nutrition to increase yields. Also, we recognize that nutrients can interact positively among themselves producing more yield than the sum of their separate benefits (eg., N x P, P x K, etc.). But this is only part of the story. The key to maximizing profit is taking advantage of all possible production inputs, some of which add nothing or little to the cost of production. Properly combined (ie., managed), they can produce significant positive interactions and greatly increase the return on fertilizer as well as all other necessary inputs. Consider the following examples:

Interactions Among Nutrients

An experiment in northern California (Table 1) demonstrates how P and K can positively interact to produce more forage than the sum from each nutrient applied separately.

Table 1. Phosphorus and potassium produce positive interaction in forage.

P_2O_5		K_2O	Hay (3 cuttings)	Increase over no fertilizer
	lb/A		T/A	T/A
-	None	-	2.5	-
120		0	3.5	1.0
0		200	2.7	0.2
120		200	4.9	2.4

Soil test: P, low; K, medium
Legume - grass mix
Univ. of Calif.

Fertilizer placement can not be overlooked when considering methods to maximize fertilizer returns (Table 2 and Figure 2). The advantage of banding and placing NH_4-N and P together are illustrated in these data.

Table 2. Dual N-P application influences potato yield.

Application method		Tuber yield		Increase over NP Broadcast	
Banded	Broadcast*	Total	No.1	Total	No. 1
			cwt/A		
NP	--	232	122	49	44
P	N	186	77	3	-1
N	P	207	104	24	26
--	NP	183	78	-	-

* Fertilizer was ammonium sulfate and triple superphosphate at 80 and 160 lb/A, respectively.

Avail. soil P: Low Oregon State Univ.

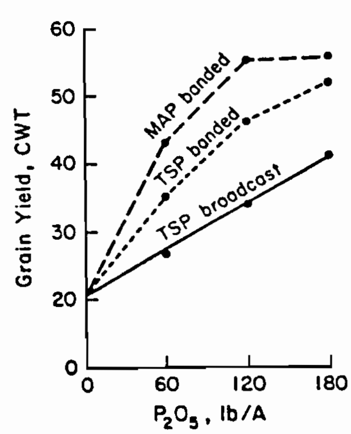

Figure 2. Wheat responds to source and method of P placement (Available soil P, high; previous crop, rice).

Univ. of Calif.

Positive interactions do not always occur when two nutrients are applied even though both are limiting. This is illustrated in Table 3 for lamb gain/A to P and S fertilization of subclover--grass pastures in northern California. Response to P and S in combination is excellent and certainly the most profitable treatment. However, further research is needed to determine those factors causing the additive benefits of P and S in this case to be more than the same treatments applied in combination.

Table 3. Lambs respond to P and S fertilization of forage.

P_2O_5	S	Yield[1/]	Increase over no fertilizer
lb/A		lamb gain, lb/A	
-	None	81	-
115	0	163	82
0	88	127	46
115	88	191	110

1/ March 8 to April 6, 1983

Hopland Field Station
Univ. of Calif.

Fertilizer - Management Interactions

As previously observed, fertilizer efficiency is highly influenced by crop management decisions. This is extremely important to recognize because many of these decisions add little, if anything, to the cost of production, yet they can have a big impact on yield and ultimate profit. In the following series of examples (Figure 3, and Tables 4 and 5) note the strong positive interactions and how each crop management decision (variety, plant population, and planting date, respectively) influences fertilizer efficiency.

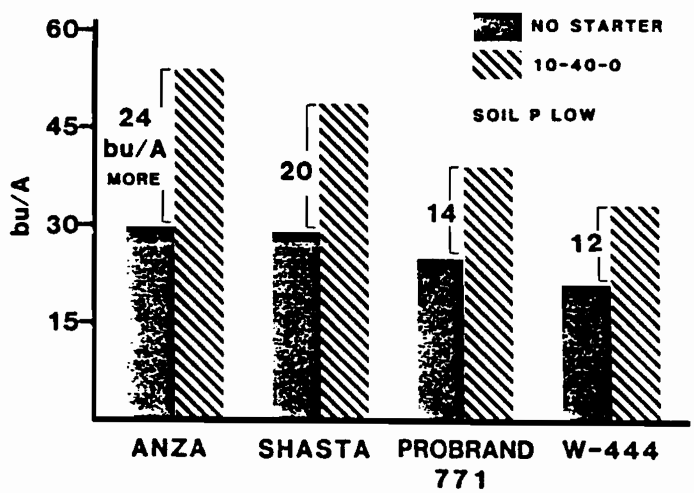

Figure 3. Variety selection of wheat influences benefit from starter fertilizer.

Univ. of Calif.

Table 4. "Low-cost" input influences fertilizer efficiency.

N lb/A	Plants/Acre 18,000	26,000	34,000
	Corn grain, lb/A		
0	9,370	9,340	10,170
200	11,520	14,040	15,190
Response	+ 2,150	+ 4,700	+ 5,020

Sacramento Valley
Univ. of Calif.

Table 5. "No-cost input influences fertilizer efficiency.

N lb/A	Early planted (May 9)	Late planted (May 30)
	Corn grain, lb/A	
0	10,170	9,190
200	15,190	11,850
Response	+ 5,020	+ 2,660

Sacramento Valley
Univ. of Calif.

The above are just a few simple examples of how production factors can impact each other. Unfortunately, there are too few such examples available. The challenge in production research today is to identify these interactions, to determine the conditions prequisite for an interaction to occur, and to quantify (predict) its effect on yield. Additionally, all research should be conducted under maximum yield conditions. After all, how much value is production research if farmers are raising crops at yield levels higher than those in our research program?

Some specific areas that need attention in addition to or as part of interaction studies include:

Nutrient uptake -- total and by stage of growth

Fertilizer placement

Long-term crop and nutrient management (rotations)

Tillage systems (emphasizing conservation tillage)

In summary, skillfully integrated management decisions leading to positive production interactions is the surest way to higher yields. Those higher yields will require a greater investment in fertilizer, but the key is cost per unit (bale, cwt, etc.), not cost per acre. Research and experience have shown higher yields per acre mean lower cost per unit and higher profit per acre.

Modelling Nutrient Uptake by Crops

Stanley A. Barber

Purdue University

Nutrient absorption by crops is an important process that has been studied by both physiologists and agronomists. Our knowledge of the processes involved has gradually developed so that information is sufficient to mathematically describe these processes. This has led to the development of mechanistic mathematical models which can be used to predict nutrient uptake under varying soil and crop conditions.

Most soil nutrients must move to the plant root before they become positionally available for uptake. Plant roots usually occupy less than one percent of soil volume, hence less than one percent of the nutrients will be directly contacted by the growing root. Nutrients move to the root by mass flow and diffusion. Plant roots absorb water causing a convective flow of soil solution to the root. The nutrients in this solution are transported to the root by mass flow. Levels of P and K in the soil solution are usually low so that little P or K reaches the root by mass flow.

Additional absorption by the root reduces the concentration at the root surface. This creates a concentration gradient normal to the root surface and nutrients diffuse along this gradient to the root. Hence the supply of nutrients from the soil to the root is by mass flow and diffusion.

Autoradiographs using radioactively labeled nutrients and analyses of soil slices taken normal to the root have verified the predicted nutrient gradients about plant roots.

Nutrient uptake by plants growing in soil involves both soil and plant properties. Soil tests measure only soil properties of nutrient supply. We frequently calibrate soil tests differently for differing plant species and, in this way, add some measure of plant properties to the system. Our mechanistic model involves the interaction of soil supply properties with plant uptake properties to calculate total nutrient uptake.

Several assumptions were made in developing the model in order to simplify calculations. We assumed plant roots were smooth cylinders with a uniform radius. They absorb nutrients only from solution at a rate independent of age but dependent upon nutrient concentration in solution at the root surface. Uptake vs. concentration was assumed to follow Michaelis-Menten kinetics. Root growth rate is measured to determine its relation to time. Nutrients were assumed to move to the root by mass flow and diffusion. We initially ignore root hairs, mycorrhizae, exudates and microorganisms. When predicted uptake agrees with observed uptake we assume their effect is minimal.

The model uses a transport equation describing the concentration gradient normal to the root and its change with time. The equation is:

$$\frac{dC_l}{dr} = \frac{1}{r}\frac{d}{dr} r\,De\,\frac{dC_l}{dr} + \frac{r_o v_o C_l}{b} \qquad [1]$$

where C_l is the concentration in solution, r is radial distance, D_e is the effective diffusion coefficient, b is buffer power of ions on the solid phase for ions in solution, r_o is root radius and v_o is water influx.

Equation 1 is used with appropriate boundary conditions, describes the change in C_l as influenced by the balance between supply to the root by mass flow and diffusion and uptake by the root as related to C_l. Where roots are close enough to compete, the expression is modified to account for the reduction in uptake due to root to root competition.

The model has 11 parameters. Three, L_o, initial root length; k, rate of root growth, and r_o, root radius describe the size and geometry of the root system and its rate of change. Three describe uptake vs. C_l; I_{max} is maximal influx; Km, is C_l where net influx, In, is 1/2 I_{max}, and C_{min} is C_l where In = 0. Water flux is v_o, r_1 is the half-distance between root axes and t is time. The soil supply characteristics, described are by C_{li}, the initial concentration in soil solution; b, the buffer power; and D_e, the effective diffusion coefficient. In this discussion we are primarily interested in the three soil supply parameters.

With the exception of soils very low in P, the model closely predicts observed uptake. On soils low in P, root hairs and mycorrhizae increase P uptake over what is predicted assuming a smooth cylindrical root. In one study, adding calculated uptake by root hairs resulted in agreement between observed and calculated uptake. Since the model accurately predicts P and K uptake under most situations it can be used to investigate soil tests. Soil tests are usually chemical extractants of the nutrient from the soil and are designed to measure the soil supply of the nutrient. The model shows that nutrient uptake depends both on the supply by the soil and the size and uptake characteristics of the plant roots. Changes in the root parameters can cause changes in crop response to added fertilizer where the soil supply remains the same.

The model can be used in a sensitivity analysis to determine the relative influence of each model parameter on predicted nutrient uptake. A sensitivity analysis where individual parameters are changed independently while keeping the remainder constant shows that size of the root surface has the greatest effect, soil supply is second and the kinetics of uptake had the least effect. Hence, if some soil condition results in a greater density of roots in the soil per unit of shoot growth the nutrient deficiency will be reduced.

CONVERSION OF ANNUAL RANGE FORAGE TO BEEF IN THE SIERRA NEVADA FOOTHILLS

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M. R. George, K. D. Olson, K. L. Taggard, and R. E. Delmas
Departments of Agronomy and Range Science,
Animal Science, and Agricultural Economics
University of California at Davis

ABSTRACT

Conversion of plant to animal product in a Mediterranean annual grassland was studied in a type-converted oak woodland, annual-legume-reseeded, lower foothill area of the Sierra Nevada. Major objectives were to assess both short- and long-term biological and economic responses to additions of selected levels and combinations of nitrogen, phosphorus, and sulfur where soils were known to be limiting in all three elements.

Seasonal (late November to late May) grazing was done in a controlled, seasonally-increasing manner, employing stocker steers and heifers weighed initially and at either 4-week or 3-week intervals throughout the season. Esophageal-fistulated animals were used to collect forage samples from which treatment and season related changes in quality could be assessed.

Concurrently, periodic measurements were made of plant biomass levels across the grazing season and of summer dry residue. Changes in botanical composition were monitored before and through the course of the experiment and samples of the three most important plant species groups - indigenous grasses, seeded annual legumes, and filaree (an annual forb) - were taken for subsequent chemical analysis.

Field-scale treatments of nitrogen-only, phosphorus plus sulfur, and all three elements together were aerially applied in early October of 1982 and the experiment was conducted for three consecutive years without additional fertility adjustment. In addition to data collected for plant and animal levels of the system, an initial assessment of soil nutrient status was made and climatic data, especially precipitation, were used as an aid in interpretation of results.

The significant general results of this experiment were as follows:

1. Normal costs of fertilizer materials and application were recovered in the first grazing season (a good production year).
2. Best results, under conditions of the experiment, were from the multiple-element (NPS) and the higher-level PS treatments. This in part reflected the higher stocking rates in two of those treatments.
3. An extremely important element in recovery of fertilization benefits was properly adjusted stocking rates.
4. In spite of comparable levels of grazing pressure (units of animal weight per unit weight of available forage) across treatments, average daily gains were higher for fertilized fields, indicating benefits of fertilization to forage quality.
5. In a growing season of normal length and weather conditions, the most important yield-limiting factor is transfer of additional forage produced from fertilization to livestock which can efficiently convert it to economically useful gain. This may require four-fold or greater intra-seasonal increases in stocking rates and close attention to the phenological progress of plant development.

RATIONALE

One of the oldest agricultural production ecosystems is the grazed (or grazing) ecosystem, wherein animals (generally domesticated livestock) are managed according to some scheme of regulated frequency and intensity of forage utilization in order to optimize three parameters of the production system: plant production; transfer of plant material to the animal (of which process intake is only one component); and conversion to useful (generally but not always in an economic context) animal product. Worldwide, the variation in characteristics of these systems is enormous, and there is often an unnecessarily arbitrary separation made into systems based on rangeland (numerous constraints, minimal control over environmental and management variables) and systems based on arable-land pastures (suitable for alternate cropping uses), which may be either rainfed or irrigated.

Research oriented to improving the productivity of California's versions of the so-called Mediterranean climate annual rangeland has been conducted for over a half century. From this multi-faceted effort flowed the development and application of, as examples, vegetation-type conversion (most often by employing control burns); "re-seeding" with exotic species of annual legumes and perennial grasses (the latter not so successful as the former); concurrent correction of major soil nutrient deficiencies (notably nitrogen, phosphorus and sulfur); and, more recently, attention to controlled grazing (e.g., the widely publicized Savory Grazing Method).

The present experiment incorporates some elements of all of these, and was an attempt to combine them into a whole system for which an accounting was made continuously over a three-year time period.

ECOSYSTEM SPECIFICS

General Location

These experiments were conducted at the University of California's Sierra Foothill Range Field Station, Browns Valley, Yuba County, on a site of approximately 330 meters elevation (1,000 feet), with latitude and longitude approximately 39°14" N 121°18", respectively.

Characteristics of the Site

This location, which is representative of the lower-foothill oak woodland zone of the northern Sierra Nevada, receives an average 75-90 cm (30-35 in) of rainfall (snowfall is very rare and transient) between mid-October and late April in a typical Mediterranean climate. Herbaceous vegetation is almost completely annual, a variable mixture of grasses, legumes and other forbs. Soils are mainly of the Sobrante and Las Posas series with smaller amounts of Auburn and Argonaut, i.e., mostly fine to fine-loamy, mixed, thermic Mollic Haploxeralfs or Typic Rhodoxeralfs (Alfisols).

The site had been completely converted from an oak woodland with shrub understory by herbicidal killing of the oaks (1961-'63) followed by a control burn in 1968. It subsequently was divided into 16 fields of roughly equal size (13.2 ha, 32.6 ac). Reseeding was done using a mixture of subterranean (*Trifolium subterraneum* L.) and rose (*T. hirtum* L.) clovers during the period 1971-1974. Various range utilization and livestock management experiments employing beef cattle have been conducted since that time.

Beyond climatic constraints (e.g., with winter-growing annuals the amount and seasonal timing of rainfall is critical to the initiation and sustained growth of forage), the next most-limiting factor probably is plant nutrition.

MATERIALS AND METHODS

Objectives of the Experiments

The experiment was designed to provide information in three areas:

a. The current economic feasibility of fertilizing annual rangeland with selected combinations of nitrogen, phosphorus and sulfur where soils are limiting in all three elements.

b. Behavior over time of a mixed-species annual range plant community subjected to differential fertilization.

c. The nature of transfer and conversion between primary and secondary trophic levels, including the relationship of animal response (average daily gain) to level of forage on offer, phenological stage of plant development, and species composition. The experiment accounted for three consecutive whole seasons of grazing at known levels of grazing pressure which were equalized across treatment.

Experimental Approach

Fertilizer treatments, main fields. The 16 fields were used for two replications of seven fertilizer treatments, as follows:

1. Control (each replication is a mean of two fields)
2. 40 lb/ac N
3. 80 lb/ac N
4. 40 lb/ac N, 30 lb/ac P, 33 lb/ac S
5. 80 lb/ac N, 30 lb/ac P, 33 lb/ac S
6. 30 lb/ac P, 33 lb/ac S
7. 60 lb/ac P, 66 lb/ac S

Nitrogen was applied as urea; phosphorus and sulfur as a mixture of 0-20-0-12S and 0-25-0-10S. These materials were separately applied by helicopter on October 5 and 6, 1982. The experiment was designed to run for three years, so as to a) allow determination of nitrogen carryover, in year 2 from N applied initially, and in year 3 from N legume-fixed in year 1 and made available in year 2, and b) permit an assessment of fertilization effects on plant species composition. Preliminary soil tests, field plots at eight locations, and a greenhouse pot experiment using soil from the eight plot sites had previously established initial conditions of soil fertility and plant (grass and legume) responses to applied nitrogen, phosphorus and sulfur.

Grazing regime. Beginning mid- to late-November, each field (replication) was uniformly set-stocked with steers (initial weight, approximately 250 kg) at about 2 ha per steer. Subsequent changes in stocking rates were determined by biomass levels measured along permanent transects in each field and were increased at least twice each season, to a maximum of 0.4 ha per animal. Heifers were also used for part of the stocking rate increases. Grazing was continued until forage quality declined to a point where approximately zero gain could be estimated from previous weighings. At this point, the season's grazing was terminated.

SELECTED RESULTS

Climate

A particularly important determinant of seasonal plant production, both total yield and intra-seasonal distribution, is the total amount and intra-seasonal distribution of rainfall. Figure 1 illustrates that 1982-83 had a long growth period, with ample rainfall well distributed, and exceptional weather conditions in late spring. One positive effect was a dramatic response of the resident population of annual legumes to the phosphorus-sulfur treatments. On the negative side, earlier work by Martin and Berry and others showed that rainfall seasons of this magnitude sharply attenuate the carryover, or second year, response from applied nitrogen. Years two and three were characterized by successively declining rainfall amounts which, however, were well distributed.

Plant

Figure 2 shows biomass levels as measured across each grazing season. Only in the first year was a definite fall accumulation of growth apparent. Forage levels were essentially constant until early March, at which time the spring "grand period of growth" began. Overall, it is clear that the very high potential rates of growth were markedly attenuated by upward adjustments in stocking rate, yet at no time during the three years was animal demand sufficiently greater than plant growth rate to after the general nature of the seasonal production curve. The extent of potential disparity between plant growth and animal intake is illustrated by the greater biomass accumulations for the phosphorus-sulfur treatments in the first year, where significant understocking did occur.

Fall-winter levels of forage were lowest in year two, spring levels were lowest in year three. Apart from the expectation of declining forage productivity as applied nutrients were used in plant growth or leached away, a question can be raised about long-term effects of higher stocking levels such as employed in this experiment. The experiment is being continued for at least a fourth year as an aid in determining longer-term effects, however, a lack of adequate rainfall in the fall season of 1985 may preclude a valid comparison with previous fall seasons.

Animal

Figure 2 presents season-long patterns of stocker average daily gains. In general, these seasonal response curves can be separated into three distinct phases. First, a late-fall and winter segment, with gains rising linearly as forage amount and quality increased, and as decreasing environmental stress (cold, wet weather) and increasing animal size operated positively at the animal level. Second, a peak, or actual plateau occurred where, on the average, the biological response potential of the animals (stocker steers and heifers) was met and adequacy of forage quantity and quality (especially energy content) allowed an adequate opportunity for the animals to select an optimally nutritious diet. Third, a brief and precipitous decline, occurring as forage matured and rapidly lost its palatability (with exception of a few species) and nutritional value. Also, increasing size of animals and initial occurrences of hot-weather related animal stresses may have contributed to this unexpectedly rapid decline. At this time in any year, animal expression of forage preference is very strongly evident and the opportunity for spatial control of forage utilization is virtually eliminated since animals tend to only graze those areas where the preferred plants are growing.

Economics

Table 1 presents a preliminary economic analysis of the results, with an additive approach. Important variables in determining whether a given treatment proved profitable were: initial cost of treatment, level of PS-only treatments, stocking rate adjustments, and the general legume-enhancement response to the phosphorus-sulfur treatment. Clearly, all three elements needed to be supplied, with nitrogen provided either directly or through symbiotic fixation by PS-enhanced annual legumes.

Table 3. Preliminary economic analysis of liveweight gain responses from selected combinations of nitrogen, phosphorus and sulfur applied to cleared Sierra Nevada foothill annual legume-seeded rangeland.

	Gross income/ac			Treatment cost	Gross income per acre above control treatment		
Treatment	1982-83	1983-84	1984-85		1982-83	1982-84	1982-85
lb/ac		$/ac		$/ac		$/ac	
Control	50.28	47.71	69.65	.00	.00	.00	.00
40N	64.64	52.61	59.18	16.80	-2.44	2.46	-8.00
80N	77.97	50.72	58.43	29.00	-1.31	1.71	-9.51
40N30P33S	104.28	77.02	74.25	31.90	22.10	51.41	56.01
80N30P33S	120.67	51.31	75.29	44.10	26.29	29.89	35.54
30P33S	53.80	46.07	61.39	15.00	-11.48	-13.12	-21.38
60P66S	72.23	66.51	98.45	25.45	-3.50	15.30	44.10

Note: Actual costs of fertilizers were used, plus $4.25/ac application costs ($8.50 for the NPS treatments), and interest charges at 12% for eight months. Gross income was calculated as - (No. head sold x sale wt x sale price) - (No. head purchased x purchase wt x purchase price), using prices for the dates of entry and removal from the Cottonwood Sale Yard as reported in the USDA Livestock Market News.

Another interesting response to the qualitatively different fertilizer treatments was the difference between the two-year and three-year summations for the NPS treatments on the one hand and the higher PS level on the other. We could hypothesize that the combination of a) an existing legume population producing marginally with b) a sufficiently large adjustment to soil phosphorus-sulfur status resulted in a true "enabling improvement," the positive results of which could continue for some additional years.

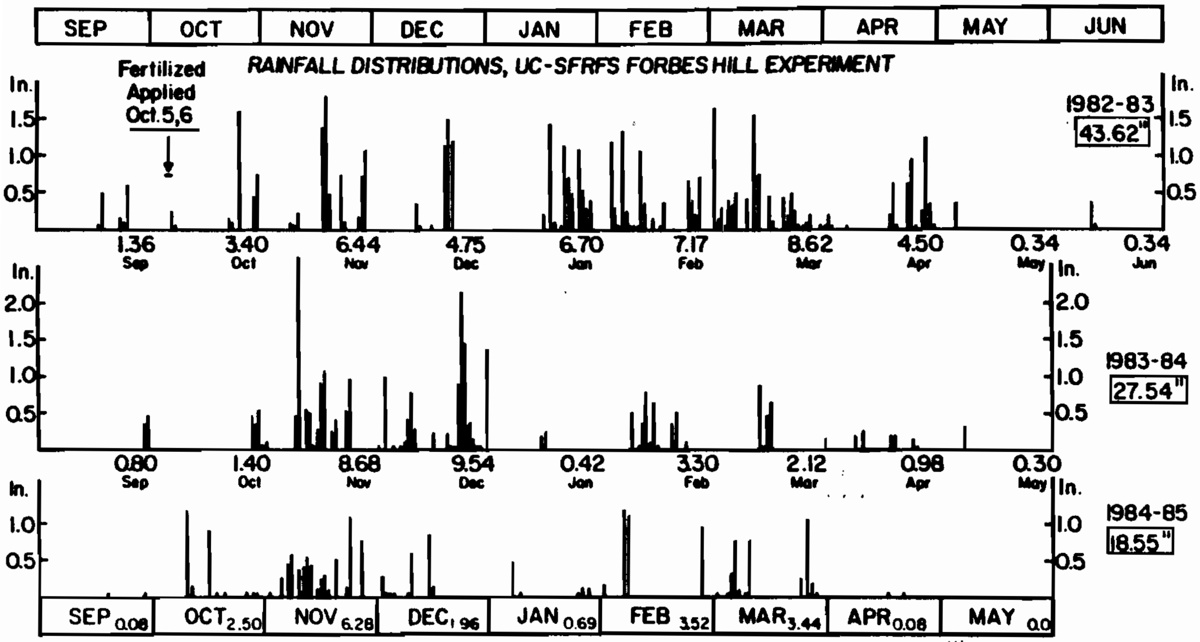

Fig. 1. Intraseasonal distribution of rainfall during the three years of the UC-SFRFS Forbes Hill experiment.

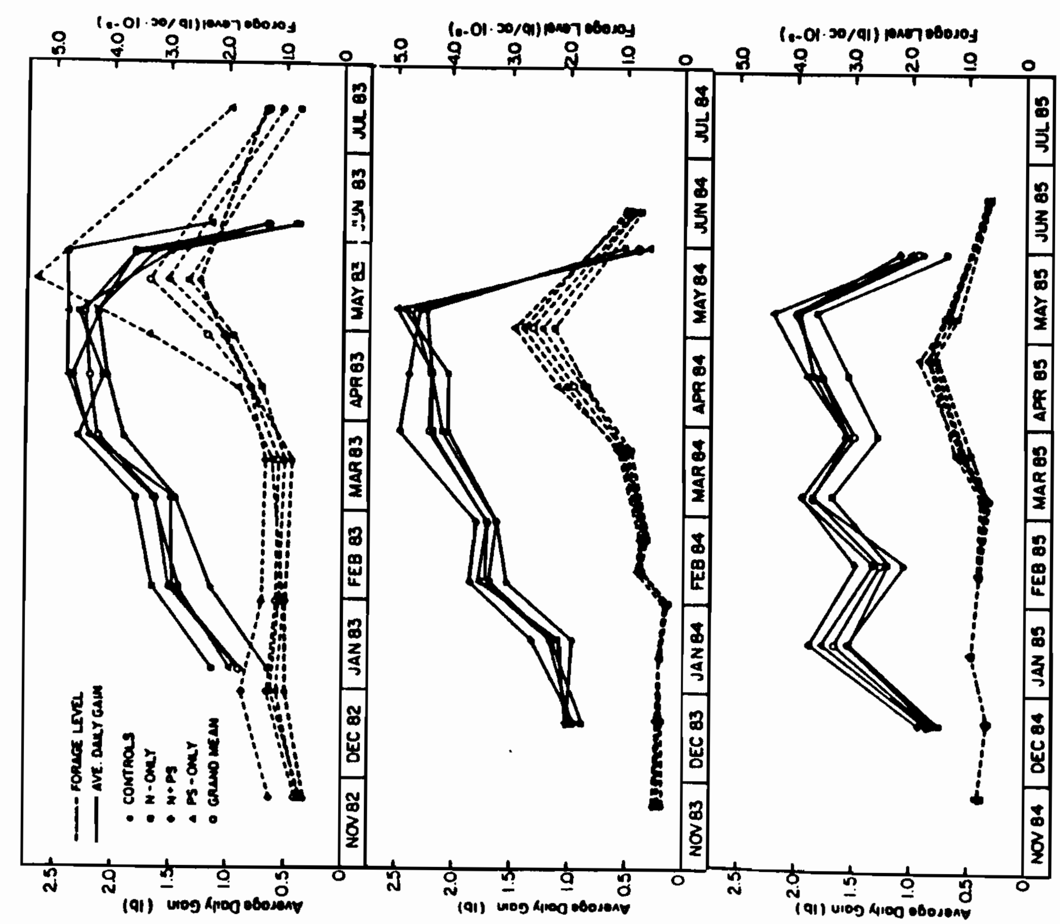

Fig. 2. Intraseasonal variations in stocker animal average daily gains and available forage for controls and three categories of fertilizer treatments during three years of the UC-SFRFS Forbes Hill experiment.

Phosphorus Transformations in Flooded-Drained Soils

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Upland crops grown on soils that have been under anoxic conditions, even for short periods of time, often show poor growth and respond markedly to phosphate (P) fertilization. Phosphorus deficiency is not usually a problem prior to waterlogging but after flooding and drainage severe P deficiencies can develop. Studies in California during the 1970's have shown that the flooding-induced P deficiency problem could be effectively and economically corrected by band-placement of P fertilizers. Similar observations have been made in other areas where it was observed that 2-4 days of flooding, followed by draining, was sufficient time to immobilize native as well as fertilizer P. In California research, Brandon and Mikkelsen (1979) showed that P fertilizers banded 3 cm deep directly below seed of wheat and barley produced significantly higher grain yields than broadcast-incorporated P. Banded-P affected greater P uptake by the crops and increased P availability relative to broadcast or broadcast-incorporated P. The relative efficiency of P sources and methods were banded MAP > banded TSP > broadcast-incorporated TSP. In recent experiments (Unpublished, Mikkelsen, 1984) P banded on corn increased yields by 48% over P broadcast-incorporated and safflower yields were increased by 30%. These P responses are consistent with yield increases observed in a wide variety of California soils examined in pot experiments.

When soils are flooded redox potentials decline, soil pH tends to approach neutrally and pCO_2 increases leading to higher solubility and availability of soil P. The reactions involved in this change in availability are (1) a reduction of ferric-phosphate (Fe-P) to the more soluble ferrous form (2) hydrolysis of iron and aluminum phosphates (Al-P) which occur as soil pH increases and (3) greater dissolution of calcium phosphate (Ca-P) because of higher CO_2 pressure in the soil. The most affected Fe-P, Al-P and Ca-P minerals are strengite, variscite and fluorapatite, respectively. During flooding, strengite is transformed primarily to vivianite with the release of hydrated oxides of Fe and Al. Anaerobiosis also results in the reduction of Fe (+3) iron to Fe (+2) and brings more iron into solution. Upon soil drainage, the transformations of phosphate minerals and Fe occurs in the reverse direction. Thus Fe(+2) is reoxidized and precipitales as oxides or hydroxides of Fe(+3). The soil reoxidation occurs so rapidly that crystalline minerals do not form immediately. The result is the precipitation of amorphous Fe-gels which have a large surface area capable of sorbing large quantities of soluble P.

In addition to soil flooding and draining, which has a very profound effect on P availability to crops, other factors such as soil organic matter content, soil pH, soil temperature and drainage time after flooding also affects the soil P status.

The research work to be presented was undertaken to obtain information on P transformations and immobilization in soils, namely:

1) The nature of P transformations in soil during soil flooding (conditions analogous to rice culture) and subsequent draining periods;
2) The effects of temperature on P availability and sorption;
3) The effects of time after soil drainage on sorption and bioavailability of P;
4) The effects of anaerobic decomposition of organic matter on transformations and sorption of P;
5) The effects of pH adjustment during flooding on transformations and sorption of P.

<u>Summary</u>

The transformations of inorganic P fractions in soil during flooding or drainage periods depend on the chemical characteristics of the soil. Soils inherently high in total inorganic P generally show higher magnitudes of P transformations than soils low in total inorganic P. There is a general decrease in the Al-P fraction during flooding (Table 1) due to its transformation into Fe-P (vivianite).

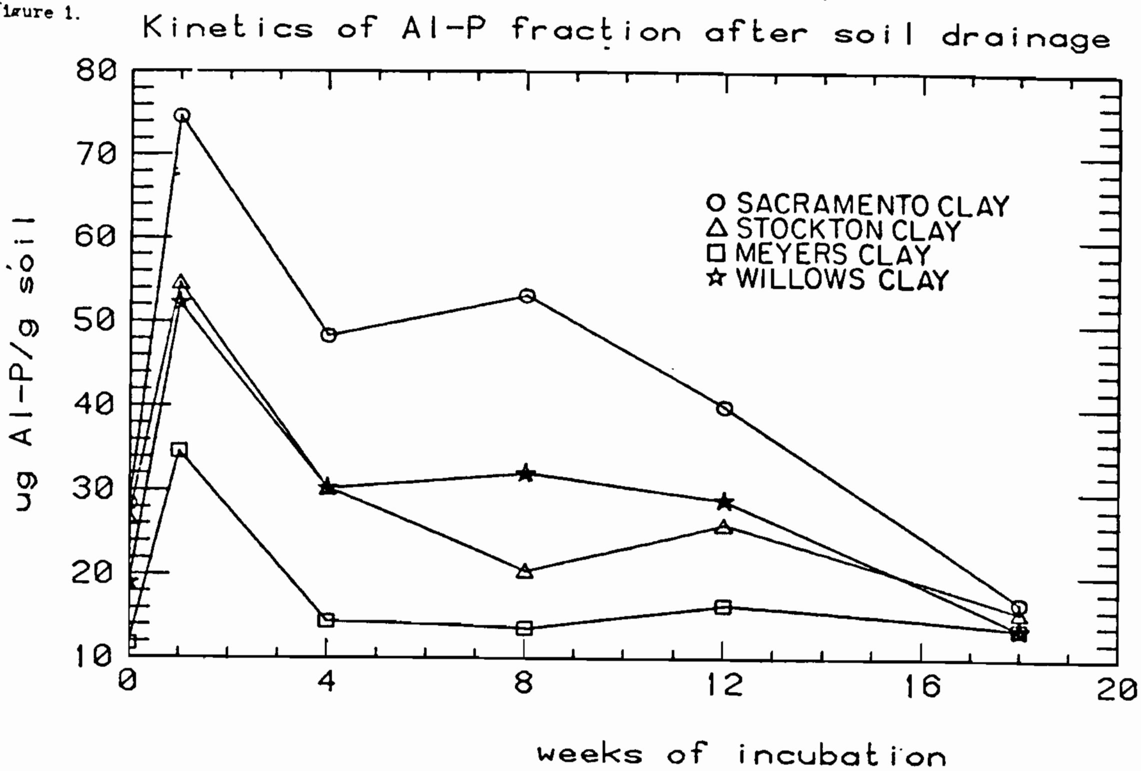
During the drainage period of flooded soils, Al-P increases initially at the expense of other P fractions probably due to rapid adsorption on precipitating aluminum oxides. During later periods, however, Al-P fraction decreases with time after drainage (Fig. 1). During the reoxidation of soil, the stability of strengite is greater than the stability of variscite. This favors the precipitation of P as Fe-P rather than Al-P.

Table 1

Effects of 16 weeks of soil flooding on Al-P fraction in soil

Soil	Al-P fraction (ppm)		
	Before flooding	After flooding	% decrease
1. Sacramento Cl.	59.0	28.3	208
2. Stockton Cl.	44.9	26.6	169
3. Meyers Cl.	36.6	11.7	313
4. Willows Cl.	54.2	18.9	287

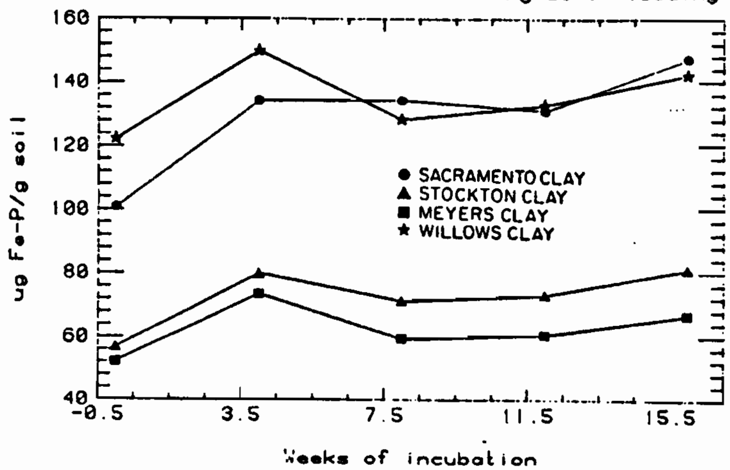
Figure 1.



During the flooding period, the Fe-P fraction generally increases. The largest increase in Fe-P is usually during the initial 4-8 weeks of flooding (Fig. 2). The increase in Fe-P is primarily due to transformation of variscite (Al-P) into vivianite (Fe-P) (Lindsay, 1979) and the release of occluded P (Mahapatra and Patrick, 1969). During drainage period of soil, the Fe-P fraction generally decreases during the first week as compared to a peak attained during flooding. After the initial first week of drainage, however, Fe-P is not much changed.

The changes in Ca-P fraction during flooding is generally not consistent in all soils. In some soils it increases while in others it may not change. During the drainage period of soil, Ca-P fraction consistently shows no change. Transformations in the RS-P fraction in soil during flooding or drainage periods also depends on soil type.

Figure 2. Kinetics of Fe-P fraction during soil flooding



Phosphorus applied to flooded-drained as well as to unflooded soils is recovered mostly in the Al-P and Fe-P fractions. The proportion of added P recovered in flooded-drained soils, however, has a dominant proportion of Fe-P whereas that recovered in unflooded soils has a dominant proportion of Al-P fraction (Table 2). This suggests that the reactivity of Fe in soil increases due to flooded-drained conditions.

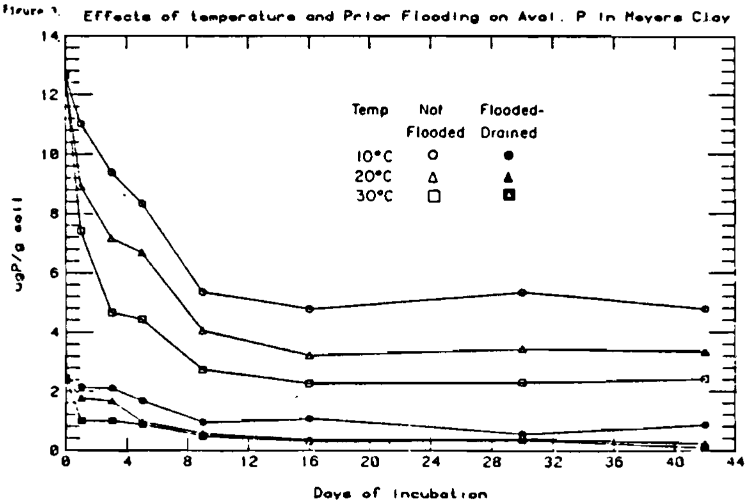
Table 2

Recovery of 100 ppm applied P

	% recovery as Al-P		% recovery as Fe-P	
Soils	Flooded-drained	Unflooded	Flooded-drained	Unflooded
Sacramento cl.	44.2	51.2	45.6	16.1
Stockton cl.	34.4	41.5	41.5	36.2
Meyers cl.	34.4	42.4	53.4	12.9

The soil solution P concentration, as extracted by .01M $CaCl_2$ in P amended soil, decreases with time of incubation, prior flooding and increasing temperature. Between 1 and 9 days, the soil solution P follows first order kinetics. At about 9 days, the soil solution P concentration attains an equilibrium value and maintains this value during later time. The soil solution P decreases as temperature of incubation increases. The decrease in soil solution P due to prior flooding is, however, more drastic than the effect of temperature increase over the range of 10°C to 30°C (Fig. 3). The activation energy calculated from an Arrhenius plot is 8.9 to 34.5 KJ per mole depending on soil types.

Figure 3. Effects of temperature and Prior Flooding on Aval. P in Meyers Clay



Phosphate adsorption in flooded-drained, as well as unflooded soils increases with temperature. The increased phosphate adsorption with increasing temperature explains the decrease in soil solution P with temperature. Effects of prior flooding are very drastic on increasing P adsorption. At any temperature, phosphate adsorption in flooded-drained soil is much higher than nonflooded soil (Fig. 4). The bonding energy of adsorption, calculated from the Langmuir isotherm increases in near linearity as temperature increases (Fig. 5). The apparent heat of adsorption reaction for flooded-drained soils is 0.146 KJ per mole against 0.178 KJ per mole for unflooded soil.

Figure 4.

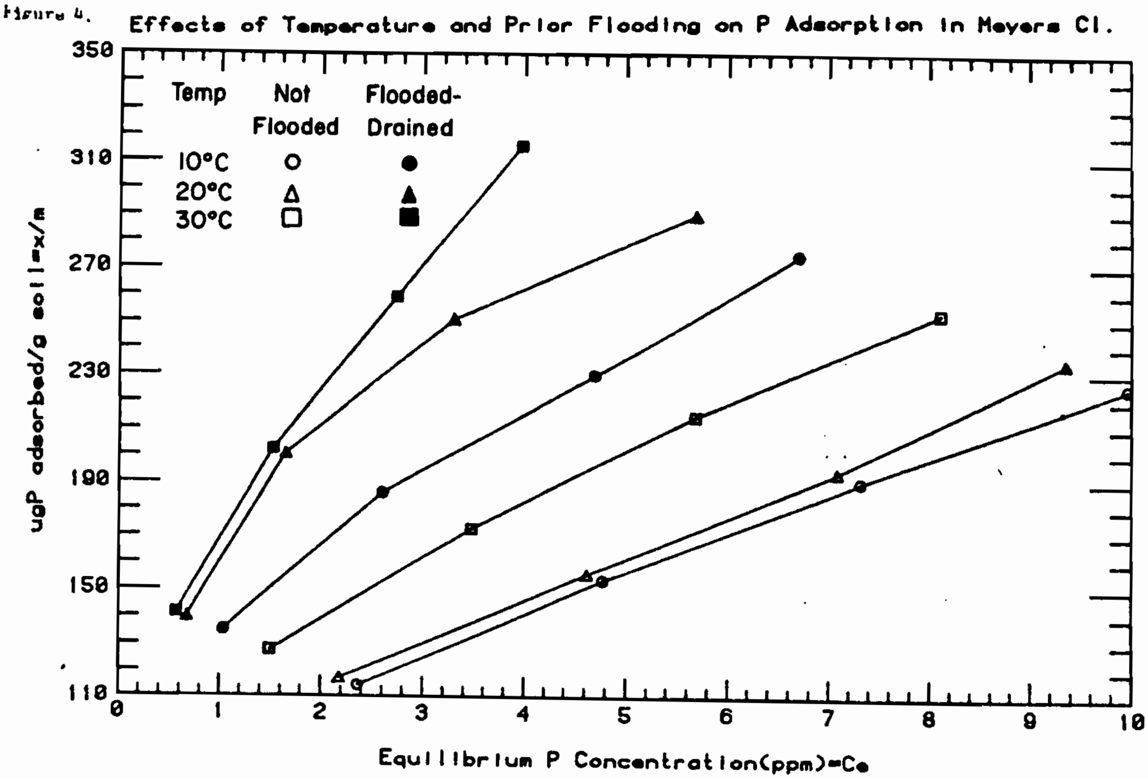
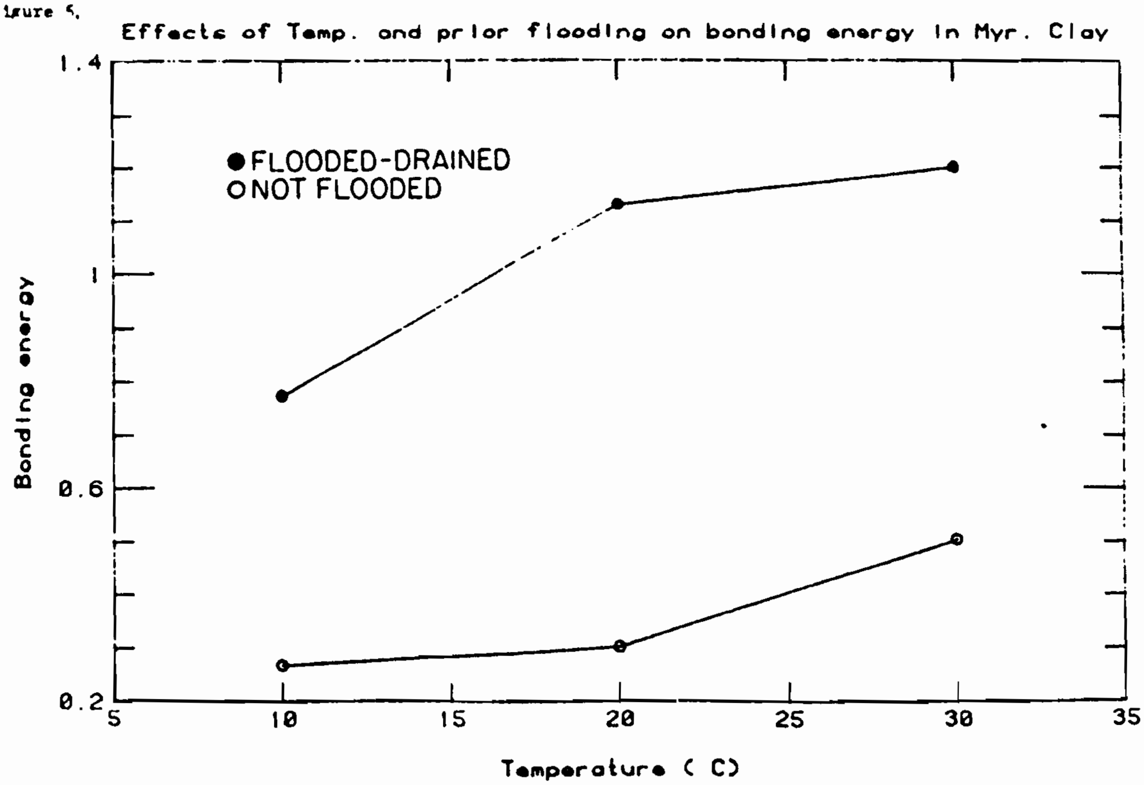


Figure 5.



Phosphate adsorption studies as well as short term bioassay experiments suggest that there is a tendency for P adsorption in soil to decrease and for bioavailability of P to increase after about 4-4.5 months of draining. The 4-4.5 months period is, however, not enough to re-establish the status of adsorption and bioavailability of P existing in soil prior to soil flooding. There is a decrease in bonding energy of adsorption with time after drainage of soil (Table 3) and therefore fertilizer response should increase with time. The response of wheat to P suggests that fertilization can correct P deficiency problems in rice rotation crops.

Table 3

Effects of period after drainage on Langmiur Constant b for bonding energy of adsorption

Soil	Constant b (μg P/ml) Days after drainage 15 days	199 days	Not flooded
Sacramento cl.	10.8	3.2	1.4
Stockton cl.	20.3	16.1	5.2
Meyers cl.	1.13	0.82	0.3
Willows cl.	2.86	2.42	0.83

The effects of pH adjustment during flooding of soil on P adsorption in drained soil is not consistent in the soils tested. An input of organic matter (cellulose) during flooding, however, invariably increases the P adsorption in drained soils very significantly. Due to anaerobic decomposition of organic matter, P transformations in soil lead to an increase in Fe-P and RS-P and decrease in Al-P fractions in drained soil (Table 4).

The extraction of soil with 0.2 M ammonium oxalate at pH 3.0 virtually negates any difference in P sorption in soil caused by soil flooding and anerobic decomposition of organic matter. The 0.2 M ammonium oxalate solution at pH 3.0 extracts amorphous iron selectively. This suggests that the increased P sorption sites (causing increased P adsorption) caused by the anaerobic decomposition of organic matter are associated mostly with amorphous iron. This hypothesis is further supported by the fact that oxalate extractable iron in flooded-drained soils increases as the input of organic matter in soil during soil flooding increases.

Table 4

Effects of Anaerobic Decomposition of Organic Matter On Transformations of Inorganic Soil-P in Drained Soil

	LEVEL OF O.M	INORGANIC P FRACTIONS (ppm)			
		Al-P	Fe-P	Ca-P	RS-P
Sacramento	0%	76.7	135.8	208.6	102.7
	0.5%	74.0	142.6	203.7	105.9
	1.0%	65.0	141.7	206.8	135.2
Stockton Clay	0%	48.7	72.4	13.5	63.7
	0.5%	39.7	80.8	14.4	107.5
	1.0%	37.0	79.1	14.4	138.4
Meyers Clay	0%	37.9	64.9	84.0	127.0
	0.5%	27.6	72.4	85.9	143.3
	1.0%	21.7	72.4	85.0	140.0
Willows	0%	62.4	123.0	136.5	19.20
	0.5%	43.3	143.5	159.2	229.4
	1.0%	36.1	151.0	153.7	235.9

In flooded-drained soils, it is mostly the Al-P and Fe-P and in some cases Ca-P, and RS-P that undergoes transformation. As a result of flooded-drained conditions, P sorption capacity of soils increases causing a decrease in soil solution P concentration. The efficiency of added P in flooded-drained soils is greatly decreased due to increased P sorption and higher bonding energy of adsorption. Low temperature after rice harvest does not seem to be involved in phosphate reversion process. The input of organic matter during flooding does intensify this phenomenon. However, the severity of the P deficiency problem gradually decreases with a minimum threshold time of about 4-4.5 months after soil reoxidation. Satisfactory crop production can be achieved with P fertilization, but the amount will be more than required on unflooded-drained soils.

CEREAL FERTILIZATION IN THE SACRAMENTO VALLEY

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The fertilization of cereals (wheat and barley) is not a simple technique in the Sacramento Valley because it can be significantly influenced by several factors. These factors can have a significant effect on the amounts of fertilizer nutrients which can be effectively utilized. The main factors which prevent a cook book fertilization program for cereals in the Sacramento Valley are: Diseases, particularly septoria tritici of wheat and scald and net blotch of barley; lodging; sterilization of pollen by spring frosts; weeds; and moisture supply. Weeds and moisture supply under irrigated conditions can be controlled; however, they need to be considered when making fertilizer recommendations.

The main fertilizer element needed for cereal production in the Sacramento Valley is nitrogen. The rates used generally range from 60 to 180 kg/ha. A review of the record wheat yields obtained in Yolo County Cooperative Extension trials show that the record yield of 9,480 kg/ha of Phoenix wheat was obtained with 164 kg/ha of nitrogen following a fallow soil condition in a high water table area. The second highest yielding was 9,340 kg/ha of Yolo wheat with 68 kg/ha of nitrogen following tomatoes with one irrigation. One of the main problems with nitrogen fertilization in the Sacramento Valley is efficiency. High rainfall early in the growing season combined with soils high in clay content often produces poor efficiency from early nitrogen applications. The loss of early nitrogen is attributed to denitrification and leaching. To overcome this problem, many growers use split applications applying a portion of the nitrogen before or at planting and the remainder topdressed. The disadvantages of topdress applications are the uncertainty of rainfall after application and the stimulation of grassy weeds if present. The proper timing for topdress application is between tillering and stem elongation. High or excessive nitrogen can increase lodging and increase the severity of leaf diseases.

The second most important fertilizer element for cereal production in the Sacramento Valley is phosphorus. The initial need for phosphorus is best determined by a soil test. The critical value for wheat and barley is 12 ppm using the sodium bicarbonate method. The recommended phosphorus rates in a deficient situation are 6 to 28 kg/ha. Phosphorus should be banded with or near the seed for the maximum efficiency.

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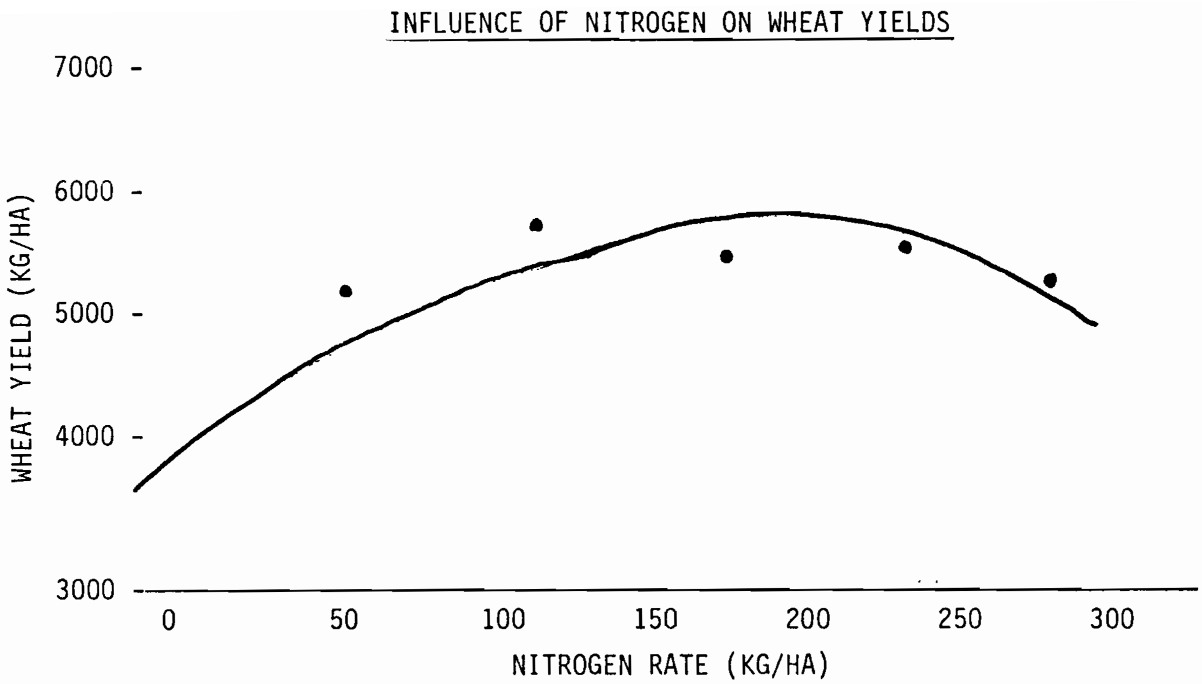
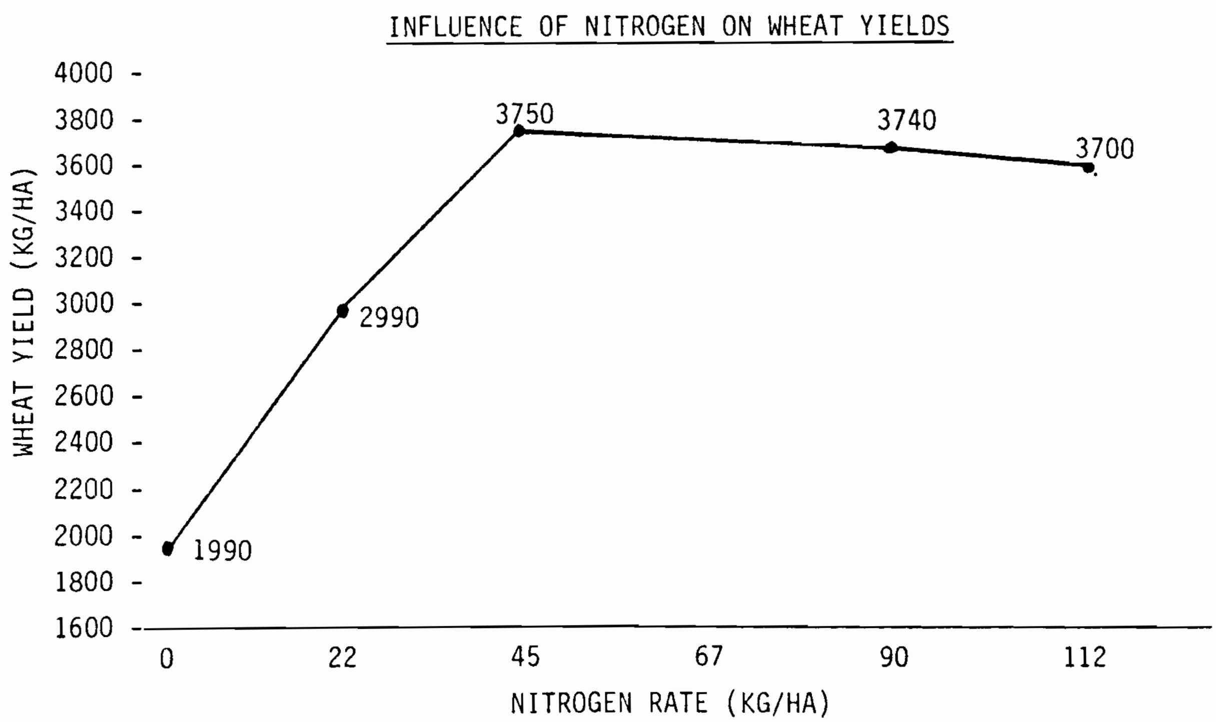


LSD @ 5% = 289 kg/ha
CV% = 4%

Figure 1 - Relationship between nitrogen fertilization rate and the yield of INIA 66 wheat following oat hay on Class I soil. Yolo County. Each point is the average of four replications.



LSD @ 5% = 504 kg/ha
CV% = 11%

Figure 2 - Relationship between nitrogen topdress fertilization rate and the yield of Anza wheat on Class II soil. Yolo County. Each point is the average of four replications.

INFLUENCE OF PHOSPHORUS ON WHEAT YIELDS
IRRIGATED SOILS

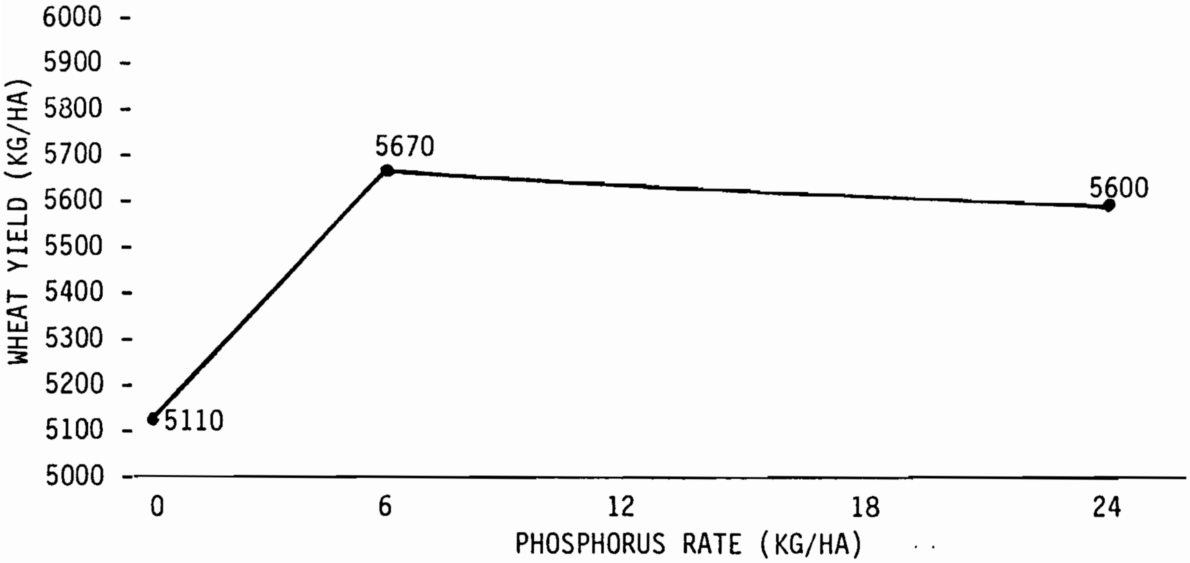


Figure 3 - Relationship between phosphorus fertilization rate and wheat yields on irrigated soils in Yolo County. Average of two trials. Each point is average of eight replications. Average soil test 13.6 ppm phosphorus.

INFLUENCE OF PHOSPHORUS ON WHEAT YIELDS
DRYLAND SOILS

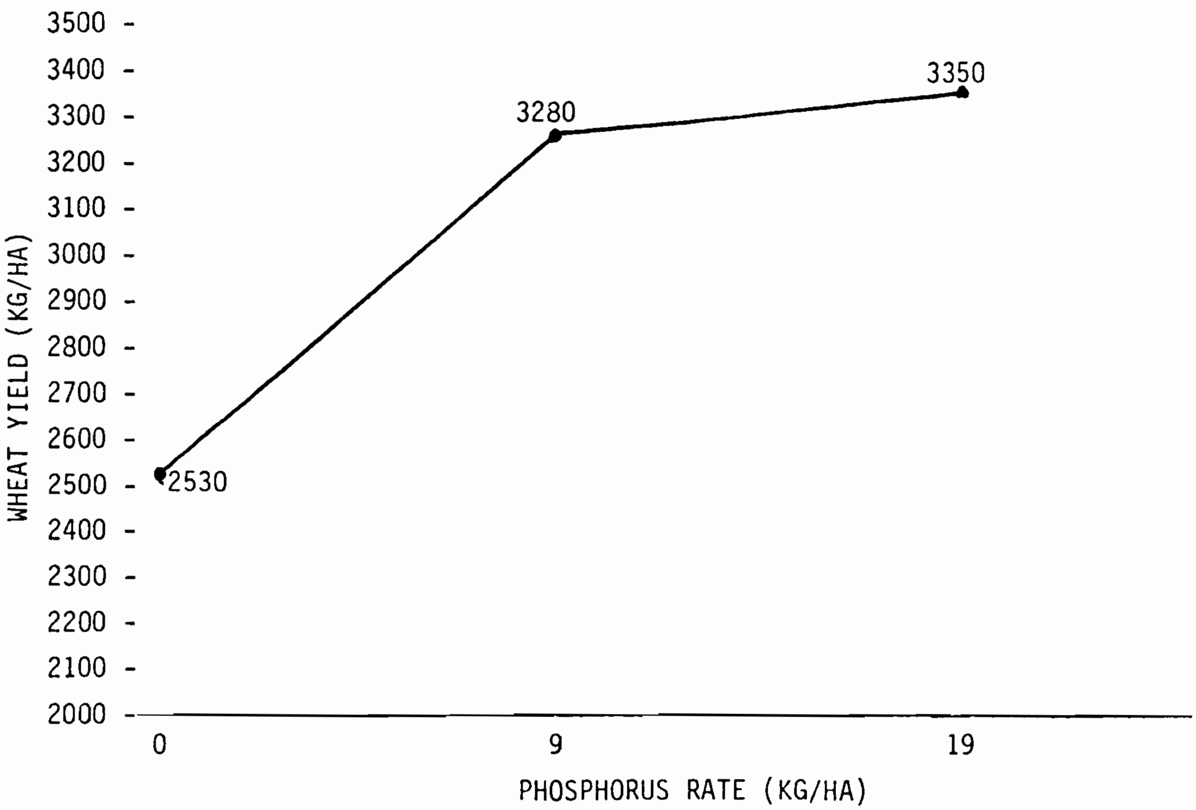


Figure 4 - Relationship between phosphorus fertilization rate and wheat yields on dryland soils in Yolo County. Average of eight trials. Each point is average of 32 replications. Average soil test 10.2 ppm phosphorus.

UREASE ACTIVITY AND UREA TRANSFORMATIONS DURING GROWTH OF A RICE CROP

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Nearly all soils contain urease activity; consequently, applications of urea as fertilizer are quickly converted to ammonium carbonate, which in turn can release ammonia and carbon dioxide into the atmosphere. Although urea is not a major source of N for rice in California, it is very important on a world scale. Since urease activity may contribute to losses of N by ammonia volatilization where urea is applied on rice, information is needed on levels of urease activity in rice soils, the distribution of such activity in the soil and floodwater, and how it is affected by environmental factors such as soil temperature. The sources of urease in soils are microorganisms, plant roots, and residues of plant material left on or in the soil after the crop is harvested. Most soil urease is bound to the clay and organic colloids which are present. The bound urease appears to be more stable, more resistant to adverse environmental conditions, and less susceptible to microbial attack than is free urease.

A simple method for estimating urease activity in soils is to add a known amount of urea to the soil and then measure the quantity of ammonia which is formed over a given period of time, usually not more than a few hours. If three or more different concentrations of urea are added to soil, measurement of urease activity at each concentration permits estimation of two useful parameters, K_m and V_{max}. A plot of rate of ammonia formation against concentration of urea added produces a hyperbolic curve with its y-asymptote equal to V_{max}, corresponding to the urea hydrolysis rate when all the urease is in the form of a reactive urea-urease complex. The constant K_m is equal to the urea concentration at the point where the urea hydrolysis rate is half of V_{max}. It is also a measure of the affinity of urease for urea.

Data from experiments to determine the effect of temperature on urease activity in Meyers clay are presented in Figure 1, each curve representing values obtained from four replications, each receiving seven different concentrations of urea. Table 1 gives rates of urea hydrolysis at 25^{o} and 35^{o} C at two depths

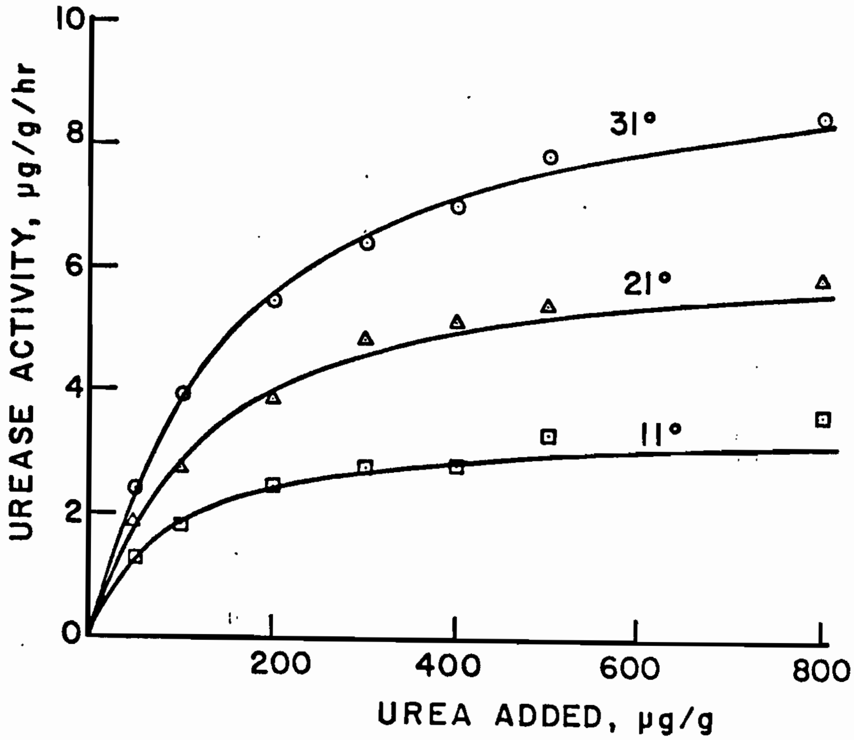

Figure 1. Effect of temperature on urease activity in Meyers clay.

Table 1. Urease activity in Meyers clay at two temperatures and two depths.

Temperature	Depth 0-5 cm	Depth 5-10 cm
	μg/g/hr	
25° C	4.24	4.44
35° C	6.15	6.54
Q_{10}	1.45	1.47

in this soil. The mean 10° temperature coefficient was 1.46. No differences in urease activity between the 0-5 and 5-10 cm depths were observed in this experiment. A comparison of urease activity in previously air-dry Meyers clay with that in saturated soil (Table 2) showed that there were no significant differences due either to moisture content or sample depth.

Table 2. Influence of rice plants on urease activity in Meyers clay.

	Weeks 1	2	3	4
		μg/g/hr		
Unplanted	1.99	0.828	2.08	2.29
Planted	1.90	1.88	2.06	2.04
F-value for plant differences	.044	28.4***	.004	1.41
100 ppm urea	1.69	0.707	1.56	1.66
500 ppm urea	2.20	2.00	2.57	2.68
F-value for urea levels	1.21	43.0***	9.26*	24.3***

In a greenhouse pot experiment an attempt was made to measure the effect of rice roots on levels of urease activity. Determination of urease activities in unplanted and planted pots were made 1,2, 3 and 4 weeks after flooding. Data presented in Table 2 show that statistically significant differences due to the presence of plants were observed only at the 2-week sampling date, when urease activity in the unplanted pots had dropped to a rather low level. Obtaining a representative soil sample from the planted pots was difficult owing to non-uniform distribution of rice roots throughout the soil mass. On the other hand, significant differences in urease activity at the two levels of urea application were found at all except the 1-week sampling date.

Preliminary data from a field experiment on Sacramento clay after application of 90 kg urea-N per hectare broadcast on the surface and then incorporated showed urease activity equivalent to 11.1 μg/g soil/hr in the 0-5 cm layer at a 500 ppm level of urea addition. By contrast, urease in the 5-11.5 cm layer of soil was negligible. Urease activity in the floodwater of this soil was 20.4 μg/l/hr. On an equivalent weight basis, urease activity in the surface soil was 544 times as great as that of the floodwater.

MYCORRHIZAE, AGENTS OF NUTRIENT EXCHANGE BETWEEN PLANT AND SOIL

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Most plants form symbiotic associations with vesicular-arbuscular mycorrhizal (VAM) fungi which colonize plant roots (mycorrhiza = fungus root). External fungal hyphae reach soil microsites outside the rhizosphere and extend the depletion zone for immobile nutrients around the root. By making these nutrients available to the host plant, VAM fungi can enhance plant growth dramatically in nutritionally marginal soils (1). Perhaps for this reason, VAM research has focussed in the past on P-nutrition effects. More recent work shows that VAM fungi are involved in virtually all aspects of interchange between plant and soil (2). This interchange, a stabilizing factor in the plant-soil system, attains additional significance in direct proportion to the degree of fragility of the ecosystem under consideration (3). Fragility is influenced by stress, as exemplified by the condition of semidesert grasslands in North America, where frequent drought and continual abuse by man has resulted in accelerated soil erosion, brush invasion and reduced forage production (4).

Effects of the VAM symbiosis in reacting to and counteracting stresses in semi-arid grasslands under grazing stress are complex (3). As obligate symbionts, VAM fungi are directly affected by the ability of their host plants to supply them with photosynthetically fixed carbon. If adversely affected by overgrazing (5), deterioration of the fungal component of the mycorrhiza may trigger a little-understood chain of reactions. These reactions are based on the dual function of the fungus as a pipeline for mineral nutrients to its host plant and as a conduit of carbon from the host to the soil (6,7). This latter function is perhaps the least understood (8), and involves an exchange of nutrients by VAM fungi and the soil biota (7). There is increasing evidence that the products of this exchange are instrumental in stabilizing soil by aggregate formation (9). Soil structure influences water-holding capacity and moisture availability. The interaction between the availability of water and phosphorus involves VAM fungi in the uptake of both (10). While an alleviation of drought stress in the presence of VAM fungi has been attributed to the effect of soil moisture on P diffusion in the soil (10), evidence is emerging that VAM fungi may be able to utilize soil water not available to the non-VAM plant (11), and that the amount of this water is proportional to plant growth enhancement by VAM fungi (12).

Cultural stress (e.g. grazing) may have effects on the plant-microbe-soil association that are not immediately obvious. It is conceivable that critical threshold levels of utilization may be exceeded, even under careful management, if key interactions between the biotic and abiotic components of the system are not fully understood and considered. If the system is subject to stress not under control (e.g. drought) as well, the effects of cultural stress will be aggravated. Arid and semi-arid lands occupy a substantial portion of the North American continent. Since much of the land available for agricultural expansion (or rehabilitation) falls into this category, there has been increasing interest in understanding and identifying mechanisms that have evolved to enable plants to cope with these stresses (13). The mycorrhizal plant symbiosis is such a mechanism. We suggest that the use of VAM fungi may be developed as a technology to improve water utilization practices and to help reduce catastrophic losses of topsoil in agricultural lands.

In order to develop the technology for the use of VAM fungi in soil conservation efforts, many little-known aspects of the physiology and ecophysiology of VAM fungi and of the symbiotic VAM association must be elucidated. Adaptation to soil types, host-endophyte preference, source-sink relationships among symbiotic partners within the association and between the association and the soil, and axenic culture of VAM fungi for commercial production of inoculum are research aspects which need to be addressed in detail before VAM fungi can become a useful tool in the service of agriculture on a large scale.

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PERFORMANCE OF RHIZOBIA UNDER ADVERSE SOIL CONDITIONS

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"Performance" of rhizobia entails several things: survival, growth and colonization in soil, invasion of the host plant's rhizosphere, infection, nodulation, and efficient, vigorous nitrogen fixation within the nodules. The ability of a rhizobial strain to fulfill each of these functions under stress depends on properties of the organism -- its sensitivity or tolerance. But it also depends on properties of the host legume. Indeed, the host plant's stress sensitivity frequently limits nodulation and nitrogen fixation regardless of rhizobial tolerance. Thus nitrogen fixation failure under stress can result from sensitivity of the rhizobia as free agents in the bulk soil or the rhizosphere, or from the plant's inability to maintain the growth that ultimately controls fixation. And sometimes the symbiotic system of the nodule is more sensitive than either the plant or microbe individually.

These alternatives are sometimes difficult to distinguish, but the following observations can help. If the stress makes the plant N-deficient, i.e., yellow and responsive to ammonium or nitrate, the stress is limiting rhizobial growth or survival, nodulation, or nodule function. If the plants have no nodules, failure of rhizobial growth or infection is suspect. If the plants, though N-deficient, have root nodules, impairment of nodule effectiveness is suspect. If the plants, though stunted, are green and not N-responsive, the critical sensitivity is in the plant.

My students and I have done research on effects of salt, P deficiency, heat, and acidity. I will outline the findings.

Soil Salinity

Almost all rhizobia grow well at salt concentrations (100-200 mM) that severely damage most legumes. Small effects of salinity on nodule formation have been observed in a few species (soybean, chickpea, tropical pasture legumes) but not in others (alfalfa, mesquite, leucaena) (12, 13, 21). Evidently a major limiter on rhizobial performance in saline soils is the salt-sensitivity of the legume (12, 13, 21, 22). Some useful legumes have considerable tolerance (e.g., alfalfa) but many are among the most sensitive (e.g., common bean, chickpea). Varietal differences in tolerance of salts in soybean and chickpea have been shown to exist but not shown to be agronomically valuable (12, 21).

Phosphate

Despite extensive agronomic research on the phosphate fertilization of legumes, the phosphate nutrition of rhizobia has been neglected until recently. We now know that most tested strains of rhizobia grow well if phosphate concentrations of only 0.05 to 0.5 μM are maintained in solution (2, 5). Even in P-deficient soils such low concentrations would occur only in the rhizosphere, a major habitat of rhizobia. The literature contains no clear indication of adverse effects of P-deficiency on nodulation or nitrogen nutrition of a legume, other than secondary effects resulting from reduction of growth of the plant.

A few rhizobial strains have been found less P-efficient than the majority (2). As inoculants in pot trials in soil they have performed poorly. But this poor performance might not be due to their high P requirement; it is not clearly improved by additional phosphate fertilizer.

Given luxury (millimolar) phosphate levels, as in plant cells and most microbiological media, rhizobia accumulate P up to 2-3% of their dry weight, much of it deposited in intracellular granules of polyphosphate (4). Most rhizobia can mobilize this stored P to support a few generations of growth when deprived of external P supply (2).

Rhizobia seem excellently adapted to a wide range of external P levels including the lowest concentrations likely to exist in soil-plant systems. Phosphorus deficiency frequently limits rhizobial performance, but the effect, like that of salt, operates mainly through inhibition of growth of the host plant.

High Soil Temperature

In greenhouse and growth chamber experiments heating of the root system is a potent inhibitor of nitrogen fixation in many legumes. They vary in sensitivity; for example, cowpea and soybean are less sensitive than common bean and alfalfa, whose performance falls off sharply at temperatures above

30C. Symbiotic nitrogen fixation is reduced at temperatures that do not harm the independent growth of either the plant or the rhizobia. Depending on conditions and genotypes, high temperature inhibits either nodule formation or nodule function, in both cases inducing responsiveness to ammonium or nitrate as well as other symptoms of N deficiency (16, 20).

In the field, soil temperature limits nitrogen fixation less severely than research in growth chambers and greenhouses would indicate, because of spatial variations in nodule distribution and soil temperature. In field experiments, alfalfa did not become N-responsive even when surface soil temperatures reached 45C for several hours a day, because the nodules were placed mostly at 5-20 cm depth, where temperatures remained close to an ideal 27C (16). Trials with common bean in the last two seasons confirm this story. The relative N accumulation (ratio of N uptake in symbiotic plants to N in nitrate-treated controls) was the same in a cool summer as in a hot summer, did not change when selected heat tolerant strains were used as inoculants, and was not affected by mulching treatments that moderated soil temperature. The mulching treatments did affect nodule distribution: plants without mulch developed few nodules in the topmost few centimeters of soil, more nodules further down (20).

Soil Acidity

Symbiotic nitrogen fixation commonly fails in acid soils either because the rhizobia grow too slowly or because they fail to infect. Rhizobial screening for ability to grow in appropriate acid media is easy (1), and helps identify tolerant inoculant strains (6, 7, 15). Confirmatory tests of performance on the plant in acid soil are necessary. Some strains are sensitive to low pH itself. Others succumb to the Al toxicity commonly associated with low pH in soil (7, 11). Aluminum at low pH has little effect on the survival of rhizobia, but it slows the rate of cell division and eventually causes division to fail, as in plants (18). Tolerance of acid-Al conditions varies within all major groups of rhizobia, and a strain's tolerance is a stable property (18). Tolerance associates loosely with a strain's tendency to produce extracellular polysaccharides, suggesting that these reactive gelatinous materials help the microbe to protect itself by modifying its immediate microenvironment (8, 9).

Many legumes fail to nodulate or grow well at low (submillimolar) Ca concentrations, but this is true of few rhizobia except those of the alfalfa/medic group, which need high Ca when grown with low concentrations of phosphate such as are found in soil solutions (3). The latter finding resolves controversy over the Ca requirements of this rhizobial group.

Soil acidity usually makes symbiotic legumes poorly nodulated, yellow, and N-responsive, as would be expected when it interferes with rhizosphere colonization and nodule initiation. In such cases, tolerant rhizobia are helpful up to a point. However, in some important legumes acidity or Al toxicity primarily affect the plant, not the rhizobia. The result, like that of salt or P deficiency, is not stunted yellow plants that respond to N, but stunted green plants that do not respond to N. Several North American soybean cultivars showed this behavior when inoculated with any of several good inoculant strains (17). So did Al-sensitive cultivars of cowpea when grown with selected tolerant rhizobial strains in acid soils (10, 19). This condition, calling for improved tolerance in the host legume rather than in the rhizobia, may become common as more kinds of rhizobia are selected for acid-soil tolerance.

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MICROBIAL PRODUCTION OF BIOREGULATORS IN SOIL

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Although the existence of plant growth regulators (PGRs) has been known for many decades, the role of soil microorganisms in the production of plant hormones is a relatively obscure research field with great potential in influencing crop production. Plant growth regulators are currently being applied in agricultural practice in order to influence plant growth and development by affecting vegetative growth, root/shoot ratios, flower and fruit formation and overall yield. Bacterial inoculation of seeds or roots has led to changes in plant growth, yield alterations and control of some plant pathogens. Experimental results have verified that microorganisms can produce various plant growth regulating substances. Researchers have reported microbial synthesis of auxins, gibberellins, cytokinins, ethylene, abscisic acid, and trisporic acid. The effects of these exogenous hormones on plant growth have been demonstrated. Stimulatory and inhibitory effects have been reported, but clearly the effects depend on the concentrations of exogenous and endogenous hormones, microbial degradation, uptake by the plant, and stage of plant development.

AUXINS

Indole-3-acetic acid (IAA) is considered to be the primary auxin produced by plants and microorganisms. Several pathways for the formation of IAA have been proposed. Thimann (26) was the first to demonstrate that Rhizopus sinuis released indole-3-pyruvic acid (IPyA) giving rise to indole-3-acetaldehyde (IAAld) and IAA. Bentley et al. (7) found that the keto acid is unstable and may transform into indole-3-lactic acid (ILA) and tryptophol (Tol, also known as indole-3-ethanol) under anaerobic conditions. With the use of radioautograms, Magie and his associates (21) reported that both indole-3-acetamide (IAM) and IAA were secondary metabolites of Pseudomonas savastanoi. Chalvignac and Mayaudon (9) reported that soil extracts contained IAM and IAA. Auxins in soil are believed to be produced by autochthonous microflora as they decompose carbonaceous materials. Typical concentrations of auxins in soil have been reported to range from 0.5 to 50 $\mu g\ g^{-1}$ soil (10). Until recently, identification of specific plant growth regulators produced by microorganisms has primarily been accomplished by using partition chromatography followed by a bioassay. The lack of specificity of these bioassays often yields results such as "auxin derivations" or "auxin-like effects". Recently, Frankenberger and Brunner (13) have isolated IPyA, IAM and IAA from soil extracts using reverse phase, ion-pair, high performance liquid chromatography (HPLC) with identification by mass spectrometry.

GIBBERELLINS

Gibberellins (GA's) are a group of phytohormones produced by plants and microorganisms. All gibberellins are tetracyclic diterpenes which differ from one another only by the placement of certain functional groups. Gibberellins regulate numerous physiological processes in plants, including cell division and enlargement of vegetative tissue, budding, flowering, and fruiting.

Certain gibberellins (GA_3, GA_4, and GA_7) are used commercially to promote vegetative growth in crops such as lettuce, celery, sugarcane, and grapes. They are also used to increase fruit size of grapes, to control sex expression in cucumbers, and to prevent rind defects in citrus. Field and greenhouse tests have indicated that GA treatments can enhance the quality or yield of many crops, but the need for high GA concentrations or multiple foliar applications often render it economically unfeasible to use gibberellins on a commercial basis. However, the cost-benefit ratio might be improved through the use of a less expensive method of supplying gibberellin to the plant's active site.

Many soil microorganisms produce gibberellin-like substances in pure culture (3, 27, 29), and inoculation of plant roots with Azotobacter cultures stimulates plant growth responses similar to those elicited by authentic gibberellic acid (GA_3) (6, 8). These results suggest that indigenous microbial populations might synthesize gibberellins in soils under favorable environmental conditions. If gibberellins are produced by the soil microflora *in situ*, it may be possible to increase the gibberellin content of soils by adding a suitable substrate. In order to enhance crop yield economically, microbial conversion of the added substrate must be efficient. In addition, gibberellins present in the soil must be soluble and available to plants; either the gibberellins or their precursors must be sorbed into root vascular tissue.

CYTOKININS

Cytokinins are another major class of phytohormones and are described as N^6-substituted amino purines. More than forty cytokinins have been identified from plant tissues; the most active forms being adenine derivatives. Several biosynthetic pathways have been proposed with adenine as the common major precursor for plant tissues (24), the moss, *Physcomitrella patens* (28) and the fungus *Rhizopogon roseolus* (22). Other precursors of zeatin formation include adenosine monophosphate (AMP), incorporated by the slime mold *Dictyostelium discoideum* and hypoxanthine, 4-amino-5-imidazole carboxamide and 6-(γ,γ,-dimethylallylamino) purine, incorporated by *Rhizopogon roseolus* (22).

Studies on microbial production of cytokinins has primarily been conducted on pathogens causing abnormal plant growth such as Agrobacterium tumefasciens, Corynebacterium fasciens, Pseudomonas savastanoi and Taphrina spp. Little emphasis has been placed on the production, isolation and quantification of cytokinins produced by non-pathogenic bacteria in the rhizosphere of plants. Cytokinin-like compounds have been detected in culture filtrates of rhizobacteria isolated from tree seedlings (25, 12), grasses and vegetables (5, 6), however, no attempt has been made to purify or identify these compounds.

The nonsymbiotic nitrogen fixing bacteria Azotobacter spp. and Azospirillum brasilense have been inoculated onto several plant species resulting in enhanced vegetative growth, flower and fruit formation (5, 6, 8). Similar plant responses were observed by the application of gibberellin (GA_3) and kinetin (synthetic cytokinin) to uninoculated roots suggesting that these changes may be a result of microbial production of plant growth regulators and not entirely due to nitrogen fixation. The stimulation of indigenous microbial populations to produce cytokinins might serve as a mechanism to regulate plant growth for the attainment of optimum yield and crop quality.

ETHYLENE

Ethylene is an olefin gas produced by plants, microorganisms, and free soil enzymes which influences many aspects of growth and development of plants. The regulatory effects of this plant hormone include: fruit ripening, senescence, abscission, breaking of dormancy, regulation of swelling and elongation, hypertrophy, promotion of adventitious roots, modification of root growth, inhibition of root hairs, epinasty, hook closure, inhibition of leaf expansion, exudation and control of flower induction (23). Methionine is believed to be the major precursor for ethylene synthesis in higher plants. Adams and Yang (2) identified 1-aminocyclopropane-1-carboxylic acid (ACC) as an intermediate in the conversion of methionine to ethylene in apple tissue. Data obtained with tracer experiments led them to propose the following pathway for ethylene biosynthesis: methionine --> S-adenosyl-methionine (SAM) --> ACC --> ethylene. This pathway has been confirmed in many other plant tissue extracts (18, 19, 30); however, microbial production of ethylene has yet to be thoroughly investigated. While methionine was determined as the major precursor of ethylene production in higher plants, 2-oxoglutarate and glutamate (11, 15, 17) have been postulated to be substrates for ethylene biosynthesis in fungi. Other substrates utilized by fungi in producing ethylene include glucose, alanine, glycine, aspartic acid, methionine, serine, acrylic acid, propionic acid, glyoxylic acid, acetic acid, citric acid, fumaric acid, pyruvic acid, and succinic acid (1). The immediate precursor of ethylene and its biosynthetic pathway in microorganisms has yet to be established. Preliminary results in our laboratory have shown that ACC added directly to soil promotes C_2H_4 production.

INHIBITORS

Recently it has been reported that the fungus, *Cercospora rosicola* produces abscisic acid (ABA) as a secondary metabolite. Mucoraceous fungi produce trisporic acids during sexual reproduction which are structurally similar to ABA (20). Although trisporic acids have ABA-like activity on seed germination and pea growth, they are fully conjugated molecules and extremely unstable. The breakdown products of trisporic acids are suggested to be responsible for the ABA-like activity (20).

CONCLUSION

Microbial produced plant growth regulators should be recognized in having a potential influence on plant growth and development. Plant response is governed by the rate of hormone uptake, the active concentration of regulators in the rhizosphere and the modification of the plants own pool of growth regulators due to the addition of exogenous supplies. Further studies are needed to investigate factors affecting microbial production of plant growth regulators, their distribution and stability in soil, and their specific sources.

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RELATIONSHIPS BETWEEN IRRIGATION UNIFORMITY AND OPTIMUM WATER MANAGEMENT

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Uniformity of water infiltration is an important factor in irrigation management decisions. Nonuniformity may result from nonuniform water application by sprinkler and drip irrigation systems, or variable intake opportunity time and infiltration rate for surface irrigation. The effect of nonuniformity on yield is the same regardless of the factors causing the nonuniformity.

Irrigation scheduling recommendations based on evapotranspiration (ET) estimates recognize irrigation nonuniformity and usually account for this factor. If water sufficient only to replenish the ET losses were nonuniformily applied; part of the field would be over irrigated resulting in deep percolation, and part of the field would be under irrigated resulting in yield reductions. Because it is normally considered that the loss in revenues from yield loss exceeds the costs for additional water, an amount in excess of ET is recommended. The amount selected is somewhat arbitrary and is almost never quantitatively determined.

The goal of agricultural management is to maximize profits. A trade-off between additional water costs and reduced yields exists in making a water application recommendation under the nonuniform situation posed above. The optimal (profit maximizing) amount of water application can be computed (Letey et al., 1984) if information is known on the a) relationship between yield and amount of uniformly applied water, b) irrigation uniformity distribution over the field, c) price of water, and d) income per unit of yield.

Computed relationships between corn grain yields and average applied water (AW) are presented in figure 1 for various assumed water infiltration uniformities. Christensen's uniformity coefficient (CUC) was determined for each infiltration distribution so that it could be identified by one number. Decreasing values of CUC represent decreasing uniformity of irrigation. Except under low water applications leading to sub-economic yields, production at any AW declines with decreasing infiltration uniformity. For the case that yield loss doesn't occur from water-logging at high water application (the situation depicted in figure 1), increased water application can substitute for

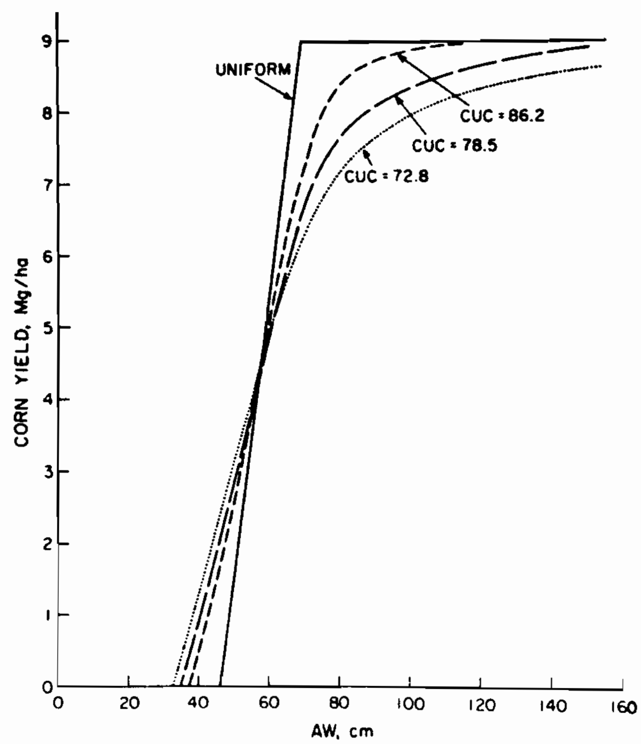

Fig. 1. Relationship between corn grain yield and AW for various levels of infiltration uniformity.

uniformity. In other words, if sufficient water is applied, maximum yields can be achieved even under low uniformities. Note, however, that the slope of the yield versus AW curve decreases an AW increases. The optimal AW is when the monetary return from increased yield equals the cost for the additional water. If water costs are low, considerably higher application rates are optimal for nonuniform when compared to uniform irrigation. Profit losses are incurred by nonuniform irrigation because of a combination of additional water costs and decreased yield. This profit loss represents the upper limit to the costs which could be incurred in upgrading irrigation systems for uniformity.

The discussion thus far has assumed that the farmer does not incur costs from the water percolating below the root-zone other than the purchase price for the additional water. However, if the farm is situated over a shallow water table requiring drainage, additional costs will be imposed by the "excess" water. These costs may be very high depending upon the available options for drainage water disposal.

The relationships among irrigation uniformity, drainage condition, optimal applied water (AW*), and profit (P*) are illustrated by the computed values presented in table 1. The data are for irrigating cotton with nonsaline water and water with EC equal to 3 dS/m under conditions of no drainage requirement and drain water being disposed by an on-farm evaporation pond. The profits are defined here as returns to land and management. Average of the 1971-83 crop prices were used in the analysis.

The AW* and P* values for a given CUC are about the same for both irrigation waters when no drainage is required. Similar results occur when drainage is required if the drainage water can be disposed at no cost to the farmer (not presented in table 1). Profits are significantly reduced when irrigating with water having EC equal to 3 dS/m as compared to nonsaline water

TABLE 1

Optimal applied water (cm) and profit ($/ha) for cotton produced under various conditions.

	CUC	nonsaline water		EC = 3 dS/m	
		no drainage	evap. ponds	no drainage	evap. ponds
AW*	72	140	80	150	80
P*		1256	970	1241	880
AW*	86	100	70	100	80
P*		1333	1201	1321	1094
AW*	100	80	70	90	80
P*		1359	1334	1349	1199

when evaporation ponds are required. In all cases, profits decrease with decreasing uniformity, but the decreases are proportionately much greater when an expense for drainage water is incurred. Over $200- and $300/ha/yr could be justified for upgrading CUC from 72 to 86 and from 72 to 100, respectively when evaporation ponds are required. Approximately one-third of that amount would be justified if drainage had no costs.

Some farmers on the west side of the San Joaquin Valley are presently facing extremely high costs for draiange water disposal. Nonuniformity of irrigation is especially costly to these farmers and optimal irrigation management is significantly different from farmers without a drainage water disposal problem. Indeed, irrigation uniformity becomes the most significant irrigation factor in their operation. Rather large investments in improving irrigation uniformity are justified under these conditions.

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BIDIRECTIONAL UNIFORMITY OF WATER APPLIED BY CONTINUOUS MOVE SPRINKLER MACHINES

by

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Traditionally, continuous move sprinkler machines such as center pivots and linear moves are evaluated along the lateral length only. Uniformity along the travel path is assumed high. Although these machines are classed as continuous move, in reality, the forward motion is a series of stops and stops controlled by a guide tower. The start/stop sequence may vary considerably among the towers. The movement of a particular tower may affect the uniformity of water applied by the machine. Thus, we investigated possible uniformity - movement relationships of a linear move and center pivot sprinkler machines.

The system design and operating characteristics are in Table 1. The evaluation involved installing transects of catch cans along the travel path near the guide towers and near tower 5 of both systems. Transects were also installed along the lateral and across selected spans. Nozzle discharges were also measured and distance per move and on/off times of the tower nearest the transects along the travel path were recorded.

Statistics for the can data and the movement characteristics are in Tables 2 and 3. High uniformity occurred along the travel path near the guide towers. Lower uniformity occurred near the interior towers. Distances per move and on/off times were nearly constant for the guide towers. Large variability in these characteristics occurred for the interior towers where in general large distances per move were followed by small distances per move.

Spectral analysis was used to correlate can nonuniformity with tower movement. The data near the guide towers showed considerable periodicity not clearly related to the tower movement. The data near tower 5 of the linear move also showed considerable periodicity but again was not related to the tower movement. However, for tower 5 of the center pivot, a clear relationship between periodicity in the can data and tower movement existed.

The difficulty in relating periodicity in the can data with tower movement is believed caused by the complex pattern in the data. No single large peak equal to the mean distance per move occurred except for tower 5 of the center pivot. This complex pattern is believed caused by overlapping both along the lateral and along the travel path where distances per move were small relative to the wetted diameter of the spray pattern. The distances per move of tower 5 of the center pivot, however, were large relative to the wetted diameter, thus overlapping along the travel path was minimal.

Data from transects across a particular span showed periodicity related to the closely spaced spray nozzles. The overlapping of the spray patterns contributes to most of the nonuniformity in the can data.

Data from the transects along the lateral also contained periodic behavior, which was quite evident for the center pivot. However, a comparison of variability in the can data with that of the nozzle discharges showed no relationship between the two. Thus, variability in the can data is independent of the variability in the nozzle discharges, which was surprising. We hypothesize that the periodicity in the can data along the lateral is related to the movement of the towers.

Both systems had similar uniformities of application however, the nature of the uniformities was very different for each machine. The scale of the nonuniformity was relatively small for the linear move but it was relatively large for the center pivot.

Table 1. Descriptions of linear move and center pivot machines.

Linear Move

Number of spans = 9

Span length
First six = 38.4 meters
Remaining = 54.0 meters

Lateral length (includes overhang) = 401 meters

Time averaged travel speed = 0.78 meters minute^{-1}

Pressure = 103-207 kPa (15-30 psi)

Spacing of spray nozzles = 2.6 meters

Center Pivot

Number of spans = 10

Span Length = 38.5 meters

Lateral length (includes overhang) = 395 meters

Time- average travel speed = 1.97 meters minute^{-1}

Pressure = 96.5 kPa (14 psi)

Spacing of spray nozzles = 3.2 meters

Table 2. Statistics for catch can data.

Transect	Location	$\bar{X}$ (ml)	s (ml)	CV[1]	CU[2]
	Linear Move				
9L	Inside tower 9, along travel path	104	15	14	89
5L	Inside tower 5, along travel path	134	43	34	75
LL	Along lateral length	101	34	33	73
5SL	Across span 5	76	39	52	76
9SL	Across span 9	84	26	31	59
	Center Pivot				
10C	Inside tower 10, along travel path	26	3	13	90
5C	Inside tower 5, along travel path	27	8	30	76
LC	Along lateral length	40	20	50	77
2SC	Across span 2	37	17	46	67
5SC	Across span 5	24	9	38	70
10SC	Across span 10	34	11	33	71

1 Coefficient of variation

2 Christiansen's coefficient of uniformity

Table 3. Statistics for distance per move and on/off times.

Tower	Distance per move (meters)	On time (minutes)	Off-time (minutes)
	Linear Move		
Tower 5			
$\overline{X}$	1.24	0.45	1.18
s	0.65	0.21	66
CV(%)	52	47	56
Tower 9			
$\overline{X}$	0.80	0.36	0.66
s	0.04	0.11	0.12
CV(%)	6	30	18
	Center-Pivot		
Tower 5			
$\overline{X}$	3.71	1.55	2.25
s	0.79	0.4	0.4
CV	21	25	19
Tower 10			
$\overline{X}$	0.98	0.38	0.12
s	0.19	0.0024	2.2×10^{-8}
CV	20	0.6	1.9×10^{-9}

Techniques for Assessing Soil and Water Variability: Field Scale

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Farmers in Kern, Kings, and Fresno counties are constructing on-farm evaporation ponds for drainage water and salt disposal. Pond area ranges from 10 to 20% of the irrigated area served, and depends primarily on the spatial variation of water infiltration within irrigated fields. Five percent or less of the irrigated area would be sufficient to evaporate the drainage water required to assure salinity control. Except for the experience in sizing on-farm evaporation ponds and estimates of drainage volumes based on field water budgets, infiltration variability has not been characterized: infiltration is a difficult parameter to measure. This paper reports preliminary results obtained from a study to determine if the new methods to measure soil conductance can be used to characterize infiltration variability.

The hypotheses of the study were: 1) soil salinity variability results primarily from water infiltration variability, and 2) new resistivity and electromagnetic methods facilitate rapid measurement of soil salinity variability and, if hypothesis 1 is valid, of infiltration variability also.

EXPERIMENTAL PROCEDURES

Six fields in Kings County were selected for this study. Measurements of crop quality and of soil conductance, using resistivity and electromagnetic techniques (Rhoades, 1984), were made along three transects in five fields; in a sixth field, crop quality, soil conductance, water infiltration and water advance rates were measured along a single transect. Calibration relationships between soil conductance and saturation extract electrical conductivity were established for each field based on soil samples obtained at selected sites along the transects. The spectral transmittance of aerial photographs (both regular color and infrared) of each field was determined, on a grid of about 1 m^2, using computer technology available at UCD. The degrees of correlation among crop quality, soil conductance and spectral transmittance were determined using standard- and geo-statistical methods.

RESULTS

Crop quality, soil conductance, and transmittance were correlated with one another ($0.4 < r < 0.97$). Crop quality and transmittance correlated best with the average soil conductance of the 0 to 30 cm and 30 to 60 cm depth intervals. Including deeper depths decreased the correlation. Along the one transect where water advance rates were also measured, the lowest soil conductances occurred where the advance rate was the slowest and the infiltration rate was the highest. Consequently, soil conductance measurements may be useful in the characterization of infiltration uniformity.

Aerial photography may greatly expand the land area characterized provided soil salinity effects on the crop are visually evident. Figure 1 illustrates the correlation between transmittance and soil conductance, determined using the electromagnetic method, along one transect in an alfalfa field. A camera-computer system digitized the aerial photograph of the alfalfa field [30 ha (80 ac)] in several minutes. Soil conductance measurements required from one to three minutes per site for a crew of two. Consequently, the data shown in Figure 1 were obtained in about two hours.

Characterization of infiltration variability on a field scale using soil conductance and aerial photography may be possible provided field-specific soil conductance and associated spectral transmittance data are correlated (see footnotes a-d, Table 1a and b). The frequency distributions of the transmittance data, on a scale of about 1 m^2, for the entire field are given in columns 2 and 3 (Table 1a and b); the corresponding soil conductance, EC_a, and the electrical conductivity of the saturation extract, EC_e, for the 0 to 30 cm depth interval are given in columns 4 and 5. For an EC_e of 2 dS/m, the cumulative distribution for the alfalfa field is 10% and for the cotton field it is 11%. These percentages are the estimated field areas with EC_e's equal to or less than 2 dS/m in the 0 to 30 cm depth interval.

The distribution of EC_e can be related to that of irrigation uniformity, or the distribution of leaching fraction, with the aid of available computer software (Oster and Tanji, 1985). Preliminary estimates indicate an EC_e less than 2 dS/m in the alfalfa field corresponds to a leaching percentage greater than five; the corresponding leaching percentage for the cotton field is twelve.

ACKNOWLEDGEMENTS

D. Monson and R. Strohman assisted in the collection and analysis of much of the data used in this paper. Dr. W. Wildman obtained the aerial photographs and assisted in their interpretation using the computer/camera system at UCD.

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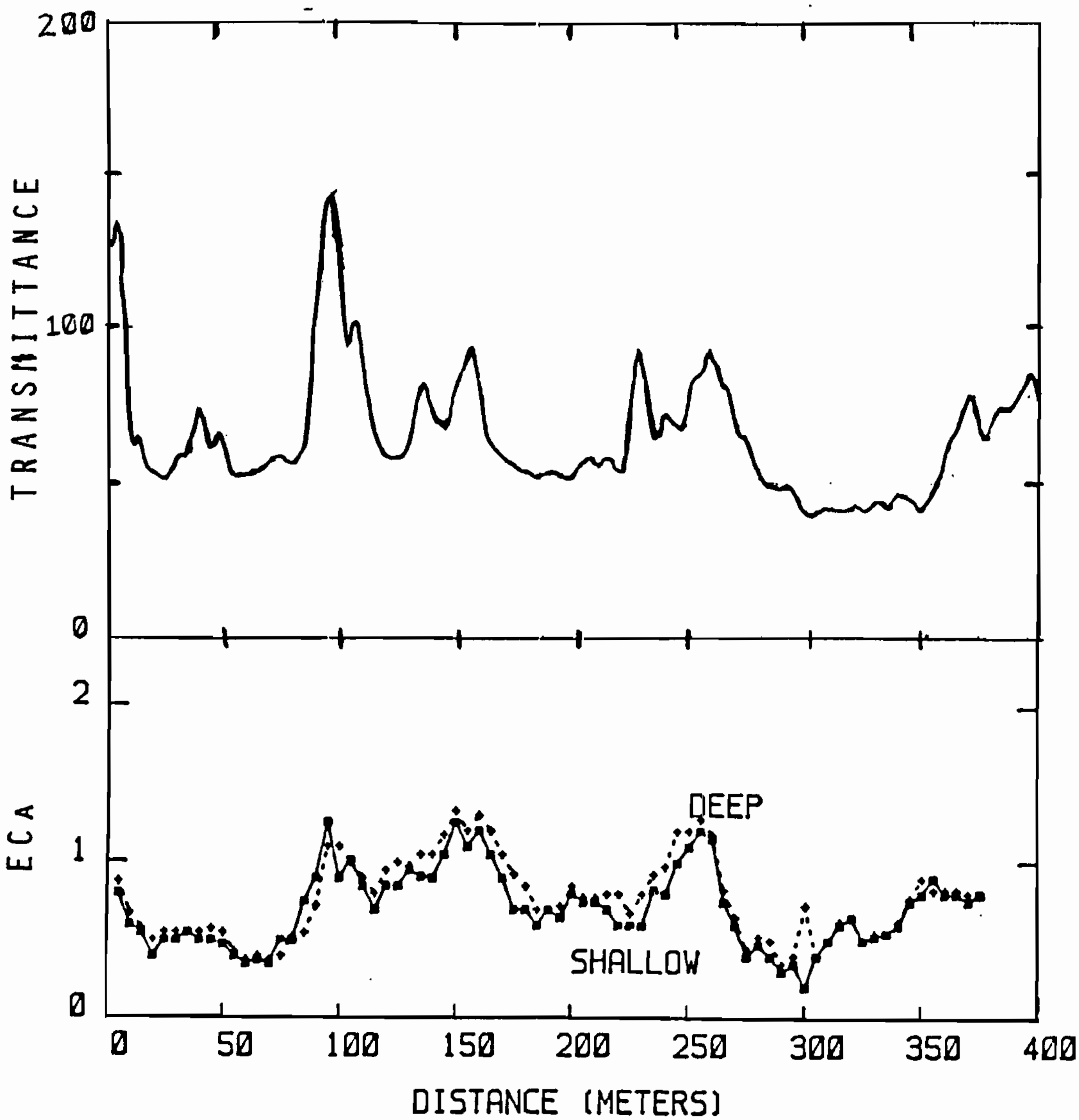

Figure 1. Soil conductance and transmittance of a regular color aerial photograph along coincident transects in an alfalfa field located in Kings county. $EC_a = 0.33 + 0.0067$ trans ($r = 0.5$) is the regression equation at a lag of zero; the probability that r equals zero is less than 0.01.

Table 1. Transmittance distribution of regular color aerial photographs, and of associated soil conductance, EC_a, and electrical conductivity of the saturation extract, EC_e, for two cropped fields in Kings county. The conductivity data are for the 0-30 cm depth interval.

a. Alfalfa (80 ac)

Transmittance Class Interval	Distribution Interval	Cumulative	EC_a[a]	EC_e[b]
	------- % -------		------- dS/m -------	
0.0- 34	3	3	0.7	1
34.1- 49	7	10	0.8	2
49.1- 64	18	28	0.9	3
64.1- 96	38	66	1.2	5
96.1-127	16	82	1.5	7
127.1-157	5	87	1.8	9
157.1-188	3	90	2.1	11

[a]$EC_a = 0.34 + 0.0093$ trans, $r = 0.47$
[b]$EC_e = -3.6 + 7.0\ EC_a$, $r = 0.81$

b. Cotton (160 ac)

Transmittance Class Interval	Distribution Interval	Cumulative	EC_a[c]	EC_e[d]
	------- % -------		------- dS/m -------	
0.0- 13	11	11	1.1	2
13.1- 27	11	22	1.5	3
27.1- 55	35	57	2.2	5
55.1- 83	24	81	3.0	7
83.1-111	10	91	3.7	9
111.1-139	4	95	4.4	11

[c]$EC_a = 0.77 + 0.026$ trans, $r = 0.66$
[d]$EC_e = -1.0 + 2.7\ EC_a$, $r = 0.96$

On-Farm Alfalfa Production Function of Applied Water versus Yield.

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With the cost of energy going up and the price of alfalfa hay staying stable or decreasing, the need for a way of determining appropriate amounts of irrigation water is essential for survival in irrigated agriculture. Most growers irrigate for maximum yield assuming that maximum yield equals maximum profits. However, high irrigation cost and/or low crop prices may mean maximum profits may occur at less than maximum yields.

A key to answering this question is the crop production function relating yield versus volume of applied water for a given farm. A number of production functions for alfalfa relating yield to ET have been developed at various locations in the west and midwest. These functions can be used to describe the relationship between yield and applied water if the uniformity of the irrigation system is known.

A concern is crop production functions developed for one area may not be appropriate for quite different areas. We investigated this matter by developing on-farm production functions for alfalfa relating yield to applied water at two sites in northern California in 1984. One site was in Surprise Valley near Cedarville and one site in Scott Valley near Etna. The Cedarville site had an irregular stand so the data from it was not used.

Measurements of Applied Water Versus Yield

A line source irrigation experiment was initiated in April of 1984 on the Keith Whipple ranch in Scott Valley area of Siskiyou county.

The experimental procedure consisted of the following: Lines of caught cans were placed perpendicular to a wheel line that irrigated the field. The caught cans were placed 5 feet apart in a line. Three lines of cans were spaced 30 feet apart. Two lines had 15 cans and one line contained 10 cans. The cans held approximately 500 cc. of water. The cans were affixed to a steel rod that could be moved up and down to keep up with the growth of the alfalfa so that the can caught all of the applied irrigation water. The rod was inserted into a length of P.V.C. plastic pipe so that the rods could easily be removed during harvest time, and to allow the can to be adjusted to alfalfa canopy height.

The experiment was continued in 1985. The 1984 data suggested that an additional amount of water might increase the yields. Larger cans were attached to the rods, and a second sprinkler head was added to the irrigation line that covered the plot area. As you can see from the data nearly twice the amount of water was added to the plot area in 1985. The winter of 1984 produced 16.07 inches of moisture as rain or snow. The winter of 1985 produced 14.70 inches of moisture as rain or snow.

Data from both years shows that there is no effective irrigation that takes place during the first cutting, however, practically speaking we know that if- no irrigation is applied during the early spring during first cutting the crop will suffer during late July or August when evapotranspiration is higher than the irrigation system can apply water.

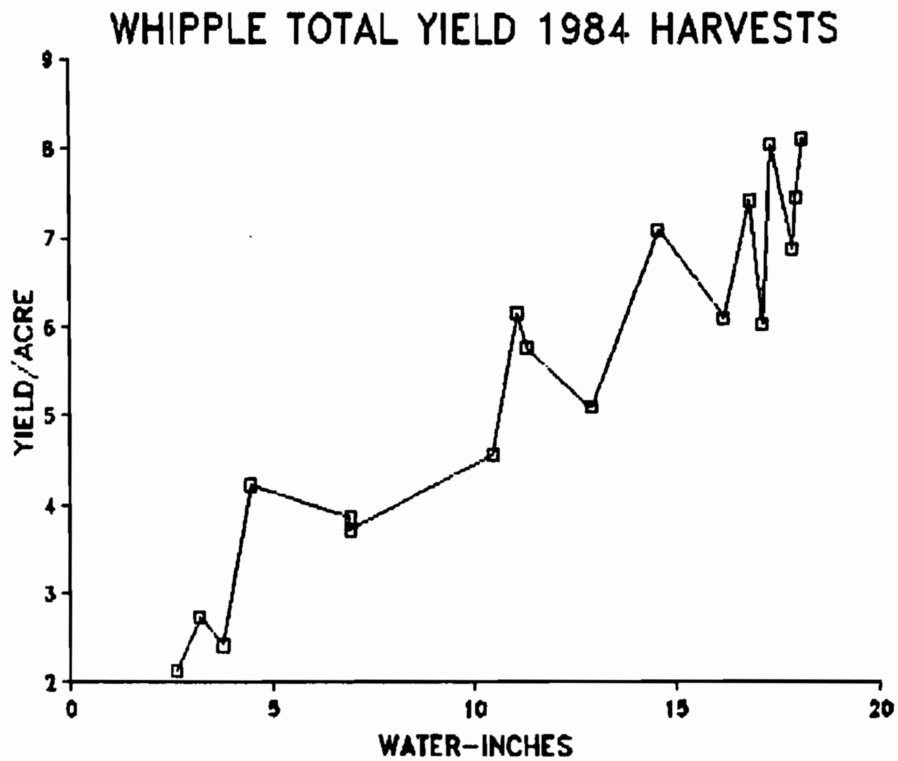
During 1984 four cuttings were harvested, but only three cuttings were taken in 1985. Usually only three cuttings are taken in the mountain area.

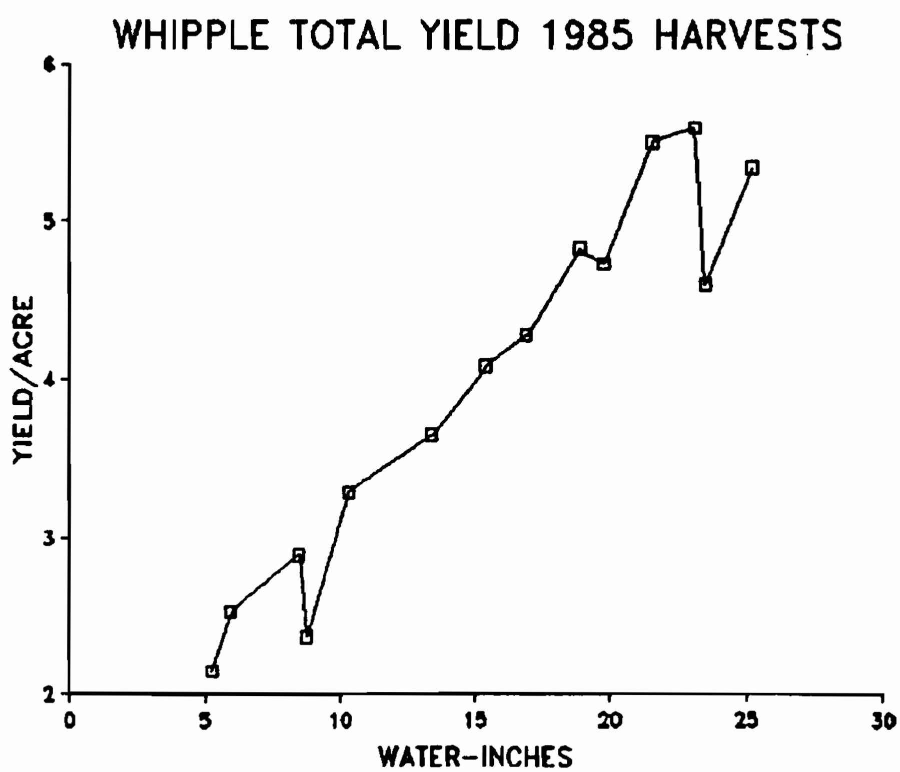
A linear regression analysis showed an r^2 value of .927 for 1985 data and a value of .863 for the 1984 data.

Conclusions

Maximum yields of 8.03 t/a with 18.49 inches of applied water was obtained with four cuttings in 1984. Maximum yield of 6.21 t/a with 31.03 inches of applied water was obtained with three cuttings in 1985. I have shown the yield data in the tables only to the point where the yields plateau and level off with additional irrigation input.

If the 4th cutting yields are removed from the 1984 data the peak yield would be 6.15 tons/acre for 13.27 inches of applied water. The three cuttings in 1985 yielded 5.59 tons/acre for 23 inches of applied water. As you can see the yield per unit of applied water in 1985 was very poor compared to 1984. In 1984 approximately 2 inches of water produced a ton of alfalfa, but in 1985 4 inches of water produced a ton of alfalfa.


WHIPPLE TOTAL YIELD 1984 HARVESTS
YIELD/ACRE
WATER-INCHES
2
3
4
5
6
7
8
9
0
5
10
15
20


WHIPPLE TOTAL YIELD 1985 HARVESTS
YIELD/ACRE
WATER-INCHES
2
3
4
5
6
0
5
10
15
20
25
30

WHIPPLE TOTAL YIELDS

1984 YIELD /ACRE	WATER INCHES	1985 YIELD /ACRE	WATER INCHES
2.13	2.61	2.15	5.25
2.73	3.19	2.52	5.96
2.42	3.77	2.89	8.49
4.22	4.47	2.37	8.76
3.86	6.92	3.29	10.33
3.71	6.92	3.65	13.42
4.56	10.47	4.09	15.43
6.15	11.10	4.28	16.95
5.76	11.35	4.83	18.93
5.09	12.95	4.73	19.82
7.08	14.61	5.50	21.62
6.10	16.21	5.59	23.18
7.41	16.86	4.60	23.54
6.02	17.16	5.34	25.28
8.03	17.37	5.66	27.35
6.88	17.90	5.09	28.53
7.45	17.98	5.83	28.55
8.10	18.14	5.56	29.72

Cotton Production under Alternate Row Trickle Lateral Spacing

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Trickle irrigation has been used extensively in California on permanent plantings such as tree and vine crops. It has only recently begun to be used on field crops such as cotton and tomatoes. As the price of water has increased or the quality has decreased the interest in using trickle irrigation on field crops has increased.

A grower in Arizona has reported a savings of $75 per acre in water costs for irrigating cotton by converting to drip irrigation. He applied 26 inches of water with drip tubing placed under every plant row compared to 60 to 72 inches applied with furrow systems. The soils were a sandy loam and were not ideally suited for furrow irrigation.

The Paloma ranch in Arizona reported 5 bales per acre yields with 40 inches of water applied by drip irrigation (Anon, 1983). This compares to 3 bales per acre with 80 inches of furrow applied water in other work at the Paloma Ranch. In this instance the drip tubing was placed between every other row.

Erie, et al. (1983) have estimated the consumptive use of cotton to be 41 inches of water in the Southwestern United States. Davis, et al. (1980) have determined the consumptive use of trickle irrigated cotton for the San Joaquin Valley. They determined that 26 in produced the maximum yield.

One of the major expenses for a trickle system is the cost of the lateral line and the installation and retrieval. If it is possible to reduce the total number of laterals and still maintain productivity then trickle irrigation of row crops becomes a more attractive irrigation option.

This presentation will review the results of water a management study which investigated the use of saline water for drip irrigation with 2 lateral spacings and 2 irrigation frequencies.

Field Studies

The study was run on a 5 ac field located on Murrieta Farms, Mendota, CA. The soil is an Oxalis silty clay loam and there is a water table at a depth of 5 ft. Cotton (Acala SJ-2) was grown on 30 in beds. Final plant populations of 100,000 to 115,000 plants/ha were achieved in the sampled plot areas.

The lateral spacings used were 2.3 m (every third row, designated as plot 731) and 1.5 m (every other row, designated as plot 733). These two plots were operated on a near daily frequency. A third plot (732) with lateral spacings of 1.5 m was operated with an application occurring every 3 to 4 days.

The irrigation water was saline drainage water (7 dS/m) which had been filtered prior to irrigation. The irrigation was scheduled using screened pan evaporation (plots 731, 733) and potential evaporation times a crop coefficient (plot 732). Plot 732 was irrigated after 25 to 30 mm of E_t was accumulated.

Yield comparisons were made using a well watered furrow irrigation plot which had been irrigated with non-saline water. Yields were determined from 3 separate 3 m lengths of row in 3 field replications. Plant vegetative and reproductive characteristics were evaluated every 1 to 3 weeks, throughout the growing season, using 6-9 plants from 3 field replications.

Results

Even without marked indications of plant water deficit responses (leaf conductance, leaf water potential)to salinity, it is important to determine treatment influences on components of plant growth and yield. Numerous studies have described salinity effects on cotton in terms of plant height, total leaf area, dry matter accumulation, and boll maturation rates (Francois, 1982; Longenecker, 1973; Thomas, 1980), and these parameters were also evaluated in this study.

The number of nodes was not significantly different across treatments except for a 12 percent mean reduction in node number in stressed plants of Treatment 731. In this plot with 2.3 m lateral spacing (every third row), the plant rows adjacent to each lateral were designated Plot 731-A, while those furthest from the laterals were designated as part of Plot 731-B. The plants in rows 731-B represent those subjected to water deficits. Final plant heights were highest in Plots 731-A, 733, and 81, intermediate in Plot 732, and shortest in the stressed plants in Plot 731-B (Table 1). Leaf areas at any time during the season (not shown) and peak leaf area index values (Table 1) exhibited the same treatment ranking. Leaf area differences were principally due to reductions in number of sympodial leaves rather than in leaf size.

The highest peak dry matter accumulation and leaf area indices were observed in plots receiving the largest water application amounts (Plot 733, 731-A, and 81), but no significant differences in either parameter were found between well-watered saline and non-saline treatments (Table 1). Both peak leaf area indices and peak dry matter accumulation were reduced more than 40 percent in Plot 731-B. Plants in plot 731-B were actually more efficient than those in other plots in terms of number of bolls produced per unit leaf area and the percent of total dry matter consisting of bolls (Table 1). This enhanced efficiency demonstrates that it is possible to use water management in cotton to reduce leaf area by a greater percentage than boll number. Management of soil water availability, and perhaps management of root zone salinity, need to be evaluated as tools to manipulate leaf area development and plant harvest index.

Francois (1982) and others have previously demonstrated that increasing root zone salinity hastens maturation (opening) of cotton bolls. In this study, boll maturation was earliest in Plot 731-B and the ranking in terms of earliest progressed next to Plot 732, then 733 and 731-A. Despite the fact that plants in the non-saline treatment (Plot 81) were planted 19 days earlier than those in the saline treatments, bolls in the saline treatments opened as early or earlier than those in Plot 81. The extreme earliness in Plot 731-B can be attributed largely to the influences of soil water deficits.

Table 1. Plant growth characteristics as of September 23, 1984.

	Treatment 1/				
Parameter	731-A 3/	731-B 4/	732	733	81
Number of main stem nodes	24	21	24	24	26
Plant height (cm)	127	76	118	134	115
Total dry matter (g/m^2)	1578	902	1414	1543	1437
Peak leaf 2/ area index	4.27	2.32	3.55	4.16	4.01
Leaf area (cm^2) per boll	376	298	360	410	438
Boll dry matter per unit total dry matter	.49	.55	.50	.46	.50

1/ Values shown represent means of 6 to 9 plants in each of 3 field replications.

2/ Peak leaf area indices were measured September 4 except in Plot 731-B, which peaked September 23.

3/ Rows adjacent to the laterals in Plot 731.

4/ Middle row between laterals in Plot 731.

Despite large differences in amount of applied irrigation water, no major differences in seed cotton yield were observed between Plot 731, 732, and 733, or between well-watered saline (Plot 733) and non-saline (Plot 81) treatments (Table 2). Large differences in seed cotton yield existed between 731-A and 731-B plants, but yield reductions observed in the more stressed, short plants of 731-B were largely compensated for with the very high boll numbers and yields of 731-A plants, which exhibited the highest mean yield of any plants in this experiment (Table 2). This phenomenon of a "ripple" canopy (plant rows of alternating size and yields), which may have been produced by a combination of salinity and water stress, is important for demonstrating the flexibility cotton exhibits in total yield production and in yield production per plant. The average number of bolls per m^2 and bolls per plant were not influenced by salinity or water management treatment with the exception of Plot 731 (Table 2). Average boll dry weight was not greatly affected by any treatment (Table 2).

Table 2. Yield and yield components for final harvest at Murrieta Farms, 1984.

	Parameter 1/			
TREATMENT	Bolls/m^2	Seed cotton dry weight per boll (g)	Bolls/plant	Seed cotton yield (Kg/ha)
731-A	114	5.87	8.4	5990
731-B	61	5.64	5.0	3043
731-Combined Plot 2/	96	5.79	7.3	5008
732	99	6.14	8.6	5338
733	102	6.06	8.7	5412
81	92	5.86	8.0	5003

1/ All means were determined from 3 hand harvested plots (3 m in length) from each of 3 field replications.

2/ Mean determined for plot is based on two-thirds of plot rows comparable to row 731-A and one-third of rows comparable to 731-B within the overall plot.

The ultimate parameter important in determining the suitability of any management scheme for crop production is the effect on economic yield. Other than Plot 731-B, overall plot averages for seed cotton yield were relatively high and exhibited no major differences among plots included in this study (Table 2). The ability of cotton to both tolerate moderate mean root zone salinity (EC < 11 dS/m) in Plots 732 and 733 and to compensate for canopy modification in Plot 731 illustrate the range of irrigation management options possible even in the presence of moderate soil salinity.

The total water applied was measured on Plot 732 using a water meter. The applied water on Plots 731 and 733 was estimated using the appropriate application rate and time of operation. The water applied by the trickle system and the change in soil water over the growing season are given in Table 3. The calculated water use ranges from 379 mm to 584 mm.

The calculated evapotranspiration (E_t) for the period from day 187 to day 255 (the time of irrigation) was 381 mm. The measured pan evaporation for this same period was 456 mm. The water applied in both blocks 731 and 732 was less than the experimental design dictated (Table 3). On the average, the applied water was nearly equal to the computed E_t.

Table 3. Water balance summary for cotton grown at Murrieta Farms, 1984.

Plot	Applied water (mm)	Change water content (mm)	Water use (mm)	Estimated[1/] E_t (mm)
731	373	23	396	650
732	336	43	379	682
733	547	41	588	690
81	510	117	627	662

1/ $Y = -547.11 + 33.81 (E_t)$ (Wallendar, et al., 1979)
where Y = line yield (Kg/ha)
E_t = cm of water.

In a previous section, the yield data for plots 731, 732, and 733 were compared to a well-watered furrow irrigation plot (81). The estimated water use from Plot 81 is 627 mm (Table 3). Water use calculations using only applied water and measured soil water changes are difficult to assess in this experiment because of the presence of a saline water table. An independent estimate of consumptive use was made with a production function developed by Wallender, et al., (1979) for cotton grown in the presence of a saline water table. The results of these calculations are also given in Table 3. Based on the hand harvested yields, the consumptive use ranged from 650 mm in Plot 731 to 690 mm in Plot 733 with the comparison (Plot 81) having an estimated use of 662 mm. The estimate for 81 is very near the calculated value of 627. This suggests that there was very little contribution from the groundwater in Plot 81 while plots 731, 732, and 733 received from 15 to 44 percent of the consumptive use from the ground water. This percentage use from the groundwater compared favorably with values reported by Grimes and Henderson (1984).

Conclusions

From this study we concluded that:

1. Saline water can be used successfully in trickle irrigation systems.
2. A 2.3 m irrigation lateral spacing can be used in fields with row spacing of 0.7 m with little or no overall yield reduction if irrigated frequently.

3. Seed cotton yields comparable to those from plots irrigated with non-saline water can be achieved using saline water with good management and moderately saline soils.

4. In the presence of a water table, an irrigation frequency based upon the depletion of 25 to 30 mm of evapotranspiration may have produced significant uptake from the water table. The specific nature of the ET: seed cotton production functions under saline soil conditions will need further evaluation to accurately assess the water table contribution to E_t.

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THE ALLOCATION AND REGULATION OF WATER USE IN ISRAEL

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As demands for California water continue to intensify, measures for improving the management of irrigation water are likely to receive increasing attention from both the research and farming communities. Current developments in the water policy arena suggest that the future is more likely to be dominated by efforts to stretch and economize on existing supplies as costs and political factors constrain the development of new supplies to meet the demands of growth. Fruitless controversies over the possibilities and potentialities of water conservation have tended to belie the fact that there are significant opportunities to economize on water use.

The State of Israel presents the most dramatic example of how extensive irrigated agriculture and population growth can flourish despite severe constraints on the available water supply. The data presented in Table 1 show that over the past 25 years irrigated acreage has increased nearly six-fold while the total supply of irrigation water has increased less than four-fold. This has been accomplished by a nearly 40% reduction in the average level of water applied to irrigated fields. The figures also show that water allocations to agriculture have peaked. Current projections suggest that agriculture's allocation is likely to remain constant or decline modestly in the coming decade (Shevah and Waldman, 1982).

The decline in the average water application at the field level has occurred in response to a system of laws and institutions designed to regulate all water use. The purpose of such regulations is to protect renewable sources of water and ensure that those sources are used efficiently for the public welfare and the development of the State. The laws require that all water users make economical and efficient use of water and prevent waste and pollution. To achieve this objective, the government is authorized to fix and administer a system of water duties which serve to restrain overall levels of use, reallocate water from low-valued uses to high-valued uses, and guide the use of resources in promoting the nation's settlement policies. The duties cover all sectors and all sources of water, including brackish water and, in the future, reclaimed sewage water.

In Israel, the term "water allocation" refers to the division of supply among the three basic water using sectors: industry, municipalities, and agriculture. Agricultural allocations, which account for 75% of Israel's water use, are related to norms or quotas established for different crops in different agroclimatic regions. Water is allocated to individual growers by applying the crop or regional quotas to crop acreage. In mixed cropping situations (with annual crops), the grower is free to alter the mix of crops although such alterations do not generate any change in the water allocations (Grinwald, 1982b).

The need for quotas stems, in part, from the fact that water plays an important role in effectuating the settlement and population dispersal policies of Israel. Much of the unsettled land is arable but located in the southern regions where rainfall is light. Inexpensive water supplies for irrigation provide one of the critical inducements to settle. The fact that water must be made available at artificially low prices to induce economically viable settlement means that prices cannot be used to ration agricultural water. As a consequence, agricultural allocations have historically been based on norms and quotas.

Water use quotas for irrigated agriculture were initially promulgated in the late 1950s and have not been altered since. The quotas were established by administrative determination and were based on scientific evidence insofar as possible. There is no pretense, however, that they are scientifically derived since Israeli water authorities recognize that the determinants of crop water use are incompletely understood from a scientific standpoint (Grinwald, 1983). The quotas were based on the twin presumptions that yield should be optimized rather than maximized and that special allowance should *not* be made for the type of irrigation technology employed. The quotas, then, are broadly conceived and somewhat arbitrary in nature.

In Table 2, quotas are presented for crops in three representative agricultural regions. The figures illustrate that the pattern of quotas is not the same from region to region and thus there is no strict proportionality between quotas and crop evapotranspiration. Similarly, the pattern of quotas for a given crop in different regions is not consistent. For example, the figure for annual crops is invariant among regions, but for perennial crops, there is substantial variation between regions. For permanent crops, the patterns range from constant across all regions (for avocados and wine grapes) to reasonably variable across regions for table grapes.

The quotas are somewhat higher than the estimated consumptive use requirements for most crops. Estimated consumptive use figures for citrus, avocados, and apples under several conditions are presented in Table 3. A comparison of consumptive use figures with the counterpart quotas show that only the quotas for grapefruit grown in the northern Negev and citrus grown on heavy coastal soils are lower than the upper range of consumptive use. The difference between quotas and consumptive use is intended since it is recognized that no irrigation system achieves perfect uniformity or perfect physical efficiency. The quotas generally reflect the view that adequate irrigation requires applications that are 10 - 20% in excess of the consumptive use of the plant.

The quotas, prices, and rules for efficient water use are established by the Minister of Agriculture. A Water Commission within the Ministry of Agriculture is authorized to regulate extractions, storage, and transfers. This is accomplished through the issuance of licenses which stipulate both the quantity to be extracted and the ultimate users. All extractors are required to be licensed and to report quantities extracted on a monthly basis to ensure adherence to the terms of the license. The accuracy of monthly reports is reviewed by Water Commission Inspectors who have access to both meters and to electrical consumption records for all ground water pumps. There is a formal Water Court to which the decisions of the Water Commission may be appealed. Not surprisingly, there have been few successful appeals.

There are several ancillary support programs which seek to aid growers in adapting to their water allocations. The Soil and Irrigation Field Service within the Ministry of Agriculture provides information and advice in a fashion similar to the Cooperative Extension Service in the United States. The Field Service makes irrigation recommendations which need not be consistent with the quotas. Currently, the Field Service is actively involved in the dissemination of techniques for irrigation scheduling.

The Israeli Center of Waterworks Appliances is a government company which is responsible for testing, establishing codes of practice, and developing accessories for all water appliances. This company tests and certifies all types of irrigation systems as well as municipal water appliances. The testing and certification of irrigation systems centers on the uniformity of application of such systems. Specifically, the company evaluates the distribution uniformity of sprinkler systems and the emission uniformity of trickle systems in the field. Any system for which the manufacturing standards have been approved and field tests have been satisfactorily met is certified by the company. While appliances can be sold without such approval, certification is an obvious marketing advantage. All systems are tested in the field and the company continues testing for many years after approval to acquire data on the long term performance of systems. In general, the standard for sprinkler systems is a Christensen Uniformity Coefficient (CUC) of 84 or greater. The company reports that CUCs for most systems are 90 or better (Yekutieli, 1983). With trickle systems, a manufacturing variation in uniformity of 5% is allowed and field performance is evaluated for one year before certification. The company believes that trickle systems use 10% less water when compared with sprinkler systems under identical circumstances. The rapid adoption of trickle systems for irrigating cotton in Israel has resulted from this superior uniformity and the consequent water savings as well as from the ease of operation and improvements in yield. Government involvement in the certification of technology has clearly served to reduce the uncertainties associated with the adoption of new technical innovations. It seems clear, however, that the constraints on water availability have been the primary inducement to adopt such systems.

The administrative regulation of. water use in Israel through the enforcement of quotas and allocations has clearly been effective in balancing water demands with limited supplies. The quotas appear to have worked well in promoting efficient water use in the agricultural sector. Irrigated agriculture is both more extensive and more profitable in the aggregate than it would have been in the absence of reductions in unit water use. The reductions in unit water use, which occured in the face of strict water quotas, can be attributed to two factors. First, there has been since the middle 1950s a shift away from water intensive crops such as alfalfa and other fodders toward less water intensive crops such as cotton and subtropical perennials. Second, there has been a substantial improvement in the way water is managed at the field level as exemplified by the fact that yields have improved or remained constant despite a reduction in the quantity of water applied to all crops. This improved productivity is atttributable not so much to the adoption of sprinkler and trickle technologies (which are currently used on 95% of Israel's irrigated land), as it is to the variety of complimentary programs which have enabled Israeli growers to realize the potential of these technologies in managing their water.

The effectiveness of the Israeli scheme of water allocations and quotas has also been critically aided by legal and political factors. Both the government and the population of Israel have accepted the proposition that water allocations and quotas are, for all intents and purposes, water rights. The fundamental fairness or equity of the system has not been questioned and there has been no other serious attempt to undermine the system through legal challenges. In short, there appears to have been widespread understanding within Israel of the need for such a system and that understanding was translated into a general willingness to accept the specific allocations and quotas that ultimately emerged.

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TABLE 1

Changes in the Average Water Applied to Agriculture in Israel, 1948-1981

Year	Irrigated Area (10^3 acres)	Total Irrigation Water Applied (10^3 a.f./yr.)	Average Applied Water (a.f./acre)
1948	99	243	2.46
1956	259	689	2.65
1967	383	892	2.33
1973	457	973	2.13
1977	531	1,005	1.89
1978	555	1,001	1.80
1981	581	912	1.57

Source: Grinwald, 1982a.

TABLE 2

Quotas for Maximum Water Application to Crops in Representative Agricultural Regions of Israel
(In a.f./acre)

Crop	Inland North	Central Coast	Northern Negev
Citrus	2.36	2.36	2.63
Apples	2.36	2.63	2.63
Pears	2.36	2.36	2.36
Almonds	1.28	1.28	1.28
Avocado	2.45	2.95	2.95
Stone Fruit	2.63	2.63	2.95
Table Grapes	0.98	0.98	1.97
Wine Grapes	---	0.66	0.66
Annual Crops	1.31	1.31	1.31
Perennials	3.28	3.28	4.43

Source: Adapted from Grinwald, 1982a.

TABLE 3

Computed Consumptive Use and Quotas for Orchard Crops in Certain Regions of Israel

Crop	Region	Consumptive Use (a.f./acre)		Quota	Quota/Median
Citrus		Range	Median		
Heavy soil[1]	Coastal	1.97 - 2.65	2.31	2.36	1.02
Light soil[1]	Coastal	1.64 - 1.87	1.76	2.36	1.34
Graprefruit	Western Jezreel Valley	2.13 - 2.3	2.22	2.36	1.06
Grapefruit	Northern Negev	2.62 - 2.82	2.72	2.63	0.97
Avocados					
Fuerte	Coastal	2.30 - 2.46	2.38	2.95	1.24
Haas	Coastal	2.46 - 2.62	2.54	2.95	1.16
Apples	Upper Galilee	2.49		2.63	1.06

[1]Figures are for trees with rootstocks adapted for heavy soils and light soils respectively.

Source: Adapted from Grinwald, 1982a.

PROPOSED AMENDMENT TO THE CONSTITUTION AND BY-LAWS OF THE CALIFORNIA CHAPTER OF THE AMERICAN SOCIETY OF AGRONOMY

As Amended January 31, 1985

NAME

Article I, Section 1. The organization shall be the California Chapter of the American Society of Agronomy as authorized under Article XII, Section 5 of the 1984 Revised By-Laws of the American Society of Agronomy, Inc.

OBJECTIVES

Article II, Section 1. The objectives of the California Chapter shall be generally those of the American Society of Agronomy, Inc., an educational and scientific corporation qualified for exemption under Section 501 (c) (3) of the Internal Revenue Code of 1954, as amended or a comparable section of subsequent legislation.

The California Chapter shall strive to promote human welfare through advancing the acquistion and dissemination of scientific knowledge concerning the nature, use, improvement and interrelationships of plants, soils and environment. The California Chapter, like its parent society, shall (1) promote effective research, (2) disseminate scientific information, (3) foster high standards of education, (4) strive to maintain high standards of ethics, and (5) cooperate with other organizations having similar objectives.

The California Chapter supports the efforts and objectives of the Western Society of Soil Science and the Western Society of Crop Science and will operate in a manner consistent with their purposes.

MEMBERSHIP

Article III, Section 1. The membership of the California Chapter of the American Society of Agronomy shall consist of individuals actively interested in the objectives of the Chapter as outlined in Article II and who have paid dues for the current year.

Section 2. Membership in the American Society of Agronomy, the Soil Science Society of America, the Crop Science Society of America, the American Society of Horticultural Science or similar professional societies is encouraged, but not required, for full membership in the California Chapter of the American Society of Agronomy.

OFFICERS AND STANDING COMMITTEES

Article IV, Section 1. The governing board of the Chapter shall be constituted by an Executive Committee and a Council of Representatives.

Section 2. The Executive Committee shall consist of the Past President, President, First Vice-President, Second Vice-President and Executive Secretary-Treasurer. The term of office with the exception of the Executive Secretary-Treasurer shall be for one year. The Executive Secretary-Treasurer shall serve for a three-year term.

Section 3. The representation on the Executive Committee shall be split as evenly as possible between (1) industry and (2) university, college and government groups, and evenly between the broad groupings of soils and crops. For example if the President comes from a university extension, college or government agency grouping and is considered to be from the soils or irrigation discipline, the First Vice-President would be from one of the crops disciplines representing industry. The normal order of progression would be President to Past President, First Vice-President to President, Second Vice-President to First Vice-President, and the Second Vice-President elected from present or past Council Representatives.

Section 4. The Council shall consist of nine elected representatives, 4 or 5 from industry groups and 4 or 5 from public sector groups and shall represent a broad range of disciplines.

Section 5. Each Council Representative will be elected to serve a three-year term. The terms will be staggered so that three Representatives will be elected each year. When a vacancy occurs on the Council because of death, resignation or other cause, appointment to fill the vacancy will be made by the Executive Committee and the appointee will serve ~~until~~ the ~~next election~~ remainder of the term.

Section 6. The Council Representatives will be elected by the membership assembled at the time of the Annual Business Meeting. The Nominating Committee will be the Executive Committee. They will distribute the list of nominees prior to the annual meeting. Additional nominations may be made from the floor at the Annual Business Meeting in which case elections shall be by secret ballot of those in attendance and voting.

Section 7. The Council Representatives and Members of the Executive Committee will elect the President, First Vice-President, Second Vice-President and Executive Secretary-Treasurer.

Section 8. The duties of the Past President, Vice-President, Second Vice-President and Executive Secretary-Treasurer shall be those which usually pertain to such offices of similar organizations. The Past President shall serve as the chairman of the Awards Committee. The President and First Vice-President shall serve as program co-chairmen for the Annual Meeting. The Second Vice-President shall serve as chairman of the Membership and Dues Committee, and publicity.

Section 9. The President, with the approval of the Executive Committee, shall annually appoint such committees, their members and chairman, as the President or the Executive Committee deems necessary to assist in carrying out the objectives of the Chapter.

ANNUAL MEETING

Article V, Section. The California Chapter of the American Society of Agronomy will hold an Annual Meeting at such a time and place as shall be advantageous to the members. The program as developed by the Program Committee shall include papers on subjects of wide interest to educators, scientists, farmers and others who serve agriculture. Emphasis will be on the applications of scientific developments. Sectional meetings, special symposia, joint or cosponsored meetings with other groups may be arranged by the Executive Committee and may be held separately from or in conjunction with the Annual Meeting.

DUES

Article VI, Section 1. Annual membership dues shall be set by the Executive Committee and shall be assessed and collected as provided for in the By-laws.

Section 2. Fees or dues associated with the operation of the California Chapter will be held to a minimum.

AMENDMENTS

Article VII, Section 1. The Constitution and By-laws may be amended by a two-thirds (2/3) majority vote of the members present at the Annual Meeting, providing such amendments have first been presented, in writing, to the Executive Committee for consideration not less than sixty (60) days prior to the Annual Meeting.

BY-LAWS

PUBLICATIONS

Article I. The publications of the California Chapter may consist of proceedings made up of abstracts or submitted papers, reports of committees, minutes of the Annual Business Meeting and such other items as shall have general interest to the members. The Executive Committee is authorized to charge for publications in such a manner as to reclaim actual costs.

DUES

Article II. The annual dues to the California Chapter shall be three dollars ($3.00).

PAYMENT OF EXPENSES

Article III. The Executive Secretary-Treasurer shall be authorized to pay all routine expenses. Expense items other than of an operational nature shall require the approval of the Executive Committee.

Infrared Thermometry for Canopy Temperature Measurements: Applications and Limitations in Irrigation Scheduling

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Successful irrigation scheduling and management requires methods for assessing both the quantity of irrigation required to replenish soil water with minimal deep percolation losses and the timing of irrigation required in order to avoid crop water deficits. Knowledge of soil water holding characteristics and crop rooting depths are necessary to determine the quantity of water to apply at each irrigation. Plant measurements, in contrast, are most useful in determining the timing for irrigation in order to minimize damaging plant water deficits.

The severity, duration, and timing of water deficits is important in determining the extent of damage to potential crop yields, therefore, considerable effort has been made to identify and evaluate plant measurements useful in describing plant water status. In order to be useful as an aid in irrigation scheduling, any measurement of plant water status should: 1) be simple enough to take that adequate measurements can be made to represent any given field; 2) require relatively small numbers of samples or be nondestructive in nature; and 3) be reasonably correlated with plant physiological processes significatnly related to growth rates and/or yield.

Tissue relative water content, leaf water potential measurements using pressure equilibration or psychrometric techniques, and stomatal conductance measurements have all been used to describe the degree of plant response to water deficits. Measures of plant water potential or relative water content typically involve destructive leaf or tissue sampling, and concentrate on determination of tissue water status of individual plants or plant parts. Measurements of leaf conductance, while non-destructive, have similar limitations for use in characterizing water deficits on a field scale because of plant to plant variability and the large number of measurements needed to characterize field crop water status. Thermal infrared radiation measurements of leaf and crop canopy temperatures are relatively simple to make and many readings can be made to represent crop water status on a "field" level. However; as with any other type of plant-based measurement; some precautions and limitations must be considered in both collecting and interpreting crop temperature data for use in irrigation scheduling. Some of these opportunities and limitations will be discussed in this paper.

Leaf and Canopy Temperature Measurements

Methods Used in Assessing Plant Water Status

The potential of leaf or canopy temperature measurements for use in assessing crop water status has been investigated by a large number of groups in recent years (Ehrler, 1973; Hiler, et al, 1974; Jackson, et al, 1977; Idso, et al, 1977; Jackson, et al, 1980. Interpretation of leaf temperature data involves consideration of the fact that transpiration results in evaporative cooling of plant tissues, often to temperatures below that of the surrounding air. One common result of plant water deficits is partial or complete stomatal closure and reductions in transpiration, resulting in less evaporative cooling and higher leaf temperatures.

Tanner (1963) was among the first to recognize the potential of infrared thermometry in evaluations of plant water status. Hiler, et al (1974) described the stress-day-index (or SDI) concept. This technique involves the use of a crop susceptibility factor which describes the relative sensitivity of crop yield to water stress during specific growth stages. In addition, this technique requires some measure of the severity of the plant water deficit, such as leaf water potential, leaf conductance, stem diameter changes, or the leaf-air temperature differential. Ehrler (1973) expanded the evaluation of leaf temperatures as a plant water deficit indicator, demonstrating a nearly linear relationship between the leaf-air temperature differential in cotton and the vapor pressure deficit. This was an important step in determining how variation in atmospheric evaporative demand can be compensated for in interpreting leaf-air temperature differences.

Many evaluations of crop water deficits through leaf temperature measurements can also be employed using an infrared thermometer with a wide field of view which measures an integrated canopy temperature on a large area basis. This integrated type of temperature measurement and the ease with which replicate readings can be made greatly reduces sampling problems and the problem of whether point measurements are truly representative of the field as a whole. Jackson, et al (1977) proposed a stress-degree-day (SDD) concept for use in wheat in which the afternoon canopy-air temperature differential was used to estimate water requirements. In this and other evaluations, accumulated stress-degree-days could be related to other plant water stress indicators, to extraction of soil available water or to the effect of water stress on yield. A number of researchers, including Clawson and Blad (1982) and Gardner, et al (1981) have used the mid-day canopy temperature differential between plants in stressed versus well-watered plots (called the Temperature Stress Day or TSD index) in order to quantify stress. Gardner, et al (1981) and Clawson and Blad (1982) and others have also evaluated an irrigation scheduling method based on canopy temperature variability (CTV), in which the deviation of mid-day canopy temperatures within a field is used as a relative indicator of plant water status. The SDD, TSD, and CTV methods each have potential uses in irrigation scheduling for some crops, but each has limitations. The critical SDD, TSD, and CTV values used to signal irrigations can all be influenced by prevailing air temperatures and vapor pressure deficits, and inherent soil variability in water-holding capacity could markedly influence CTV values in any field.

Idso, et al (1977, 1981) expanded on the work of Ehrler (1973) in proposing the use of the relationship between the canopy-air temperature difference and vapor pressure deficit as an indicator of plant water stress. This index was called the Crop Water Stress Index (CWSI). Relating temperature differences to vapor pressure deficits through this index largely compensates for environmental effects on canopy temperatures. Jackson, et al (1981) described in great detail many of the physical principles responsible for the crop-specific relationship between canopy-air temperatures and vapor pressure deficit. The CWSI, although relatively new, has received much attention with respect to its utility in providing quantitative estimates of plant water status under both non-saline (Howell, et al, 1984a; Reginato, 1982; Idso, 1981) and saline conditions (Howell, et al, 1984b). Reginato (1982) related CWSI values during certain growth stages in cotton to both leaf water potential and leaf conductance, and Howell, et al (1984) related final cotton yield to CWSI values across a range of salinity levels. Data of Hutmacher and Ayars (unpublished) indicated that use of a CWSI of 0.3 for scheduling irrigations in cotton achieved an irrigation schedule similar to that called for using leaf water potentials as described by Grimes and Yamada (1982). Jackson and Pinter (1981) suggested a relationship between CWSI values and plant growth rates in wheat. This type of data relating crop stress indices to growth and yield must be developed for each crop within each critical growth stage in order to effectively use the CWSI or any plant-based stress measurement in irrigation scheduling.

Basic Considerations in Evaluating Methods With Respect to Irrigation Scheduling

Equipment/Management Considerations

1. Care must be taken to maintain the correct operation and calibration of both the infrared thermometer and equipment needed to measure the vapor pressure deficits. See Sadler and Van Bavel (1982) for suggestions regarding calibration procedures and precautions.
2. The person(s) operating the infrared thermometer must understand both the operating features of the instrument (particularly the field of view) and the difficulties in interpreting data which can arise when either sky or soil background is included in measurements supposedly restricted to

"canopy " temperatures. O'Toole (1984) provides an excellent discussion of the importance of canopy target dimensions and "aim" in the use of infrared thermometers.

3. In using the CWSI method, in particular, it is also important that equipment used in determining vapor pressure deficits be maintained and operated carefully.

4. As with any irrigation scheduling method, you must consider whether or not the time and effort required for data collection in any of these methods can be worked in to a management schedule.

Crop/Soil/Environmental Considerations

1. Most canopy temperature-based scheduling methods will generally be most successful with crops grown under conditions of low humidity and moderate to high air temperatures (conditions which tend to produce substantial canopy-air temperature differences). These methods are generally less successful in more humid or cool environments in which canopy-air temperature differences are relatively small.

2. Reliable canopy temperature data is most easily gathered during the part of the season in which full canopy cover exists. Many irrigation decisions of key importance in efforts to both save water and avoid plant stress damaging to yield occur either early in the growing season or late in the season. Lack of full canopy cover in the early season makes measure of canopy temperatures a difficult task, while leaf senescence and the presence of reproductive tissues (with low transpiration rates) in the field of view complicate interpretations of late-season readings. More research is needed to improve our ability to assess plant water

status during these periods.

3. The water-holding capacity of the soil and the soil volume explored by the roots exert an important influence on the suitability of these techniques for irrigation scheduling in that they influence the rate of development of plant water stress and the frequency of CWSI, SDD, TSD, CTV, etc. measurements needed to determine appropriate schedules for irrigations.
4. In order for any of these canopy temperature measurements and stress indices to be useful in irrigation scheduling, information must already be available or must be developed to indicate desirable CWSI, SDD, CTV, etc. "critical values" which achieve savings in water and/or favorable yield responses. In many crops, past experience in water management research would suggest that these "critical values" may differ across growth stages.

Conclusions

Advances in both equipment design and our understanding of the principles which relate leaf and canopy temperatures to crop water water status make the use of crop temperature measurements a viable alternative for some irrigation scheduling. Field evaluations of these irrigation scheduling techniques have been conducted for a number of crops, and results for some crops have been promising. Many environmental and plant-related factors which restrict the usefulness of the indices here described have been identified, and research currently underway will more clearly identify crops and climatic conditions best suited to this type of irrigation scheduling.

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ENVIRONMENTAL DATALOGGING CONCEPTS

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The topic of data acquisition instrumentation is vast, requiring any discussion to focus on some manageable portion. After consideration, a potpourri of topics was selected for this discussion; hopefully useful to those involved with, yet not immersed in, data acquisition. Several other topics could have been chosen as well. Datalogger design features important to environmental applications are reviewed. Sensor compatibility and on-site processing, are discussed, as are resistance bridges because of the wide use of these types of sensors. Finally, measurement resolution and accuracy are discussed.

Functional Overview

Digital data acquisition requires the automated conversion of electronic sensor signals to a digital value which is then stored and/or transmitted. The frequency of conversion is referred to as the **sample** or **scan rate.** Although many hardware options exist, certain functional components are common to any data acquisition process. A broad view, from sensors to computer, is represented in the block diagram of Figure 1. The functional components can be summarized as:

1. Sensing
2. Signal conditioning
3. Analog to digital conversion (ADC)
4. On-site processing

5. Data storage
6. Data retrieval/transmission to computer

Today, many of these functions are performed by the datalogger.

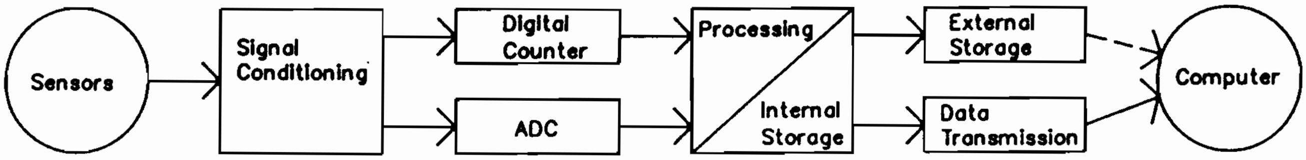


Figure 1. Generalized Functional Sequence of a Data Acquisition Process

<u>Historical Background</u>

Historically, more data has been collected on strip chart recorders than all other systems combined. Whether or not more data from these instruments has been analyzed is another question. It may be useful to identify the functions summarized above within the context of the strip chart. Strip chart inputs usually accommodate voltage signals (milliamp current inputs are common in industrial applications). External signal conditioning is required for many types of sensors in order to convert their output to a voltage signal. The sensor's output is recorded as a continuous time trace on the chart. Analog to digital conversion (ADC) is accomplished manually by "picking" the value of the trace at desired time intervals. In more sophisticated operations, automated X-Y digitizers are used. Once the trace is digitized, a notebook or keypunch form usually provides the data storage. Computer entry requires punching the values into a terminal or onto computer cards.

The development of automatic, sampling digital recorders significantly reduced the time and labor required to "pick" the strip charts. The sampling recorder switches through each input channel at the designated sample rate and records the digital value either on magnetic or punched paper tape or on printed hard copy. A one-to-one correspondence exists between an input channel and the recorded data value; e.g., the fourth data value recorded each scan represents the fourth input channel. This correspondence does not exist in processing dataloggers because sampled values from a particular input channel may be processed over time, providing several data values; e.g., a temperature input may have the average, standard deviation, maximum and minimum value recorded. With sampled values, a trade off exists between sampling often enough to accurately represent the measured parameter and having enough data storage capacity.

Environmental Datalogger Design Features

Performance specifications vary among dataloggers, depending upon their intended application. A limited summary of requirements for unattended operation in remote, outdoor environments is given below. Certain features are desirable in most datalogging applications.

1. Sensor compatibility - direct connection and measurement of sensor signals without external signal conditioning circuitry reduces cost, complexity, measurement error and power requirements. The ability to resolve signals to the required precision affects the choice of sensor.

2. On-site processing - field processing reduces data storage requirements, scales sensor signals to engineering units, and provides logic decisions for control applications.

3. Field observation of measurements - field verification of sensors requires the ability to continuously observe instantaneous measurements, in engineering units, from a display or printer.

4. Input transient protection - environmental datalogging is vulnerable to major hardware damage caused by large, lightning induced transients entering the system on sensor leads. Protection hardware such as transorbs, spark gaps, etc. and proper grounding procedures are required to minimize damage.

5. Hardware microprocessor reset - unattended, processor based instrumentation should reset the processor, restoring normal execution in the event it is altered due to input transients or intermittent component failure. User entered programs should exist in write-protected memory, minimizing the possibility that the processor can overwrite the program should an abnormal execution state occur.

6. Low power consumption - operation from dc power supplies (batteries) and low current drain are required. An average power consumption of 50mW allows 2.5 months of operation on eight, alkaline D-cells (7.5Ahr).

7. Operation in environmental conditions - operation at high temperatures and humidities are the main concerns in agricultural applications, but environmental dataloggers should operate and maintain measurement specifications over a minimum range of -20°C to +55°C. Solar heating can raise datalogger enclosure temperatures 20°C above air temperatures. Use of enclosures and desiccant provides the simplest and most cost effective means of operating at condensing water vapor concentrations.

8. Remote communication capability - this feature has become increasingly important over the last few years due to the increased use in agriculture of daily models using climatological data to predict water use, crop development, disease and pest growth, etc. This application requires the timely transfer of data, upon demand, via RF, telephone or

similar link. The ability to remotely change or restore programs or initiate control functions (irrigation, for example) at the datalogger site is also useful.

The above summary emphasizes design features for environmental applications and is not intended to be inclusive. Additional performance specifications such as sample rate, data throughput rate, data storage capacity, data transmission options, accuracy, common mode range and others may also be relevant.

On-Site Processing

The advantages of processing measured values to obtain more efficient data storage has been mentioned. Data compression is particularly important in remote applications, where site visitations are costly. Processed results such as averages, standard deviations, extremes or values recorded conditionally only at designated times, events or upon changes, all reduce data storage and handling logistics.

Processing non-linear relationships make it possible to average linearized values, for example: 1) vapor pressure can be computed and averaged from instantaneous RH and temperature measurements, whereas an average vapor pressure computed from average RH and temperature values may not be correct, 2) average wind direction must be computed as a vector quantity, requiring a polar to rectangular conversion on each direction measurement, 3) the cube of instantaneous wind speed can be averaged in wind power studies, whereas the cube of the average wind speed may not be representative.

Linear calibration constants entered into the datalogger are used to convert measurements into engineering units immediately, avoiding possible errors if done in the computer at a later date. User entered polynomial coefficients are used to convert non-linear measurements, such as from soil moisture blocks. When verifying system performance in the field, engineering units are very useful.

The ability to compare values or time, with programmable limits and make decisions, provides useful control functions such as switching on sensors with high current drain prior to the time of measurement; controlling fans, solenoid valves, etc.; or initiating telecommunication in response to a hazardous condition. Discarding measurements from AC powered sensors during power outages or when values exceed certain limits are additional capabilities.

Sensors and Signal Conditioning

The following discussion is concerned with datalogger/sensor compatibility and does not address sensor technology and proper siting techniques; however, the importance of these subjects to any data acquisition effort cannot be overstated. If a desired parameter is sensed inaccurately, the remaining functions shown in Figure 1 serve little purpose.

Sensors

A sensor possesses a property that changes, in a known way, with changes in the sensed physical parameter. For automated data acquisition purposes, we require that changes in the sensor property be converted to an electrical signal. In practice, the state of the sensed parameter may be related to one of several electrical properties; voltage, current, resistance, AC impedance, capacitance, inductance, phase, frequency, etc. Sensors with complex outputs usually require active circuitry to produce voltage signals. However, many useful sensors vary resistance, voltage, current or frequency directly. These sensors can be measured without additional circuitry by dataloggers equipped with precision bridge voltages, voltage inputs (differential inputs may be required) and pulse inputs. Table 1 shows several common sensors and their electrical property.

Signal Conditioning

For this discusson, signal conditioning circuitry refers to any circuitry required to support the proper functions of the sensor or to convert sensor outputs to high level voltages. Today many signal conditioning functions are designed into the datalogger. In general, this approach reduces system cost, complexity and power consumption, and increases reliability. For these reasons, sensor compatibility is an important criteria when evaluating dataloggers.

Several signal conditioning functions historically requiring external circuitry are listed below. The sensors shown in Table 1 are directly compatible with dataloggers having these features.

1. Amplification - low level signals such as thermocouples (40uV/°C for Type T) or metal foil strain gages (1.5mV/V full scale) require amplification if the datalogger resolution is inadequate. The high resolution and low input noise available in some dataloggers provides new options for using sensors with low level signals.

2. Output scaling - converting signals to engineering units such as °C, m/s, mb, etc., aids on-site system verification.

3. Linearization - outputs such as thermistors, PCRC humidity sensors, platinum resistance thermometers (PRT's) and thermocouples require linearization before they can be displayed or processed. Processing dataloggers linearize measurements numerically with high order polynomials.

Table 1. Examples of Common Sensors with Resistance, Voltage Current or Frequency Signals

Parameter	Resistance	Voltage	Current	Pulse
Temperature	-thermistors (lk-100k) -RTD's (100ohms-1k)	-thermocouples (uV)	-diodes (uA)	
Radiation		-thermopiles (mV)	-silicon cell (uA)	
RH	-sulfonated polystyrene (1k-2m)* -cellulose chip (1k) -thermistor or PRT psychrometer	-capacitance type (mV)** -thermocouple psychrometer		
Flow, Windspeed		-DC anemometers (V)		-contact closure, photochopped or magnetic AC flow meters and anemometers
Precipitation	-potentiometers			-tipping bucket
Soil Water Potential	-moisture blocks* (1k-1m)	-Peltier cooled TC psychrometers (NV)		
Pressure, Force, Weight	-strain gages (100ohms-1k) -potentiometers (1k-20k)			
Position, Direction	-potentiometers			-Incremental encoders
Miscellaneous	-conductivity and salinity cells*			

*AC conductivity measurement
**Sensor contains active circuitry

4. Thermocouple reference junction compensation - thermocouples require measurement of their reference junction temperature to obtain absolute temperatures.

5. Precision bridge excitation - resistance sensors such as strain gages, PRT's, thermistors, potentiometers, etc. require precision excitation voltages. Switched excitations built into the datalogger reduce power consumption for remote application. Error due to the datalogger's internal voltage reference is eliminated because the same reference is used for both the excitation voltage and the measurement.

6. AC excitation - ac conductivity measurements such as the PCRC humidity sensor, soil moisture blocks and conductivity cells require a precision ac excitation voltage to prevent polarization.

7. Frequency measurement - frequency output sensors such as anemometers and flow meters often required conversion to voltage before recording. Direct pulse counting inputs on dataloggers equipped with accurate timing record pulse signals, contact closures or magnetic ac signals directly.

<u>Resistance Measurements</u>

Ohm's Law, for linear components, describes the relationship between voltage, current and resistance:

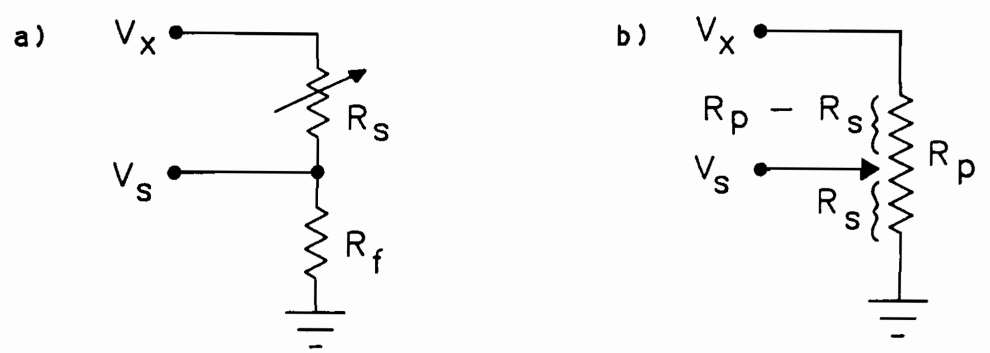
$$V = IR \qquad [1]$$

where the units are volts, amperes and ohms, respectively. This relationship is used to derive a voltage signal from resistive sensors. Figure 2 shows two **half-bridge** configurations: a) the sensor in series with a fixed resistor, R_f, and b) a potentiometer, R_p. The half-bridge is an example of a **single-ended** measurement, where the signal, V_s, is measured with respect to ground. If a known, precision voltage, V_x, is used to excite the half-bridge, V_s is related to the sensor resistance, R_s, as shown. Since the same current flows through R_s and R_f, Ohm's Law gives:

$$V_x = I\ (R_s + R_f) \qquad [2]$$

$$V_s = I\ R_f \qquad [3]$$

Taking the ratio, V_s/V_x, yields the expression for V_s. As R_s varies from 0 to a large value, V_s varies from V_x to 0 volts. Note that V_s is non-linear in Figure 2a, because R_s occurs in both the numerator and denominator; whereas V_s is linear with the potentiometer, because R_p is constant.



$V_s = V_x\ R_f/(R_f + R_s)$ $\qquad$ $V_s = V_x\ R_s/R_p$

Figure 2. Half-bridge a)Fixed Resistor b)Potentiometer

If R_s and R_f are about equal, V_s is approximately $V_x/2$. If, in addition, R_s varies only slightly, changes in the value of V_s are difficult to detect because the small changes occur about the large offset voltage, $V_x/2$. This is the situation with metal foil strain gages and PRT's, and a full bridge measurement is required as shown in Figure 3. The values of V_{s1} and V_{s2} in the two parallel current paths are given by:

$$V_{s1} = V_xR_f/(R_s + R_f) \qquad [5]$$

$$V_{s2} = V_x/2 \qquad [6]$$

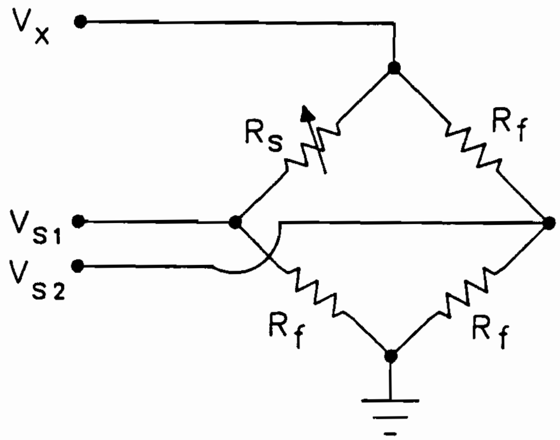


Figure 3. Full Bridge

If the measurement of V_{s1} is made with respect to V_{s2} instead of ground, the signal voltage, V_s, is given by:

$$V_s = V_{s1} - V_{s2} = V_x R_f/(R_s + R_f) - V_x/2 \qquad [7]$$

The large offset obtained with the half-bridge is removed and V_s reflects only the change in R_s.

The full bridge is a **differential measurement** and requires **differential inputs** on the datalogger to measure a voltage with respect to another voltage instead of with respect to ground. This function also rejects noise common to both signal leads.

<u>Current Measurements</u>

Current signals such as silicon cell pyranometers, are converted to voltage signals with a shunt resistor as shown in Figure 4. The voltage is described by Ohm's Law. The silicon pyranometer can be read as a single-ended measurement because the current return is held at the datalogger ground, but differential inputs are required if the return is at a voltage other than the datalogger ground.

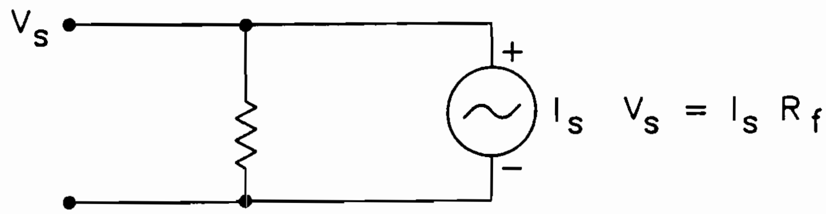


Figure 4. Use of a Shunt Resistor on a Current Signal

Resolution

An **analog to digital converter** (ADC) measures voltages and produces a digital code or number proportional to the measured value (the voltage controlled oscillator, not considered here, outputs a frequency). Since most digital systems are based on the binary number system, digital resolution often is expressed as the number of binary bits available to represent the full scale voltage which can be measured. One bit represents the smallest increment the maximum voltage can be divided into. For example, a 14 bit ADC can produce a maximum number of $2^{14}-1$ or 16383. If the measurement circuitry is designed such that 0 to 16383 represents 0 to 5V, one bit of resolution is 5V/16383 or about 300 microvolts. In practice, however, a number somewhat less than the maximum usually is used to represent the full scale voltage, for example 15,000. Dual polarity measurements, where both positive and negative voltages are accepted, decrease the resolution because the voltage range is doubled. In this example, the resolution is about 600 microvolts for a ± 5V input range.

Resolution and accuracy are oftentimes confused. In many applications, the detection of small changes in the signal is more important than measuring the signal value accurately. Load cell lysimeters, pressure transducer piezometers and thermal diffusivity soil moisture blocks are examples requiring high resolution. Use of the full input range yields the highest resolution. For example, a 0.1V full scale signal measured on a 1V input has ten times worse resolution than if it were measured on a 0.1V full scale input. A selection of input ranges on the datalogger accommodates this practice with dataloggers having programmable excitation voltages; a value can be selected such that the full scale signal from a resistance bridge matches the input range.

Accuracy

Measurement accuracy is the degree to which the measurement represents the real value and usually is expressed in terms of the error; e.g., 0.1% of reading or 0.1% of full scale range. Several sources of error contribute to the measurement accuracy, and all are a function of temperature. Voltage measurements require comparison of the input value to a voltage standard contained in the datalogger. The precision and stability of this standard, over the environmental temperature range, is contained in the accuracy specification. The use of processors has led to self-calibration techniques where measurements are obtained from various portions of the circuitry, in the absence of an input signal, and used to correct the measurement result numerically. These methods, along with advances in linear integrated circuits, attain accuracies found only in costly equipment a few years ago.

CLONAL PROPAGATION USING TISSUE CULTURE

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Many crop species can be regenerated through tissue culture to produce numerous individuals with special properties. In general current techniques of plant tissue culture are used only for the commercial propagation of ornamental plants such as orchids or Boston fern. Asparagus and oil palm are examples where crops of agronomic importance are being commercially propagated by tissue culture. Both of these crops have field life allowing the high per plant cost to be amortized over the life of the planting. The challenge of tissue culture production of elite germplasm *en masse* is to reduce the per plant cost down from the 0.50 to $2 cost of currently available plants.

Commerical Production of Disease Indexed Potato Using Meristem Culture

Potato is planted by "seeding" fields with tuber pieces rather than true seed. This practice has resulted in the establishment of at least seven viruses, three bacterial problems, and one nematode in North American seed potatoes. Infection of seed potatoes with these pathogens may result in yields ranging from imperceptible decreases to total loss of the crop. The cost of production of disease-free seed potato has, until recently, limited the availability of good quality seed potato. These programs are usually found in universities and the seed potato production costs have been largely borne by taxpayers rather than the end user. Establishment of methods to produce large numbers of potato plant or tuber units of high quality at low cost is one target we have. Systems now in place for commercial production of disease indexed potato tubers will be presented. Prospects for further development of potato cloning will also be discussed.

Artificial Seed Technology Applied to Vegetable and Field Crops

Many agronomically important crop species form embryos from tissue *in vitro*. This affords an opportunity to clone plants for breeding and propagation purposes on a large scale. Embryos can be produced on semi-solid medium or in liquid suspension culture. The latter system affords scale-up and mechanization of production facilities. Embryos can be encapsulated in a gel matrix to produce an artificial seed. The process for embryo production, encapsulation, and delivery; while still in a development stage; will be discussed.