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R E P C R T

STRENGTHINGING AGROMETEOROLOGICAL RESEARCH TO TO ENHANCE CROP PRODUCTION

New Delhi, India

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Consultant Report by

Wm. A. Dugas

Agricultural Research Project (386-0470)

Strengthening Agrometeorological Research to Enhance Crop Production Subproject

Implementation Order No. 104

Contract No. 386-00000-C-00-5039-00

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AGRICULTURAL RESEARCH PROJECT (386-0470)

IMPLEMENTATION ORDER NO. 104

TECHNICAL ASSESSMENT

SUBPROJECT: STRENGTHENING AGROMETEOROLOGICAL RESEARCH TO ENHANCE CROP PRODUCTION

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AICRPAM	All India Coodinated Program in Agricultural Meteorology
ARP	Agricultural Research Project
CRIDA	Central Research Institute of Dryland Agriculture
DST	Department of Science and Technology
GOI	Government of India
ICAR	Indian Council of Agricultural Research
ICRISAT	International Center for Research in the Semi-Arid Tropics
IMD	Indian Meteorological Department
SAC	Space Applications Center
USAID	U.S. Agency for International Development

Executive Summary

This subproject was designed to strengthen research capabilities in agricultural meteorology in ICAR by providing equipment, training, and technical assistance. It directly supports the ARP which states its purpose is ". . . to strengthen the Indian Agricultural research system's ability to conduct research on priority problems. . .." The following objectives were established: 1.) Model the interactions between weather and crops, 2.) Develop 'response farming' procedures, 3.) Develop crop yield forecasting models based on crop canopy spectral measurements, 4.) Develop techniques to use agrometeorological data for farm-level management decisions, and 5.) Assist in the development of the CRIDA.

The U.S. commitment to this subproject was $1,570,000, while that of the G O I was Rs. 6,999,000. Objective 1 received the most training and instrumentation. There has been no formal training on objective 2, but some of the instrumentation and training for objective 1 are applicable. Objective 3 has not received any formal training, but instrumentation was purchased. Objective 4 has received limited formal training. Objective 5 has been supported by computer hardware, personnel, and meteorological instrumentation deployed at the CRIDA. Consultants adequately conducted training activities and workshops. Appropriate instrumentation and training sites were selected.

Research progress for Objective 1 has been in the form of empirical regression relationships between yield and measured or derived climatic parameters. Research plans have been developed to quantify processes at work between crops and weather. Results for objective 2 include analyzed precipitation data for a number of locations and will provide necessary input data for developing 'response farming' procedures. For objective 3, experiments are ongoing evaluating a yield model using reflectance measurements. Little formal progress has been made on objective 4, although results from objectives 1 and 2 will apply.

U.S. inputs of training, technical assistance, and equipment have been essential for progress to date. Improved future cooperation with the U.S. is possible and likely. With this subproject, ICRISAT personnel and facilities could and should take a greater role. The U.S. has established some of the necessary requirements (e.g. training and equipment) that will enable this interaction with ICRISAT to increase and be productive.

Minor alterations are suggested in training activities. The purchase of additional equipment is critical for maintaining and improving subproject progress and, importantly, for capitalizing on the existing investment in several important other areas. This subproject has made a good start and the additional equipment will be well-used and is important to enhance prospects of cooperative research with U.S. and ICRISAT scientists.

I. Subproject Description

A. Purpose

1. Statement of Purpose

This subproject, approved in 1988, was designed to strengthen research capabilities in agricultural meteorology in ICAR by providing equipment, training, and technical assistance. For this subproject, USAID resources have been provided to facilitate the introduction of proven technologies for increasing both irrigated and dryland crop production by 1.) developing an understanding of crop-weather and crop-soil-water-management interactions and applications of these results, and 2.) strengthening the coordinating cell at the CRIDA, Hyderabad.

2. Linkage to Higher Goal

Given the higher goals in India to sustain natural resources and increase production of agricultural crops and the importance ICAR has place on increasing production and efficiency of irrigated farming (Rao, 1988), increasing the knowledge-base on the effects of weather on crops is critical. This improved knowledge-base will directly support strategic objectives for national planning (e.g. allocating research resources, identifying key regions for introduction of new crops, etc.) and tactical, on-farm decisions. This project directly supports the ARP which states its purpose is ". . . to strengthen the Indian Agricultural research system's ability to conduct research on priority problems. . . ." The ICAR has set a high priority on increasing agricultural production in the 'less-favourable' environments of India where weather and biotic and other abiotic factors may substantially limit production (I.P. Abrol, 1990, personal communication). Quantifying the effects of weather on agricultural crops will assist in this effort.

B. Specific Objectives

1. Statement of Problems/Constraints

Soil water availability is a major environmental factor affecting crop production, especially in dryland agriculture where soil water levels are primarily dependent upon the supply (precipitation) and withdrawal (evaporation) of water. This subproject focused on the interaction between crops and weather, with special emphasis on soil water, and on providing assistance to farmers for overcoming production constraints through the development and dissemination of agricultural weather advisories.

2. Descriptive Statement of Objectives

The following objectives and related methods were established for this subproject (ICAR, 1987):

a. Objective 1 (Crop-Weather Relationships): Study and model the influences of and interactions between crop genetic characteristics, weather parameters, soil properties and management decisions on crop water requirements, actual evapotranspiration, growth, and yield. This objective will be accomplished by establishing line-source irrigation experiments which simulate dryland to fully irrigated soil water conditions and by conducting detailed microclimatic studies quantifying relationships between plant response and microclimatic elements. Neutron probe measurements of soil water will be used for water balance calculations. Water production functions, i.e. linear relationships between crop yield and actual evapotranspiration (ET), as effected by fertilizer rates, plant populations, etc., will be determined from line-source irrigation experiments.

b. Objective 2 (Response Farming): Response farming means making strategic pre- and within-season management decisions (e.g. genotype, plant population, fertility) based upon expected crop yield. Procedures will be developed using : 1.) analogue modelling of historical rainfall patterns, accurate 3-10 day forecasts from DST, and/or accurate seasonal monsoon forecasts from IMD to estimate probable soil water conditions in approaching cropping seasons and 2.) results obtained under objective 1. Relationships will be developed, for example, between the date of monsoon onset or monsoon duration and total seasonal precipitation. These precipitation analyses will be hastened by the establishment of computerized agrometeorological data bases and analytical capabilities at subproject locations.

c. Objective 3 (Spectral Models): Develop crop yield forecasting models based on crop canopy spectral measurements as affected by crop growth and development, incidence of pests and diseases, and moisture stress. Spectral measurements will be made at Jodhpur, New Delhi, and Hyderabad. These, in conjunction with agronomic measurements (e.g. leaf area, above ground dry matter, etc.), would be used to develop the relationships.

d. Objective 4 (Agricultural Weather Advisories): Develop techniques to use agrometeorological data for tactical farm-level management decisions. This objective will be accomplished by combining research findings from weather forecasting (e.g. 3-10 day forecasts from DSTI and modelling studies (e.g. yield-ET relationships) to formulate recommendations to guide farmers and advisors on tactical management practices to achieve maximum production from specific crops in localized areas. Working linkages will be created with other ICAR projects engaged in on-farm trials and demonstrations.

e. Objective 5 (Assist CRIDA): Assist in the development of the CRIDA as the center for data compilation, analyses, and dissemination.

C. Input/Output Matrices by Objective

1. Specification of Inputs

a. U.S. The U.S. money commitment to this subproject was $1,570,000. This total was divided into training ($408,000), consulting services ($260,000), and equipment ($917,000). Training and instrumentation allocated to each objective are summarized in Table 1.

Appropriately, objective 1, quantifying relationships between crop production and weather, received the most training and instrumentation. The workshop by Dr. Taylor provided an introduction to crop models and PCs, while the workshop by Dr. Hanks provided training on establishing line-source experiments, calibrating neutron probes, operating data loggers, and developing yield-ET models, all of which are essential for progress on objectives 1 and 2.

There has been no formal training on objective 2, but training and a workshop should be provided (see Recommendations). The PCs could be used for data analyses. Results from line-source experiments and analyzed precipitation data could be used to develop software, probabilities, and data bases.

Objective 3 has not received any formal training. but is indirectly supported by training on objective 1 and directly supported by the spectral radiometers.

Objective 4 was partially covered in the training received at Iowa State University and University of Nebraska, but additional training on this objective is needed (see Recommendations).

Objective 5 has been supported by the computer hardware, personnel, and meteorological instrumentation deployed at the CRIDA.

b. G O I. The G O I commitment of money to this subproject was Rs. 6,999,000. This total was divided into pay and allowances (Rs. 5,528,000), T.A. (Rs. 257,000), recurring contingency (Rs. 914,000), and non-recurring contingency (Rs. 300,000).

The G O I deployed personnel for training on objectives 1 and 4 and on delineation of agroecological environments and Geographical Information System software. Training is planned on the spatial dynamics of insect pests; crop growth modelling and instrumentation; and line-source irrigation, water production functions, and instrumentation. The latter of these should be deleted and training and a workshop on agricultural weather advisories should be completed.

2. Specification of Linked Outputs

The combination of exposure to crop simulation models and micrometeorological instrumentation will provide an excellent opportunity for enhancing research capabilities of Indian scientists.

II. Technical Assessment

A. Input/Output Progress by Objective

1. Assessment of Inputs Provided

a. U.S. (Appropriateness, Timeliness, Quality)

1.) Expert consultants for workshops. Consultants hired for workshops were good scientists and were capable of developing and conducting the workshops. There was, however, uncertainty on their part regarding responsibilities of the U.S. and Indian leaders for the first two workshops (e.g. what materials consultants were to bring to India and who was responsible for 'leading' the workshop). This uncertainty has been clarified.

2.) Instrumentation. Appropriate instrumentation was purchased (Table 2). The following points are relevant:

a.) Delayed instrumentation delivery caused minor problems with successful completion of the first two workshops.

b.) Some instrumentation suggested in the design team report (Stewart and Dugas, 1988) has not been ordered (e.g. line-source irrigation systems). However, the G O I has allocated resources for their purchase; field research should begin in 1991.

c.) Additional instrumentation is needed (see Recommendations).

d.) Calibration standards have not been ordered and procedures have not been established for periodic re-calibration of radiation and humidity sensors at research stations. Instrumentation was compared at the CRIDA before field deployment. Procedures for repeating this need to be established. For example, annual checks ought to be made to ensure that sensors are within IMD specifications. Procedures for comparing temperature, precipitation, and wind speed measurements from instrumentation associated with this subproject and from IMD sensors at subproject locations need to be developed. Without both of these efforts, instrumentation will likely be useless in the near future.

e.) Scientists have received training on use of most of the instruments at the workshop led by Dr. Hanks. Training should be continued on this activity (see Recommendations). The purchase of this equipment provides an important opportunity to utilize this relatively small investment to bring much greater returns. This equipment, for example, provides for the possibility of closer linkages with crop modelers, inexpensive measurement of other important meteorological elements (e.g. UV-B), and possible interation with other disciplines (e.g. animal science, plant pathology, etc.). These oppourtinities should not be missed. Efforts need to be put forth to ensure it is used efficiently and properly.

f.) Appropriate software has been ordered for the subproject (Table 2).

g.) Computers purchased for the subproject are in line with those recommended by Hatch (1989) and are sufficient for subproject tasks.

3.) Training venues. U.S. training sites agreed with those recommended by the design team (Stewart and Dugas, 1988) and were appropriate.

b. G O I (Appropriateness, Timeliness, Quality)

1.) Personnel. Staffing of ICAR centers needs to be completed quickly. Without proper staff, returns on instrumentation and training investments will not be maximized. At present, 54 posts out of a total of 72 have been filled (Ramana Rao, 1990b).

2.) Training workshops. Workshop success has inreased with each one. Success of first two was limited by access to a sufficient number of adequate computers. This was less of a problem in the third workshop. This problem needs to be resolved by deploying at a location, either temporarily or permanently, a sufficient number of computers for workshop use. Pre-workshop training courses on basic microcomputer skills should be provided for workshop participants. The level of computer skills of workshop participants varies markedly. Therefore, workshops are not as efficient as they could be in accomplishing goals because 'background' material on microcomputer basics needs to be covered.

3.) Trainees.

a.) Trainees have varied in their background and capabilities for training activities. This has affected success of training activities. A common problem has been the lack of basic computer skills.

b.) Trainees should be given a pre-training course on microcomputer basics.

4.) Coordinating Committee. This committee has provided important guidance on training venues, trainee selection, instrumentation purchases, and project direction. It is essential for effective communication within India and between the U.S. and G O I.

2. Assessment of Outputs Achieved (Qualitative)

For the purposes of this subproject, outputs consist of research results or plans. Research plans should identify sites, timetables, objectives, methods (instrumentation, personnel, facilities, analytical procedures), expected results, and, perhaps most importantly, publication plans. Adequate research plans are especially important for objectives 1, 2, and 4. Some research plans have been developed (Ramana Rao, 1990b).

Research activity has varied for each objective:

a.) Objective 1 (Crop-Weather Relationships). Research results have primarily been empirical regression relationships between yield and measured or derived climatic elements. Although these are reasonable first efforts and useful to a limited extent, these results can be site-, crop-, and location-specific. Additional research is needed to quantify fundamental processes that are operating.

Several experiments have been and are being conducted which could be used to develop/describe these processes, but they often have been limited by the lack of critical measurements of radiation, canopy development, and soil water. This has been eliminated with equipment delivery.

Also, plans have been made to conduct future research wherein data could be collected to quantify these processes (Ramana Rao, 1990a). Appropriate crops have been selected and uniformity has been established on data collection, storage, and analyses, and experimental procedures. The latter includes number of replications, and measurements of phenological stages, yield components, soil moisture, and canopy development (determined from radiation interception measurements and measured leaf area). Subproject participants are to be commended for detailing such an thorough program.

Field experiments using line-source instrumentations will begin in 1991. ICAR funds have been provided for purchase of irrigation equipment for five centers following guidelines put forth by Stewart and Dugas (1988). Research plans similar to those described in the preceding paragraph need to be developed. Progress on this effort is critical to complete the 'response farming' package.

b.) Objective 2. Results for objective 2 include analyzed precipitation data for a number of locations. Primarily descriptive, these results (e.g. probabilities of weekly precipitation amounts) do, however, provide necessary input data for developing 'response farming' procedures. Extensive work has been completed, for example, on probabilities of precipitation amount and growing season length as a function of the timing of monsoon onset.

c.) Objective 3. Experiments are ongoing at Anand, in conjunction with the SAC, evaluating a yield model which requires inputs of canopy reflectance measurements. Experiments will be conducted at three subproject locations in 1991 in conjunction with the SAC.

d.) Objective 4. Little progress has been made on this objective. Significant progress on this objective in India is dependent upon establishment of the necessary data bases, models and associated software, and communications facilities.

e.) Objective 5. The coordinating cell at the CRIDA has been strengthened in terms of personnel and equipment.

An assessment of the progress made in training, instrumentation, and workshops provided by U.S. funds will be discussed individually. Most subproject activities have been concentrated in the past two years (Table 3).

a. Training in the U.S.

1.) Success of U.S. training activities depended upon trainee background and initiative and upon the 'fit' between trainee research objectives and training objectives. Trainees need to be encouraged to share experiences with others in subproject upon return to India (see Recommendations).

2.) Pre-trip briefing of Indian scientists on training objectives and activities has been insufficient. Timely pre-training briefings would enable them to prepare, for example, data sets for use in training activities. This lack of pre-training briefings has reduced the efficiency of training activities.

b. Workshops. Workshops have been successful and the success has improved with each one. This is partially due to increased awareness in India regarding logistics (computers, facilities, etc.) and to increased familiarity of workshop participants with microcomputers and software. For the first two workshops, misunderstandings existed on the part of the technical experts concerning teaching material required and responsibilities, respectively.

c. Expert consultants. Consultants have provided needed subproject input for planning (Stewart and Dugas, 1988) and directing workshops. A lead consultant should be retained to provide continuity, serve as a 'point of contact' for the ICAR coordinator, assist in the U.S., and provide technical guidance.

d. Instrumentation. Instrumentation purchased was appropriate, was needed, and could have a large impact on research in India.

B. Progress toward Objectives

1. Appropriateness of Objective Priorities

a. ICAR/SAU System. The ICAR system is ideal for this activity. It has the advantages of direct linkages with the state agricultural universities, working relationships with other government agencies (e.g. DST) and a history of interaction with U.S. universities.

Objective 1 (Crop-Weather Relationhsips). Quantification of the fundamental processes at work in relationships between weather and crop yield is critical. This quantification will allow research in India to go beyond its current level of descriptive climatic analyses (means and deviations of particular elements and agronomic measurements) and of developing empirical relationships (typically using least squares regression analyses) between yield and a number of climatic elements. Therefore, ICAR was correct is establishing objective 1 as a high priority.

Objective 2 (Response Farming). The application of 'response farming' to Indian agriculture is worthy of pursuit. If ICAR is interested in making rapid progress, it should involve Dr. Ian Stewart, an individual who knows the subproject, knows the response farming concept well, and is committed to its implementation. This activity should proceed after the first line-source results are available.

Objective 3 (Spectral Models). The importance of work on objective 3 is of lower priority. The relationship between spectral responses from crops and yield (or other agronomic parameters) is often not straightforward and equipment sophistication also complicates the task. Excessive resources (money and people) should not be expended on this marginal activity.

Objective 4 (Agricultural Weather

Advisories). ICAR was also correct in attempting to relate research to on-farm use. This objective needs more support by research, training, or workshops. There are several locations in the U.S. where operational agricultural weather advisories are being developed and disseminated (e.g. Clemson, SC; Raleigh, NC; Lincoln, NE; Urbana, IL). One or more of these locations should be integrated into the subproject. Given the existing relationship with the DST concerning use of 3-10 day forecasts in advisory development, the U.S. venue should be one where active National Weather Service participation exists. Investment of time and money on this objective need not wait until significant progress is made on objective 1.

Objective 5 (Strengthen CRIDA). The current effort to transform the AICRPAM coordinating cell into a National Research Center on Agrometeorology deserves consideration. Many of the efforts of this subproject are directly supportive of this effort.

b. Indian System. Non ICAR/SAU participants in this subproject include ICRISAT, DST, and SAC.

Objective 1 (Crop-Weather Relationships). This objective has a high prirority in the Indian system and most of the linkages are in conjunction with this objective. These are appropriate and should be expanded. For example, currently a peanut growth and leaf spot disease model are being evaluated by ICRISAT and subproject scientists at Anantapur and Anand (Ramana Rao, 1990b).

Objective 2 (Response Farming). This objective is marginally appropriate outside of ICAR/SAU.

Objective 3 (Spectral Models). This objective has relevance to the SAC because of the efforts to develop relationships between spectral measurements and crop response (canopy development, water deficit stress level, etc.) and the interests of SAC in satelitte observations, although direct linkages with and use of satellite observations are not a part of this subproject at present.

Objective 4 (Agricultural Weather Advisories). This objective is appropriate to IMD and DST. IMD is currently involved in developing agricultural advisories and as this subproject begins to generate information for them, interaction with IMD will be important. DST will interact by the possible future integration of the data sets and crop-weather relationships developed from this subproject with their 3-10 day forecasts.

Objective 5 (Strengthening CRIDA). This objective links with IMD. There should be close cooperation between ICAR and IMD on this effort.

2. Importance of U.S. Interests.

a. Current.

For all objectives, U.S. inputs of training, technical assistance, and equipment have been essential for progress to date. Additional input would be useful in developing and evaluating research plans (e.g. by the lead consultant).

b. Future.

Improved cooperation is possible and likely in the future. U.S. interests could again be essential. However, with this subproject, ICRISAT personnel and facilities could and should take a greater role. The U.S. has set up some of the basic requirements (e.g. training and equipment) that will enable this interation with ICRISAT to be beneficial and increase.

3. U.S. Role and Advantage in Cooperation

For all objectives the U.S. role (equipment, training, and technical assistance) has been critical for progress toward objectives. In terms of advantages for cooperation, the following can be summarized:

Objective 1 (Crop-Weather Relationships) and Objective 3 (Spectral Models). The advantage of U.S. cooperation on these objectives is access to Indian data sets for model development, validation, and calibration.

Objective 2 (Response Farming), Objective 4 (Agricultural Weather Advisories), and Objective 5 (Strengthening

CRIDA). No significant advantage in U.S. cooperation.

C. Progress toward Purpose

1. Relevance

a. ICAR/SAU System. Progress toward strengthening research capabilities has been excellent and on schedule. The instrumentation, increased computer expertise, and familiarity with crop simulation models are integral parts of this progress. It is now critical that this strengthening be translated into application. A detailed plan of work needs to be developed which outlines the steps by which agricultural weather advisories will be developed from this research. Some of the steps in the process would include the following:

1. Development of data bases (historical data and probabilities) for locations (Objective 2, estimated completion in about 12 months).

2. Development of crop-weather relationships (Objective 1, completion, 24 months).

3. Collection of 'real-time' weather data and weather forecasts for locations for which advisories are being developed (In conjunction with IMD and DST, 12 months).

4. Preparation of agricultural weather advisories (18-24 months).

Trainees in the U.S. have had excellent opportunities for exposure to U.S. science. For example, trainees at Texas A&M Univ. visited research locations in Lubbock, TX, Amarillo, TX, Davis, CA, and Mexico City and attended two scientific professional meetings. These two individuals probably interacted with about 30% of the agricultural meteorologists in the U.S.

b. Indian System. Non ICAR/SAU entitites are also conducting research which assists in progress toward this purpose. The assistance and training by ICRISAT is noteworthy here. Additional interaction and cooperation is needed between this subproject and IMD (e.g. data, advisory development and dissemination, etc.) to assure efficient use of resources.

2. Mutuality of Interests

a. Current.

1.) Data for model validation and calibration. Most simulation models developed in the U.S. have not been developed using nor tested against non-U.S. data. One of the strengths of the existing agrometeorological program in India is the multitude of locations collecting agronomic and meteorological data. (The latter is essentially complete given the instrumentation deployed in conjunction with this subproject). There is an excellent opportunity for a 'two-way' synergistic exchange here: U.S. expertise (models) toward the Indians and Indian data toward the U.S. Most model developers would welcome the opportunity to test their models in these different environments (physical and biological). The Indians benefit by increasing their knowledge of these models and applying them to Indian problems.

b. Future.

1.) Real-time weather data for crop assessment. With the establishment of satellite communication facilities between some of these centers and DST and with the addition of the instrumentation associated with this subproject, there could be a large increase in the amount and quality of 'real-time' weather data available for India. Government and private agencies in the U.S. could use this data.

2.) Access to unpublished information. With participation in this subproject, data, relationships, and results in notebooks or on computer files would be more accessible to researchers, government action agencies, and, to a lesser extent, private interests.

3. Follow-On Cooperation

a. Scientist to Scientist. Cooperative research between U.S. and Indian scientists could result because of the training activities of Indian scientists in the U.S. and workshops led by U.S. scientists in India. This activity could be enhanced by a follow-up visit by the management team to the U.S.

b. Inter-Institutional. Possible linkages exists here following the 'gateway' model, wherein a U.S. university could utilize the Indian contacts to apply, test, and develop research products. Examples of specific linkages that could be developed include:

1.) SAU/U.S. university. Given a similar interest in a commodity (e.g. groundnut) linkages could be set up wherein the Indian scientists would conduct the agronomic experiments in the field and they, in conjunction with the U.S. university scientists, would analyze the data to evaluate crop models.

2.) SAU/National Weather Service. When the Indian activities on developing and dissemination agricultural weather advisories develop, there could be linkages here also.

c. Within India. Significant potential exists for expanding the good existing interaction between subproject participants and ICRISAT. ICRISAT staff serve as valueable resource persons for training and workshop activities. Currently, there is a cooperative project underway between Dr. D. R. Butler, ICRISAT, and subproject scientists at Anand and Anantapur. This activity, validating and calibrating groundnut growth and late leaf spot simulation models, is exactly the type of cooperation this subproject should generate. Subproject scientists are conducting field research and are becoming familiar with the simulation modelsm while ICRISAT gets the opportunity to field test the models. The likelihood of success of this cooperative research has been substantially enhanced due to the instrumentation and training provided. This project would be further enhanced with the purchase of additional instrumentation (see Recommendations). The potential exists for additional cooperation verifying and developing other crop simulation models with the Natural Resources Planning group at ICRISAT.

Recommendations

The following recommendations are respectively suggested for action by USAID on this subproject:

A. Funds from this subproject or other subprojects should be provided to purchase the following additional equipment (Table 4):

1. Two additional data loggers per location (CR10s, a total of 32 at $1,000 per in the U.S.). These are needed because the one existing data logger at each location will be used for the automated weather station and another data logger is needed for intermittent measurements of light under and above crop canopies in various experiments. The latter measurements are critical for estimating canopy development. Without the second data logger, the light sensors will be essentially useless. The second additional data logger per location would serve as a back up and and for other miscellaneous purposes. Data loggers do break and meteorological sensors purchased are useless without a data logger. My experiences in the U.S. confirm that with experience and exposure the needs for and utility of these data loggers will increase dramatically. The second data logger was recommended by Stewart and Dugas (1988).
2. Disk-based tutorials for training on microcomputer basics (e.g. spreadsheets, DOS, and word processing).
3. Standards for radiation and infrared thermometer measurements (e.g. Eppley PSP pyranometer, cost ca. $5,000, and standard infrared thermometer, cost ca. $2,000). Instruments should be kept at the CRIDA..
4. Instrumentation spare parts including: batteries for data loggers, belts for leaf area meters, and

disks, computer paper, etc. for computers. A specific current need exists for floppies for training workshops (ca. 20/participant).

5. Leaf wetness sensors (approximately 100 total, made in India, total cost ca. $300), temperature humidity sensors (approximately 5 at $500 each), and spore traps (2 to 3 at approximately $500 each) for supplementing instrumentation required for the cooperative project with ICRISAT evaluating ground nut models.

6. Given the importance of environmental change on agriculture and society, it is appropriate to add the measurement of UV-B at about 2-3 subproject locations. These sensors (cost ca. $700 per) would be invaluable for expanding the global network of measurements of this agriculturally important element and, importantly, would provide an excellent opportunity for cooperation with U.S. scientists.

B. Encourage trainers in the U.S. to have Indian scientists present seminars and conduct mock training activities while in the U.S to better prepare Indian scientists to be active participants in workshops held in India.

C. Involve Dr. Ian Stewart for training on 'response farming'. Without his participation, this important objective will not be fully completed.

The following recommendations are respectfully suggested for action by ICAR on this subproject:

A. Send two Indian scientists for training on development and dissemination of agricultural weather advisories.

B. Ensure that adequate number of computers and acceptable facilities are available for future workshops.

C. Establish detailed research plans for line-source experiments.

D. Assist scientists at all locations to have daily meteorological data put into a consistent computer readable format.

E. Organize another training activity on simulation models and on instrumentation use, especially re-calibration and maintenance.

F. Maintain and improve administrative mechanisms to ensure close cooperation between the AICRPAM and other relevant ICAR projects (e.g. the dryland project). This is important to ensure that relevant applications of the research results from this research are made.

G. Encourage IMD to provide daily meteorological data for subproject locations to coordinating center at the CRIDA.

Table 1. Allocation of training and instrumentation to subproject objectives.

Objective	Training/ Workshop	Instrumentation	Comments
1. Yield-ET relationships	Hanks (UT), Taylor (IOWA), and Kanemasu (GA)	Neutron probe, leaf area meter, PCs, Met. Equipt.	Hanks: line-source Exp., data acquisition systems; Taylor: PC use; Kanemasu: Met. Instrumentation
2. Response farming	Hanks (UT)	PCs	
3. Spectral response of canopies	None	Spectral radiometers, PCs	
4. On-Farm management decisions	Taylor (ISU) Hubbard (NEB)	PCs	Limited
5. CRIDA strengthening	None	PCs	Training not applicable
Climatic character. and GIS software	Dugas (TX) and Hubbard (NEB)	PCs	Not original objective. Dugas: climatic charact. and GIS software, Hubbard: data base management.

Table 2. Instrumentation and software purchased for subproject.

Name	#	Appr. Cost (1000 $)	Del. date	Vendor	Comments
Met. Stations	16	179	13/4/90	Campbell Sci., Inc.	Data logger, stands, sensors, and spare parts
Leaf area meter	16	113		C.I.D.	
Soil moisture gauge	16	160		Troxler	Model 4302
Portable Sprectro-radiometer	4	120	3/11/90	Li-Cor	Model 1800-01B
Infrared thermometers	7	29	7/10/90	Tele-temp	Model AG42
Computers and software	16	198	ca. 6/90	Local (Comp.)	DOS, Wordperfect 5.1, Lotus 3.0, DBASE III Plus, Direct Access 5.0, Norton Utilities 5.0 Adv., Harvard Graphics, and SPSS/PC+

Table 3. Major events in subproject history.

Date	Event
6/87	PAMC approves proposal.
6/88	Design team (Drs. Stewart and Dugas) to India to prepare 2-yr. work plan.
7/88	PIL issued.
4/89	3-member management team from India to U.S. for study tour.
6/89	Trainees to Iowa State Univ. (ISU).
8/89	Trainees to Utah State Univ. (USU).
1/90	Trainees to Univ. of Nebraska (UNEB).
2/90	ISU workshop in India on introduction to PCs and crop models.
5/90	USU workshop in India on line-source experiments.
6/90	Trainees to Blackland Research Center (BRC).
10/90	Trainees to Univ. of Georgia (GA).
10/90	UNEB workshop in India on data base management.
11/90	Technical assessment of subproject by Dr. Dugas.
3/91	BRC workshop in India (tentative) on climatic characterization and GIS software.
7/91	GA workshop in India (tentative) on micrometeorological instrumentation.

Table 4. Recommended new instrumentation.

Items	No. of Items	Unit Cost $	Total Cost	Comments
CR10 Data logger	32	1,000	32,000	C.S.I.
DOS Tutorials	20	100	2,000	Local
Pyran- ometer	1	5,000	5,000	Eppley Lab.
Infrared Thermom.	1	2,000	2,000	Tele-temp
Spare Parts	16 sets	300	4,800	Misc.
Leaf wetness sensor	100	5	500	Contact: Dr. Butler, ICRISAT
Spore traps	5	500	2,500	Contact: Dr. Butler, ICRISAT
Temp./R.H. sensors	5	500	2,500	Vaisala from C.S.I.
UV-B sensors	3	700	2,100	Internat- al Light, Newberry, Mass. Model SUD 240/UVB- 1/W

Appendices

1. Terms of reference

To review progress of work done so far under the respective subproject _vis-a-vis_ that originally envisaged; to make a technical assessment of the results obtained; to identify constraints if any; and to make recommendations for feasible action aimed at maximising the outputs during the remaining life of the subproject.

2. Acknowledgements

I acknowledge the following individuals for their assistance:

Abrol, I.P. (DDG, ICAR, Delhi)

Becker, John (USAID, Delhi)

Bhatia, P.C. (Princ. Sci., ICAR, Delhi)

Bhatt, S. (Winrock, Wash, D.C.)

McClung, A. Colin (Coordinator, Winrock, Delhi)

Ramana Rao, B.V. (Project Coord., ICAR, Hyderabad)

Singh, M. (Sen. Sci., Winrock, Delhi)

Srinivasan, P.S. (Adm. Spec., Winrock, Delhi)

Virmani, S. (Sen. Sci., ICRISAT, Hyderabad)

Williams, Floyd (Winrock, Wash, D.C.)

Appreciation is expressed to Drs. S. Virmani and M. Singh and Mr. Ramana Rao for insights for this assessment.

3. Itinerary and persons visited

10/11/90: Travel via Pan Am from Killeen, Texas to New Delhi, India.

11/11/90: Continue with travel.

12/11/90: Arrive in New Delhi. Visit with Colin McClung, Maharaj Singh, and John Becker regarding assignment at Winrock offices.

13/11/90: Visit in a.m. with M. Singh and C. McClung at Winrock office. Travel with M. Singh to ICAR and visit Drs. Abrol, Bhatia, and G.B. Singh. Back to hotel to work. In p.m. visit with Drs. R.K. Datta and Dr. J. Bahahur, Dept. Sci. and Tech. and Dr. D.R. Sikka, Indian Inst. Trop. Meteorol., at Dept. Sci. & Tech. regarding short range weather forecasts and their relationship to subproject efforts.

14/11/90: Work on report in hotel. In p.m. take IC #540 flight to Hyderabad.

15/11/90: Visit with Mr. Ramana Rao at the CRIDA regarding subproject progress and plans.

16/11/90: Visit with Drs. Butler, Virmani, and Monteith at ICRISAT regarding interactions between ICRISAT and subproject. Work on report in afternoon at the CRIDA. Visit with Dr. Chetty, Acting Chief, CRIDA.

17/11/90: Visit with Dr. Virmani, ICRISAT, on subproject assessment. In a.m. take IC#440 to Delhi. Work on report in afternoon at Winrock offices.

18/11/90: Work on report in a.m. and in p.m. at hotel.

19/11/90: Work on report at Winrock office. Visit with Colin McClung regarding report.

20/11/90: Submit draft copy of report to Winrock. Continue working on report.

21/11/90: Work on report. Review draft with Colin McClung and M. Singh at Winrock. Meet with J. Becker, C. McClung, M. Singh, and J.S.P. Yadav to discuss report. Prepare bio sheet and brief on report for circulation at seminar.

22/11/90: Work on report.

23/11/90: Submit final report to Winrock. Give seminar at USAID, S. Bldg. and at ICAR on report.

24/11/90: Leave on Pan Am at 0330 for U.K.

25/11/90: Holiday

26/11/90: Visit with agricultural meteorologists at Institute of Hydrology, Wallingford, U.K., regarding ET modeling and crop-weather relationships.

27/11/90: Travel on Pan Am from U.K. to Killeen, TX.

4. References

Hatch, C.R. 1989. Agroforestry-Agrometeorology subproject computer consltancy. Consultancy report to Winrock International for U.S. Agency for International Development, New Delhi, India, 15 pp.

ICAR. 1987. Strengthening agrometeorological research to enhance crop production. ICAR and USAID/New Delhi.

Ramana Rao, B.V. 1990a. Proc. of the 3rd Work. of the All India Coord. Proj. on Agromet. 26-28 May 1990. CRIDA. 41 pp.

Ramana Rao, B.V. 1990b. Proj. Coord. Report, All India Coord. Proj. on Agromet. May 1990. CRIDA. 35 pp.

Rao, G.V.K. 1988. Report of the ICAR review committee. ICAR, New Delhi, India, 170 pp.

Stewart, J. I, and W. A. Dugas. 1988. Strengthening agrometeorological research in India. Consultancy report to Winrock International for U.S. Agency for International Development, New Delhi, India, 25 pp.

VITA

WILLIAM A. DUGAS

Prepared: 22 November 1990

PERSONAL DATA

[redacted]

EDUCATION

Ph.D., Utah State University (Nov. 1979)
M.S., University of Illinois (May 1976)
B.S., California State University -- Chico (May 1973)

PRESENT POSITION AND DUTIES

Associate Professor, Texas Agricultural Experiment Station, Blackland Research Center, 808 E. Blackland Rd., Temple, TX 76502. I conduct research measuring and modeling evaporation from croplands and rangelands. Measurement techniques used include lysimeters, micrometeorology instrumentation, and sap flow gauges. I supervise post-doctorate and M.S.-level scientists.

PROFESSIONAL AND HONOR SOCIETIES

American Meteorological Society
American Society of Agronomy
Sigma Xi

TOTAL PUBLICATIONS

Scientific articles	46
Progress reports and Misc. publications	13
Published abstracts	13

CONTRACTS AND GRANTS

USDI/Bureau of Reclamation ($55,000 for FY82-83)
USDA/Statistical Reporting Service ($120,000 for FY83-84)
USDA/BARD ($55,000 for FY83-85)
USDA/Statistical Reporting Service ($70,000 for FY85-86)
USDA/BARD ($105,000 for FY88-89)
Brookhaven National Laboratory ($9,000 for FY90 and FY91)
USDA/Soil Conservation Service ($146,100 for FY90-93)
Winrock International ($38,039 for FY90)