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IRRIGATION SYSTEM MANAGEMENT RESEARCH

IMPROVING ON-FARM WATER USE AND APPLICATION (ISM/R-PARC COMPONENT)

FINAL REPORT

WATER RESOURCES RESEARCH INSTITUTE
NATIONAL AGRICULTURAL RESEARCH CENTRE
PAKISTAN AGRICULTURAL RESEARCH COUNCIL
ISLAMABAD

MAY, 1993

1. PROJECT BACKGROUND

1.1. NAME OF PROJECT	Improving Efficiency of On-Farm Water Use and Application (ISM/R-PARC Component).
1.2. AUTHORITIES AND PERSONNEL	
- Sponsoring	Ministry of Water & Power, Govt. of Pakistan.
- Execution	Pakistan Agricultural Research Council (PARC), Islamabad.
- Operation & Maintenance	- National Agricultural Research Centre (NARC) Islamabad. - University of Agriculture, Faisalabad (UAF) - MONA Reclamation Experimental Project (REP), Bhalwal. - Sind Agricultural University (SAU), Tandojam. - NWFP Univ. of Engg. & Tech., Peshawar (EUP) - Deciduous Fruit Development Centre, Sariab, Quetta. - Agri. Res. Instt. for Northern Areas (KRINA), Gilgit. - Coordinating Unit (PARC), Islamabad.
Coordinator July 1990-Oct. 1991	Dr. Zahid Hussain Director (LWR), PARC, Islamabad.
November 1991 to June 1993	Dr. Shahid Ahmad Director, WRRI, NARC, Islamabad.

Research Leader	Dr. Shahid Ahmad. Director, Water Resources Research Institute, NARC, Islamabad.
Principal Investigator	- Dr. Shahid Ahmad Director, WRRI, NARC, Islamabad. - Mr. Arshad Ali, Chairman Department of Irrigation and Drainage, Univ. Agri., Faisalabad. - Mr. Abdullah Khan, Project Director, MONA (Rec) Expt. Res. Stn., Bhalwal. - Dr. M. Nisar Memon, Associate Professor, Deptt. of Irrig. & Drg., Faculty of Agri. Engg., Sind Agri. Univ., Tandojam. - Mr. Nek M. Tareen, Project Director, Deciduous Fruit Development Centre, Quetta. - Deputy Director, Agri. Res. Instt. for Northern Areas (KARINA), Gilgit.

1.3. PERIOD 36 months (July 1990-June (1993)

1.4. RELATIONSHIP OF THE PROJECT WITH THE OBJECTIVES

Irrigation is essential to intensive agricultural productions in Pakistan. Irrigated agriculture is located largely in the Indus Plain and on alluvial fans in the hilly and mountainous areas. Farms and fields are relatively small, farming is labour rather than capital intensive, and grower literacy rate and economic status are relatively low. The main water source in the plain is the Indus river and its tributaries, augmented by an increasing number of public and private tubewells. River water is delivered to farm by the old

and established Warabundi system on a rotation schedule. Private wells are usually operated on demand. With some exceptions, the volume of water available tends to limit otherwise attainable cropping intensity. In the hilly areas water is usually obtained from adjacent mountain streams for delivery to fields under a similar rotation schedule. Karez and sailaba systems serve relatively small and isolated areas.

The production system has served nation relatively well to date, providing a stable agricultural base and employment for a large segment of the population. Nevertheless, production remains below its potential in several respects. This is due in part to several adverse conditions that have developed or persisted over the years, including poor land drainage, salt accumulation, low soil fertility, inadequate disease and pest control, and less than optimum use of available water. Some aspects of current irrigation practices, therefore, invite refinement.

The GOP with help from other countries has addressed these problems for years, with considerable success in certain aspects including performance of delivery canals. Relatively less progress has been made in the effectiveness with which water is applied to and used by the crop. Water application practices at the farm have been observed to vary from good to poor, with abuses often contributing to watertable rise and restricted crop yields. Since the transformation of water into crop yield occurs on the field it is essential that water application procedure, therefore, shall be as effective as circumstances permit. Where improvement elsewhere allow more water to reach the fields this salvaged water must be used effectively if full advantage of those improvements is to be realized.

Water use efficiency (Ewu) is the ratio of crop yield divided by the amount of water applied to the field to produce that yield. As a measure of production per unit of water used, it is a useful term where water limits production. High values are desirable for both growers and society. High values are also attainable, even in labour-intensive developing countries. The term Ewu is used in this proposal as one indicator of the effectiveness with which irrigation water is used under the conditions being tested. It, therefore, is a basis for comparing combinations of systems and practices. In this proposal its scope is limited to water used on the field, including precipitation and irrigation. Water lost elsewhere in the system is not included, nor are factors that influence crop yield other than water.

High Ewu can be attained by high crop yield (numerator), low water use (denominator), or both. Obtaining good yield with crop requirement and ability to meet that requirement efficiency. Efforts to attain high Ewu therefore, invite attention to (1) crop water requirements, (2) water application methods, and (3) the water application practices

used with those methods. In Pakistan, these efforts must conform to the flow rate and time constraints of the well established water delivery system. At present, we have considerable research data available about crop water requirements, soil-water-plant relationships and water and soil characteristics which need to be organized and documented so that required information can be extracted and/or generated for further use at farm level. In the beginning such information can be used to develop management strategies for water use at farm level under small scale farmers managed irrigation systems in Pothwar and Northern Areas.

1.5. CAPITAL COST: Rs. 3.3 million (local currency).

1.6. OBJECTIVES:

The ISM/R project seeks to increase the effective use of water through research to increase agricultural production, productivity and farmers income. Through institution - building and priority research activities, the project will improve the capability of scientists and institutions to conduct irrigation research. The specific project objectives are:

a. Develop, test and adapt improved and practical procedures for surface irrigation application methods (level borders, etc.);

b. Develop, test and adapt practical irrigation procedures for specialized irrigation systems (sprinkler and trickle);

c. Develop, test and adapt various management strategies for improving water use efficiency at farm level under small scale farmers managed irrigation systems.

1.7. PROJECT BACKGROUND

The GOP-USAID Irrigation System Management - Research (ISM/R) Project was introduced to support and train Pakistani researchers addressing irrigation related problems. ISM/R project now underway deal only indirectly with the impacts of on-farm water application methods and associated practices on crop response and water use. Considering their potential benefits to Pakistan, additional work on these topics were included in the ISM/R Programme during 1990 to stimulate and coordinate local research. The proposal was intended to accomplish such augmentation.

Based on this document, USAID developed PIL-249 by which the IMS/R activity was extended to include studies in water

application methods and practices to increase efficiency of on-farm water use and application in major irrigated areas of Pakistan.

1.7.1. Water Application Methods - Surface

In much of Pakistan, irrigation water is delivered on a rotation basis, usually weekly and for durations determined by watercourse command area. The use of what may be relatively large streams for short durations on flat fields with limited resources has encouraged widespread use of flooding, which with furrows and basins, is called a "surface" method. Pakistan's heavy dependence on surface irrigation generally and flooding in particular will continue. It is, therefore, desirable that these systems be made to operate as efficiently as circumstances permit.

It is commonly accepted that depths of water of less than about 80 mm (3 inches) per irrigation are difficult to apply with existing application systems. While 80 mm or more applied under weekly Warabundi rotation can sustain most crops grown in the region, the precision required for high yields and economic efficiency is lacking. Drought-induced crop stress occurs if irrigation is delayed even a few days, depressing crop yield and quality. Irrigation sooner than needed, or with more water than needed, invites undesirable drainage expense, water loss and development of soil salinity.

The extent to which improvement in performance of surface systems can be achieved under Pakistani conditions is not clear. However, some opportunities do exist. Furrow and bedding techniques are known to be beneficial in certain situations. Improvement elsewhere is being made through the use of advanced irrigation hydraulics, computing, and new concepts such as surged inflow and automation. Because surface irrigation will remain dominant, it is desirable that the research community determine whether, and how, similar improvements might be used in Pakistan.

Some work has been done or in progress on level basin, furrow and border irrigation at MONA, UAF, SAU, LIM and NARC. These research activities were conducted to compare the amount of water used and yield obtained under different systems. The information about theoretical framework and control environment test data is completely lacking. The soil, streamsize and field size information is compulsory to transfer the technology to farmers fields. Therefore, systematic research is needed to develop theoretical framework, collect control environment test data, evaluate system performance parameters in farmers fields, validate computer models using field data and develop criteria for technology transfer. The research work already done will help to develop the theoretical framework.

1.7.2. Water Application Methods - Special

Interest is being expressed by some innovative growers and researchers in other water application methods, as a group designated here as "special use" methods. These include sprinklers, both large and small, and the micro systems comprising drip and its modifications. In isolated situations, these spacial methods, may be more advantageous than the common surface methods. Depending upon the system, advantages reported elsewhere include (1) localized application of water to roots, (2) reduced evaporation and seepage losses, (3) improved crop responses, (4) more effective use of brackish water, (5) more effective irrigation, germination and leaching, and (6) more precise moisture control required for specialty crops. While rotation delivery, as well as energy and water quality limitations, tend to discourage use of these special methods in most situations, any advantages in special instances should be identified for interested growers and agencies.

There is a need to use the concept of these special systems and to develop modifications which suit the farmer's conditions, especially the cost effectiveness. For example, the use of tube delivery concept to irrigate the round basins in orchards seems feasible for Pakistani conditions for matured orchards. The interventions for young orchards where the farmer grows another crop seem rather difficult.

In the past decade some research and development activities has been initiated on sprinkler and trickle irrigation systems. The DFDC, Quetta is engaged in trickle irrigation on a large scale fruit plantation, whereas, NARC is trying to develop a low-cost raingun sprinkler irrigation system. The research in this area also needs a systematic effort with an objective to explore possibilities for the development of a simplified low-cost technology for introduction under Pakistani conditions. This will include theoretical framework, evaluation of system performance parameters, guidelines for the selection, design, layout, and installation of such systems, and collaboration with the local manufacturers. The primary objectives will be to develop low-cost technology by involving the local industry so that the research results can be transferred to the end users. The potential areas for the adoption of this technology are: Baluchistan, Northern Areas and Barani areas of Punjab and NWFP.

1.7.3. Water Application Practices

In general, growers must decide frequently when each crop will be irrigated and how much water will be applied to meet crop requirements. In Pakistan, where water is delivered in a fixed flow rate on a fixed rotation, grower decisions are simplified to selection of which fields will receive water and for how long. If well water is also available flexibility is

increased and the decision making is more complicated. Experience, suggests that irrigation decisions can often be improved if grower's experience, valuable as it is, is supplemented by other information in some appropriate form.

In more developed agriculture, irrigations are increasingly being based on measured or predicted moisture status of the crop or soil. Techniques vary from simple soil moisture sampling to sophisticated water budget and crop response predictors, and are used for both long-term planning and real-time scheduling.

Such technique have understandably received little attention in Pakistan to date since water is generally not available on demand and other deep seated conditions discourage change. It is probable, however, that some benefits can be found even within these constraints. Under a fixed rotation delivery, better information on crop sensitivity to water stress during the growth cycle and on current crop and soil moisture status may permit more timely selection of irrigation turn and set time for each crop. Where additional water is made available through tubewells or other improvements, flexibility no options are increased. Movements towards higher crop quality and high value moisture sensitive crops requires greater precision in water application. As such technologies are introduced, irrigation options and the care required in their selection will increase. Research is needed to help growers select wisely from options available as they change with time.

The computer models and simulations provide a cheeper way to simulate management strategies to improve the water use efficiency at farm level. Such simulations can help to improve our knowledge about the understanding of problem and the development of solutions. This will also help to select the best possible combinations for field evaluation in order to reduce the cost of field experimentation. The development of database considering soil, water, crop and climatic aspects is one of the pre-requisite for such an activity. The NARC has taken a lead in this area where an interdisciplinary team has been developed to initiate such an activity. The team includes agricultural engineer (soil and water), agronomist, soil conservationist, ecologist, agricultural meteorologist and watershed management specialist. This activity requires an interdisciplinary effort which is at present available at NARC, Islamabad.

2. RESEARCH FINDINGS

2.1. WATER APPLICATION METHODS - SURFACE

2.1.1. LEVEL BORDER IRRIGATION

2.1.1.1. Methodology

A coordinated research project was undertaken with the Water Resources Research Institute (WRRI) at the National Agricultural Research Center (NARC) as the coordinating unit under ISM/R Project. The institutions involved in this research project were in areas representing different soil types: Sindh Agricultural University (SAU), University of Agriculture, Faisalabad (UAF) and University of Engineering and Technology, Peshawar (UEP).

Physicochemical analysis of the experimental fields at these institutions was carried out and is shown in Table 1. Besides, data regarding soil moisture characteristics, bulk density etc. were also collected. The results obtained from UAF and UEP collaborating institutions are included in the paper.

The surface 30 cm soil was used to estimate the frequency of irrigation. The required depth of irrigation was computed to bring the soil moisture of 90 cm to 120 cm profile to field capacity. The net irrigation depth was applied and the cutoff time was computed. The flow rate was very precisely metered through the use of two discharge measuring devices (broad crested weir and cut throat flume) installed at the upstream section of the watercourse. The following data were collected for each irrigation.

- Soil infiltration characteristics
- Soil moisture content pre- and post-irrigation
- Soil moisture deficiency
- Advance, recession and cutoff time
- Irrigation performance parameters such as application efficiency (Ea), storage efficiency (Es) and distribution efficiency (Ed)

2.1.1.2. Results and Discussion

Irrigation systems are normally designed based on the performance parameters like Ea, Es, Ed and deep percolation ratio. In this study, the deep percolation ratio was not involved as the net depth of water required was applied at each irrigation. Thus Ea, Es and Ed parameters recommended for evaluation of the level borders were used. Since deep percolation and runoff were nil, all irrigation events were under irrigation indicating the Ea of 100%.

Storage Efficiency (Es)

The average values of Es on 30 m, 60 m and 90 m length borders with different stream sizes are given in Tables 2 and 3. It was found that Es is a non-linear function of the border length as well as of the stream sizes. However, at UAF, Es increased linearly with increasing stream size in 60 m border.

The maximum Es was obtained with 3 l/s/m discharge in 60 m border length under sandy clay loam soil conditions. At Peshawar where soil was of heavier texture (clay loam) the highest Es was obtained with 3 l/s/m discharge on 90 m border.

Statistical analysis of UET Peshawar data revealed that there was no significant difference among different discharges, border lengths (Table 4) and over all variation in the Es was less than 5%. While the analysis of UAF data showed that Es is highly affected by border length, the stream size, however, does not show any significant effect on Es (Table 5).

Prediction of Es

Non-linear multiple regression equations were developed for predicting the Es as a function of border length (L), stream size (Q), and cut off time (Tc). For clay loam soil of Peshawar unit, the equation is given below:

$$Es = \ln(e^{91.07} + 1.15x10^{36} e^{L} + 24.34 e^{Q} - 6.8x10^{-15} e^{Tc})$$

where: Es = Storage efficiency (%)
L = Border Length (m)
Q = Stream size (l/s/m)
Tc = Cut off time (minutes)

The value of coefficient of determination (R^2) for the above equation was 93%. The observed and predicted values of Es are given in Table 6. All the points are clustered around the 45 degree line. It thus shows that this equation can be used as a very good predictive model for Es.

The predictive regression equation for sandy clay loam soil of UAF unit is given below:

$$E_s = 68.249 T_c^{0.0515} e^{(-1.569x10^{-46} e^{L} + 7.049x10^{-13} e^{Q})}$$

The value of R^2 of the above equation was not very high (65%). Even then, it can predict data which may be very close to the actual/observed Es as indicated in the Table 7.

Distribution Efficiency (Ed)

The average values of Ed for different border lengths and stream sizes are given in Table 8 and 9.

On clay loam soil of Peshawar unit Ed was found to be a non-linear function of border length and stream sizes. The statistical analysis of the data revealed that stream size has a highly significant effect on Ed, but the effect of border length is non-significant at 5% probability level (Table 10). The stream size of 3 l/s/m for 90 m border gave the highest Ed of 98%.

On sandy clay loam soil at UAF, Ed was found to decrease non-linearly with an increase in the border length. However, Ed increased nearly linearly with increasing stream size for each border length.

The statistical analysis revealed that both border length and stream sizes had a significant effect on the Ed (Table 11). The highest Ed was obtained on 30 m and 60 m borders with a stream size of 3 l/s/m.

Prediction of Ed

Non-linear multiple regression equations were also developed for predicting Ed as a function of border length, stream size and cut off time. For clay loam soil of Peshawar unit the equation is given below:

$$E_d = 98.578e^{(-9.4x10^{-16}e^{L}-1.7x10^{-43}e^{Q}+1.06x10^{-57}e^{T_c})}$$

The observed and predicted values of Ed are given in Table 12 which showed agreement between the two values because of the high value of R^2 (94%).

For sandy clay loam soil of UAF unit, the predictive regression equation is given below:

$$Ed = \frac{93.075e^{(-1.36x10^{-40}e^{L}+4.934x10^{-15}e^{Q})}}{T_c^{0.0156}}$$

where: Ed - Distribution efficiency (%)
L = Border length (m)
Q = Stream size (l/s/m)
Tc = Cut off time (minutes)

The predicted Ed of the above equation were compared with the actual/observed data for different stream sizes and border lengths (Table 13). The data showed an agreement between the predicted and observed distribution efficiencies because of the high value of R^2 (94%). The above equation can thus be used with great confidence for predicting Ed.

2.1.1.3. Conclusions and Recommendations

- On clay loam soil, a unit stream of 3 l/s gave the highest storage (93.42%) and distribution (99.05%) efficiencies on 90 m border length. The same unit flow when used on sandy clay loam soil gave the maximum storage and distribution efficiencies of 93.76% and 90.54%, respectively, on 60 m border length. In the light of this analysis, it is recommended that for clay loam soil, 90 m border length should be used when a unit stream of 3 l/s is available. However, under sandy clay loam soil conditions, 60 m border length will give most efficient results with this unit stream.

- Non-linear multiple regression equations developed for predicting the storage and distribution efficiencies gave quite compatible data and thus can be used with confidence when data regarding stream size, border length and cutoff time are available.

2.1.2. LEVEL BORDER APPLICATION EFFICIENCY UNDER DIFFERENT SOIL SURFACE CONDITIONS

2.1.2.1. Methodology

Field experiments were conducted to determine irrigation application efficiencies, coefficient of uniformities and distribution uniformities on level borders under different soil surface conditions at the NWFP Agricultural University Farm, Peshawar. In this study, three different lengths of borders with constant widths of 8 m and stream sizes of 1 l/s/m, 2 l/s/m, and 3 l/s/m were used to evaluate surface irrigation performance parameters. Irrigation water was applied to the border strips at Management Allowed Deficit (MAD) of 65%. The amount of irrigation water applied to each border strip was equal to the Soil Moisture Deficit (SMD) up to a soil depth of one meter. The dominant soil class at the site was clay loam with an average sand content of 44.2%, silt 33%, and clay 22.8%. The average bulk density found was 1.60 g/cm^3, field capacity 32% (on volume basis) and permanent wilting point 18%. The chemical analysis of the water from Warsak gravity canal used for irrigation, showed pH of 8.2, EC of 0.19 and SAR of 0.77.

Experimental Design

This study consisted of two factors at three levels under three different soil surface conditions:

- Stream sizes of 1 l/s/m, 2 l/s/m, and 3 l/s/m
- Border lengths of 30 m, 60 m, and 90 m
- Soil surface conditions

  . Fresh tilth
  . post irrigation
  . under maize crop and were replicated randomly three times

There were nine total treatments, which were replicated three times for each soil surface condition.

Soil samples were collected at the middle, head and tail of each border strip before irrigation to determine soil moisture deficit (SMD) up to a depth of one meter soil profile. Before each irrigation, cumulative infiltration with time was determined at three locations randomly in the nine border strips. Depth of water applied was equal to SMD at each border strip, flow rate was measured with the help of an 8 in. cut-throat flume installed at the inlet of the field ditch. During all irrigation events, advance and recession data were collected in each grid (8 m x 5 m) of the border strips.

Relationship between cumulative infiltration with time for three soil surface conditions was developed by using nonlinear regression analysis (SAS, 1982) . The application efficiencies, distribution uniformity and coefficient of uniformity was determined from advance and recession curves for each border strip.

2.1.2.2. Results and Discussion

The data collected from three different stream sizes and border lengths under different soil surface conditions were analyzed to determine the irrigation performance parameters (irrigation application efficiency, distribution uniformity and coefficient of uniformity).

Infiltration

Double ring infiltrometers were used to determine the cumulative infiltration with time before irrigation, for three different soil surface conditions. Parameters in Kostiakov Equation and Modified Kostiakov Equation were determined from the infiltration data by using non-linerar regression. There was relatively less (about 5%) variability in slope of the Kostiakov's Equation under maize crop and post irrigation soil surface conditions. However, the slope was 46% greater under fresh tilth soil condition than crop and post irrigation surface conditions. The Modified Infiltration Equation

predicted the depth of water infiltrated within 5% of the observed values, while the Kostiakov's Equation was too low by about 40%. Therefore, Modified Equation was used to compute the depth of water infiltrated from infiltration opportunity time. In general, the steady state infiltration rate was 6 mm/hr at the site.

Advance and Recession Times

The maximum variability in advance time for a border strip (90 m x 8 m) was 83.45% between fresh tilth and crop conditions for a stream size of 1 l/s/m. However, the difference in advance time decreased (32%) with increase in stream size (3 l/s/m) for the above-mentioned conditions. The difference in advance time was less than 10% between post irrigation and crop conditions for the same border strip, with stream sizes of 1, 2, and 3 l/s/m. It is obvious that stream size of 1 l/s/m took almost three-fold more time to reach the lower end as compared to the stream size of 3 l/s/m under fresh tilth soil surface condition. However, the difference in advance time for stream sizes of 2 l/s/m and 3 l/s/m was less than seven minutes for the border strip (90 m x 8 m) under the three soil surface conditions studied.

The infiltration opportunity time varied the greatest for fresh tilth soil surface condition as compared to crop and post irrigation conditions.

Application Efficiency

The application efficiency for three different soil surface conditions, stream sizes and border lengths are shown in Table 14. The average application efficiency varied from 93.71% (minimum) to 96.76% (maximum). Researchers reported greater variation in application efficiency in Pakistan. Statistical analysis performed on the application efficiencies revealed that there was significant difference among the border lengths, and stream sizes at probability level of 0.5%. Fresh tilth soil surface condition as compared to maize crop and post irrigation soil surface conditions also showed significant difference (Table 15). The overall variation in application efficiencies was about 3%. The mean variation in fresh tilth compared to post irrigation and crop condition was less than 1%. Similarly, the mean variation in application efficiency among the stream sizes 1 l/s/m, 2 l/s/m and 3 l/s/m as well as borders lengths 30 m, 60 m, and 90 m was about 1%.

Distribution Uniformity (DU)

The average distribution uniformity ranged from 93.19% (minimum) to 99.58% (maximum) under three different soil surface conditions, stream sizes and border lengths (Table 16). The maximum ratio of advance and infiltration opportunity time in the study was less than 0.35 %. The overall mean distribution uniformity for post irrigation and maize crop

condition was about 98%. However, for fresh tilth conditions, it was about 97%. In general, there was no significant difference between distribution uniformity under crop and post irrigation conditions (Table 17). Under fresh tilth soil surface conditions, the distribution uniformity was lower. The distribution uniformity increased with increase in stream size and decreased with increase in border length significantly. However, the difference in DU for all treatment combination was less than 7%.

Coefficient of Uniformity (CU)

The Christiansen coefficient of uniformity (CU) was determined. The average CU varied from 95.26% (minimum) to 99.69% (maximum) for the three different surface conditions, stream sizes and border lengths studied (Table 18). The overall difference in CU was found less than 5%. Similar to DU, there was no significant difference in CU between post irrigation and crop condition (Table 19). However, the fresh tilth soil surface condition showed significant difference in CU in contrast to post irrigation and crop conditions. An increase in stream size from 1 l/s/m to 3 l/s/m increased CU, and with increase in border lengths (30 m to 90 m) decreased it significantly. Compared to CU, DU showed slightly greater difference in all treatments combination .

2.1.2.3. Conclusions

- The average steady state infiltration rate of the soil (clay loam) at the site was 6 mm/hr, which can be categorized as low intake family.

- The advance time for stream sizes 2 and 3 l /s/m was two to three times less than that for 1 l/s/m for the border lengths of 60 m and 90 m, respectively. However, very little difference occurred in advance time of 2 l/s/m and 3 l/s/m stream sizes for the border lengths of 30 m, 60 m, and 90 m.

- The advance time for fresh tilth soil surface condition under stream size of 1 l/s/m and for a border strip (90 m x 8 m) was about two-fold as compared to post irrigation and crop conditions.

- The application efficiencies increased with increase in stream sizes (1 l/s/m to 3 l/s/m) and decreased with increase in border lengths (30 m to 90 m) significantly. The application efficiency ranged from 93.71% to 96.76%. The application efficiencies under fresh tilth soil surface condition was significantly lower than post irrigation and crop conditions.

- Distribution uniformity (DU) and coefficient of uniformity (CU) also increased with increase in stream sizes and decreased with increases in border lengths

significantly. No statistical significant difference was observed in CU and DU between crop and post irrigation conditions, however, under fresh tilth soil surface condition the CU and DU was significantly lower than the other conditions. DU varied from 93.19% to 99.58% and CU ranged from 95.26% to 99.69% for the three stream sizes, border lengths and soil surface conditions. In general, DU was lower than CU under the soil surface conditions studied.

2.1.2.4. Recommendations

Based on the findings of this study, use of long level border (90 m x 8 m) with stream sizes of 1 l/s/m, 2 l/s/m or 3 l/s/m is recommended in cases of low intake soil families for efficient use of irrigation water and better agricultural productivity . The application efficiency, DU and CU greater than 90% can be achieved under the above conditions. Although the smaller border strip (30 m x 8 m) showed relatively better application efficiency, distribution uniformity and coefficient of uniformity as compared to longer border strip, the difference was less than 5%. Furthermore, smaller border strips increase labor cost and will hinder mechanized farming. Fresh tilth soil surface condition produce relatively lower application efficiency, DU and CU in contrast to post and row crop soil surface conditions under stream size of 1 l/s/m. If choice is available, it is recommended to use higher stream size (3 l/s/m) in cases of fresh tilth soil surface conditions for better irrigation application efficiency.

2.1.3. INNOVATIVE SURFACE IRRIGATION METHODS FOR FRUIT ORCHARDS

2.1.3.1. Materials and Methods

Innovative surface irrigation methods for fruit orchards being developed at the WRRI Field Station, NARC, using the concept of round basin and furrow irrigation were used in the evaluation. Peach plants were planted on an area of about 0.42 hectares. The soil type of the experimental field is clay loam. The field capacity and wilting point were estimated as 23% and 13% moisture contents on dry weight basis, respectively. The bulk density is 1.47 gm/cm^{-3}.

Before transplanting the peach plants, the field was properly formed. The pits of 0.3 m in diameter and 0.6 m deep were made using post hole digger by mounting it on the rear side of a tractor. The pits were made at 6 m row-to-row and plant-to-plant distances.

The pits were filled in layers with a mixture of well rotten farm yard manure and soil. The pit and mixture of farm yard manure and soil were treated with dieldrin to check attacks by

white ants and other insects. The plants were transplanted on February 16, 1991 when they were two years old.

The following surface irrigation methods were used in the study:

- Borders
- Round basins
- Modified round basins
- Modified furrows

Four methods of surface irrigation enumerated earlier were employed with two replications each. The size of each plot was 6x60 m. The plants were planted in the centre of each plot at a distance of 6 m. The graded border size was 6x60 m. The round basins were developed with 0.75 m diameters. The modified round basins were developed with 1.65 m diameters outer circle whereas inner circle of 0.75 m were maintained as raised flat. This leaves furrows of only 0.45 m width where water does not directly contact plants. The modified furrows were developed with furrow width of 0.45 m and at a distance of 0.375 m away from plant on both the sides.

All the systems represent graded plots where a slope of 0.75% was maintained for round basins, modified round basins and modified furrows. The borders were kept at a slope of 0.43%. Graded fields are commonly used in northern areas and Balochistan.

An electrically operated pumping system was installed on a dugwell using a 50 mm diameter G.I pipe to carry water from dugwell to the experimental area. The plot wetted area of each method is as under:

Method of Irrigation	Wetted Area (m^2)
Border	360.00
Round basin	44.27
Modified round basin	77.05
Modified furrow	50.11

Soil samples were taken from head, middle and tail of each plot before and after each irrigation to estimate the soil moisture contents. A stream size of 3.0 lps was used for irrigation. An equal depth of about 25 mm irrigation was applied to all the methods. The following formula was used to calculate the duration of each irrigation method.

$$QT = 27.53646*AD$$

Where Q = Discharge, lps;
T = Time, hours;
A = Area, ha; and
D = Depth of irrigation, cm.

The distribution uniformity was estimated using the following relationship:

$$D_u = \frac{Z_{min}}{Z_{av}} \times 100$$

Where D_u = distribution uniformity;
Z_{min} = minimum depth infiltrated, mm; and
Z_{av} = average depth infiltrated, mm.

2.1.3.2. Results and Discussion

Actual irrigation application was estimated using irrigation duration. Average volume of water applied and duration of irrigation for the four selected surface irrigation methods are presented in Table 20. Irrigation data revealed that on an average there was a saving of 6.03, 5.25 and 5.98 m^3 of irrigation water in round basins, modified round basins and modified furrows, respectively, as compared to borders. Similarly, the saving in irrigation duration was 33.2 minutes, 29.28 minutes and 31.98 minutes in round basins, modified round basins and modified furrows, respectively, as compared to graded borders. The data indicated that 486%, 260% and 464% saving in irrigation depth can be made under round basins, modified round basins and modified furrows, respectively, as compared to borders. A similar trend was observed for irrigation duration because the same stream size was used for all the treatments.

To evaluate irrigation, start time, cut-off time, advance time and recession time were observed for each method. Plants at 6 m intervals were used as grids for recording advance and recession time. The details of advance, recession, and infiltration opportunity time are presented in Table 21.

The distribution uniformity of 76.6%, 59.2% 81.3% and 92.3% were achieved under borders, round basins, modified round basins and modified furrows, respectively. The highest distribution uniformity was achieved under modified furrows. The highest saving in water depth applied was under round basins but this had the lowest distribution uniformity.

Peach plants are very sensitive to excessive wetness. Round basins are not suitable for peach plants because water is in direct contact with plants.

The modified furrows were developed based on the concept of trickle irrigation. This system also keeps water from direct contact with plant. Furthermore, this system is better than round basins where there are more chances of soil borne diseases transferring from one plant to another.

Based on the efficient use of water and suitability, the peach plants without intercropping can be irrigated using modified furrow irrigation method.

2.1.3.3. Conclusions and Recommendations

- Water savings of 486%, 260% and 464 % were observed in round basins, modified round basins and modified furrows respectively, compared to borders. The borders had a slope of 0.43%; the three methods 0.75%.

- The duration of irrigation had a similar trend as the water applied for the different water application methods.

- Distribution uniformity of 59.2%, 81.3%, 92.3% and 76.6% were observed for round basin, modified round basins, modified furrows and borders, respectively.

- Not only did modified furrows achieve the highest distribution uniformity, they are also more suited where water should not be in direct contact with the plants.

- Based on the efficient use of water and suitability, irrigation of peach plants can be done well by using the modified furrow method.

2.2. WATER APPLICATION METHODS - SPECIALIZED

2.2.1. DESIGN AND LOCAL MANUFACTURING OF RAINGUN SPRINKLER IRRIGATION SYSTEMS

2.2.1.1. Feasibility of Sprinkler Irrigation in Pakistan

The initial capital cost of sprinkler irrigation equipment is the primary limitation for large-scale adoption in Pakistan. The high cost and economic consideration have limited the use to fruit trees and vegetables of high value in specific problem areas. These include:

- areas of Balochistan where the value of water is high and high value crops are grown;

- green belt areas around urban centers where high value vegetables and fruits are grown;

- undulating sandy lands in the Thal, Thar and Cholistan deserts which are underlain with groundwater of reasonable quality;

- Barani lands and sub-mountainous region;

- sandy and undulating riverine area;

- uncommanded sandy high areas within Indus Basin;

- fringe areas of Indus Basin where water is either saline or extremely scarce; and

- northern areas where high value crops are grown on sloppy terraces with very coarse textured soils.

The low efficiency of surface irrigation, probably 20% or less on sandy rough lands, is well known; thus, the attractiveness of highly controlled sprinkler irrigation which has the potential to increase efficiency to 85%. Furthermore, the use of sprinklers which use pipes to convey water makes the development of the most sandy lands and rough topography practical even with relatively saline water. Existing water supplies can be greatly extended and a new class of lands made available for irrigation and for development. There is little question regarding the technical feasibility of sprinkler systems; throughout the world, extensive installations are operating successfully. The question we face is whether such systems or special adaptations are sociologically and economically practical for Pakistan.

The cost of the system depends mainly on the spacing of laterals. The cost of the unit and the net return from the crop should be compared before installing a sprinkler irrigation system. The main item of expenditure is the cost of the lateral lines.

Inefficient water conveyance and field application by surface irrigation in the Indus Basin created these problems:

- waterlogging;
- waste of available water resources;
- salinization of land and water;
- low crop yields; and
- expensive programs to control problems caused by inefficient water use.

Because of these problems and the increasing demands for additional irrigation development, there is an urgent need to control canal seepage losses, improve field water application efficiency, and establish good irrigation practices.

At present, there are development programs to control water losses from the extensive water delivery system in the Indus Basin. On the other hand, relatively little work is being done to establish efficient irrigation practices. Therefore, efforts are needed to improve existing surface irrigation and introduce sprinkler system which are simple to operate and adaptable to farmers and crops and to physical conditions of the country. If one includes the investments needed for land development and drainage in the Indus Basin, the investments

required for the installation of sprinkler irrigation system seem feasible.

2.2.1.2. State of Sprinkler Irrigation in Pakistan

Sprinkler irrigation is being introduced in the country. It has been installed in several demonstration plots in the country. Furthermore, progressive farmers are importing sophisticated systems such as center pivots and linear move sprinkler machines.

The conventional sprinkler irrigation systems are expensive. Therefore, some modifications are needed to suit the socio-economic conditions and physical requirements in Pakistan. The sprinkler system can be used with gravity flow where hydraulic head is available, reducing the initial cost. Such locations are available in northern areas, NWFP and Balochistan.

The sprinkler irrigation system can be easily introduced for high value vegetables and fruits in areas where either value of water is high or soils are of light texture. Later on, the system can be extended to field crops if the economic conditions permit its installation. The recommended systems for various physical, social and economic conditions are presented in Table 22.

Most of the system components of solid-set, hand-move and raingun sprinklers have been successfully manufactured in Pakistan.

Only cost-effective aluminum pipes need to be imported. The NARC-Water Resources Research Institute, Islamabad, in collaboration with MECO Pvt. Ltd. Lahore, developed a complete range of raingun sprinkler systems using locally available materials and technology. The high-pressure, low-density polyethylene pipes with black carbon and UV stabilizers were produced in collaboration with Griffon Industrial Corporation, Lahore. These are available in 25 mm, 50 mm, 76 mm and 102 mm diameters, which can be used for pressures up to 120 psi. Soon, other low pressure systems will be developed. The estimated installed cost of portable raingun sprinkler system in Pakistan will cost about Rs. 5000 to Rs. 6000 per acre for a system of at least 10 acres using a diesel-operated pumping system. The cost of electric-operated systems will range Rs. 3000 to Rs. 4000 per acre for a system of five acres or more.

2.2.1.3. Supplemental irrigation and rainwater conservation in Barani lands

The raingun sprinkler irrigation system is designed to provide irrigation in areas where surface irrigation is either not possible or huge investments are required for land forming. In Barani areas, the yields of major crops are 30% to 50% of the national average yields mainly because of drought

and lack of moisture at critical growth stages. The planting of crops is normally delayed due to lack of moisture and farmers waiting for rainfall. The plant population is also low due to non-uniform and inadequate moisture in unleveled fields. In certain areas, crop failures are also common if dry spells are prolonged.

Considering problems of low crop yield and low cropping intensity, there is a need to introduce supplemental or life-saving irrigation in areas where water is available. Water is available through dugwells, tubewells, mini/small dams, lakes and nullahs. At present, there are around 24 small and 94 mini dams in the Punjab Barani tract. But due to non-availability of an appropriate irrigation system, only 30% and 10% of the designed command area of small and mini dams, respectively, have been developed for irrigation.

Some farmers are practicing lift irrigation. But due to insufficient engineering and lack of scientific support, land forming farmers find it difficult to form their lands for surface irrigation. The only option left for Barani areas is to use sprinkler irrigation. Therefore, because operational cost of sprinkler irrigation will certainly increase production costs, the need arises to reduce irrigation input. It is important to efficiently use incident rainfall with an objective to reduce irrigation input. This may require conjunctive use of rainfall and sprinkler irrigation with an objective to reduce the cost of production and optimize farmers' net return in Barani areas.

For sustainable Barani farming, the development of conservation terrace farming system is a prerequisite. Therefore, efforts must be made to develop an integrated strategy for increasing crop production and cropping intensity in Barani areas.

This paper presents some designs developed for electric motor and diesel engine operated sprinkler systems. These designs will hold good for areas where peak demand of crop is around 5 mm per day. For other areas, necessary adjustments may be made for farm size and crop water requirement. However, system design procedures will hold good in almost every situation especially for the Barani tract of the Pothwar plateau.

2.2.1.4. Design of Raingun Sprinkler Systems

Eight typical designs are proposed for sprinkler irrigation systems' manufactured in Pakistan by considering mainly the size of diesel engines or tractor power available in the country. These designs provide systems for farms 2 to 50 acres. These systems therefore fulfill requirements of small and medium size Barani farmers. Designing large-scale farm irrigation systems require more information about farm layout, crops grown, water source and amount, etc. The

proposed systems can be used for field crops, vegetables, pulses and young orchards.

Sprinkler Irrigation System For 2 Acres Farm

Raingun Type	=	PY_1 20
Et Peak	=	5 mm/day
Peak Operation	=	10 hours
Nozzle Size	=	8 mm
Working Pressure	=	4 Kg/cm^2 = 57 psi = 40 m
Capacity	=	4.59 m^3/hr = 1.28 lps
Application	=	2.86 mm/hr
Maximum Command Area at One Setting	=	0.16 ha = 0.40 acres
Radius	=	23 m
Recommended Farm Size	=	0.92 ha = 2.3 acres
Maximum Pipe Length	=	100 m
Head Loss in Pipe	=	1.25 m/100 m in 50 mm (2 inch) diameter pipe
Total Head (m)	=	40 + 1.25 + 10 = 51.25

<u>Power Requirement</u>

Q	=	1.3 lps
H	=	52 m
WHP	=	0.89 hp
Motor HP	=	1.5
Engine HP	=	1.8

Considering the availability of engines in the market, the system should be redesigned for 3.0 hp engines.

Q	=	2.0 lps
H	=	57 m
WHP	=	1.5 hp
Engine HP	=	3.0

The system can be used for farms of up to 2 acres size to meet peak demand requirement. However, the system can provide irrigation to larger farms if the cropping intensity is less than 200% or irrigation is to be provided to only 2 acres at the farm.

The 50 mm diameter black carbon low-density polyethylene (LDPE) pipe is recommended for delivery and 50 mm to 63.5 mm diameter pipe is recommended for suction. The LDPE pipe is equally good for suction and has been successfully tested at the NARC Field Station. The cost of LDPE suction pipe is almost one-third of any good quality imported reinforced rubber pipe. Furthermore, the life of black carbon LDPE suction pipe is much more than the reinforced rubber pipe. The cost of the canvas delivery pipe of imported quality is almost same as of LDPE delivery pipe. However, the life of LDPE delivery pipe is much more than canvas pipe.

Sprinkler Irrigation System For 5 Acres Farm

Raingun Type	=	PY_1 30
Et Peak	=	5 mm/day
Peak Operation	=	10 hours
Nozzle Size	=	12 mm
Working Pressure	=	4 Kg/cm^2 = 57 psi = 40 m
Capacity	=	9.58 m^3/hr = 2.74 lps
Application	=	3.86 mm/hr
Maximum Command Area at One Setting	=	0.26 ha = 0.64 acres
Radius	=	29 m
Recommended Farm Size	=	2.0 ha = 5 acres
Maximum Pipe Length	=	175 m
Head Loss in Pipe diameter pipe	=	5.2 m/100 m in 50 mm (2 inch)
Total Head (m)	=	40 + 10 + 9 = 59

<u>Power Requirement</u>

Q	=	2.8 lps
H	=	59 m
WHP	=	2.17 hp
Engine HP	=	4.35

The system may be redesigned with a 5 hp engine available in the market.

Q	=	3.0 lps
H	=	63 m
WHP	=	2.5 hp
Engine HP	=	5.0

For an electric motor system

Q	=	3.0 lps
H	=	60 m
WHP	=	2.4 hp
Motor HP	=	4.0

The system can be used to irrigate area up to 5 acres at the peak demand. The actual farm size may be even more if different crops are grown.

Sprinkler Irrigation System For 10 Acres Farm

Raingun Type	=	PY_1 40
Et Peak	=	5.0 mm/day
Peak Operation	=	10 hours
Nozzle Size	=	16 mm
Working Pressure	=	4.5 Kg/cm^2 = 64 psi = 45m
Capacity	=	19.6 m^3/hr = 5.44 lps
Application	=	4.78 mm/hr
Maximum Command Area at One Setting	=	0.41 ha = 1.0 acre
Radius	=	36 m

Recommended Farm Size	=	4.0 ha = 10 acres
Maximum Pipe Length	=	175 m
Head Loss in Pipe	=	2.4 m/100 m for 76 mm (3 inch) diameter pipe
Total Head (m)	=	45 + 4.2 + 10 = 60

Power Requirement

Q = 5.0 lps
H = 60.0 m
WHP = 4.0 hp
Engine HP = 8.0 hp

For an electric motor system

Q = 6.0 lps
H = 60 m
WHP = 4.74 hp
Motor HP = 8

Sprinkler Irrigation System For 15 Acres Farm

Raingun Type	=	PY_1 50
Et Peak	=	5.0 mm/day
Peak Operation	=	10 hours
Nozzle Size	=	20 mm
Working Pressure	=	5.0 Kg/cm^2 = 71 psi = 50 m
Capacity	=	30.5 m^3/hr = 8.5 lps
Application	=	5.42 mm/hr
Maximum Command Area at One Setting	=	0.56 ha = 1.4 acres
Radius	=	42 m
Recommended Farm Size	=	6.0 ha = 15 acres
Maximum Pipe Length	=	200 m
Head Loss in Pipe	=	5.0 m/100 m for 76 mm (3 inch) diameter pipe
Total Head (m)	=	50 + 10 + 10 = 70

Power Requirement

Q = 8.5 lps
H = 70.0 m
WHP = 7.8 hp
Engine HP = 15.6 or 16 HP
Motor HP = 13 HP

Sprinkler Irrigation System For 20 Acres Farm

Raingun Type	=	PY_1 60
Et Peak	=	5.0 mm/day
Peak Operation	=	10 hours
Nozzle Size	=	22 mm
Working Pressure	=	6 Kg/cm^2 = 85 psi = 60m

Capacity	=	41.1 m^3/hr = 11.4 lps
Application	=	5.55 mm/hr
Maximum Command Area at One Setting	=	0.74 ha = 1.83 acres
Radius	=	49 m
Maximum Pipe Length	=	200 m
Head Loss in Pipe	=	2 m/100 m in 102 mm (4 inch) diameter pipe
Total Head (m)	=	60 + 4 + 10 = 74
Recommended Farm Size	=	8 ha = 20 acres

Power Requirement

Q = 12.0 lps
H = 76 m
WHP = 12 hp
Engine HP = 24 hp
Motor HP = 20 hp

This system is recommended because 24 hp Chinese engines are available in the market. The recommended farm size with 5 mm peak demand and 10 hours of operation is 20.0 acres.

Sprinkler Irrigation System For 25 Acres Farm

Raingun Type	=	PY_1 60
Et Peak	=	5.0 mm/day
Peak Operation	=	10 hours
Nozzle Size	=	24 mm
Working Pressure	=	6 Kg/cm^2 = 85 psi = 60 m
Capacity	=	48.6 m^3/hr = 13.5 lps
Application	=	5.75 mm/hr
Maximum Command Area at One Setting	=	0.85 ha = 2.1 acres
Radius	=	52 m
Maximum Pipe Length	=	200 m
Head Loss in Pipe	=	3.0 m/100 m in 102 mm (4 inch) diameter pipe
Total Head (m)	=	60 + 6.0 + 10 = 76 = 80
Recommended Farm Size	=	10.0 ha = 25 acres

Power Requirement

Q = 14.0 lps
H = 80 m
WHP = 14.74 hp
Engine HP = 29.47 = 30.0 hp
Motor HP = 25.0 hp

The recommended farm size considering peak demand of 5 mm and 10 hours of operation comes to 25 acres. The 32 hp tractors available in the country can be used for this system.

Sprinkler System For 30 Acres Farm

Raingun Type	=	PY_1 80
Et Peak	=	5.0 mm/day
Peak Operation	=	10 hours
Nozzle Size	=	26 mm
Working Pressure	=	7 Kg/cm^2 = 100 psi = 70 m
Capacity	=	60.6 m^3/hr = 16.83 lps
Application	=	5.86 mm/hr
Maximum Command Area at One Setting	=	1.03 ha = 2.5 acres
Radius	=	57 m
Maximum Pipe Length	=	200 m
Head Loss in Pipe	=	4 m/100 m in 102 mm (4 inch) diameter pipe
Total Head (m)	=	70 + 8 + 10 = 90
Recommended Farm Size	=	12 ha = 30 acres

<u>Power Requirement</u>

Q = 17.0 lps
H = 90 m
WHP = 20.13 hp
Engine HP = 40.26 = 41 hp

Recommended as PTO driven system with 45 hp or bigger tractors. The farm size recommended with peak demand of 5 mm and 10 hours of operation comes to 30 acres.

Sprinkler Irrigation System For 50 Acres Farm

Raingun Type	=	PY_1 80
Et Peak	=	5.0 mm/day
Peak Operation	=	10 hours
Nozzle Size	=	34 mm
Working Pressure	=	8 Kg/cm^2 = 114 psi = 80 m
Capacity	=	108 m^3/hr = 30 lps
Application	=	7.06 mm/hr
Maximum Command Area at One Setting	=	1.53 hectares = 3.8 acres
Radius	=	70 m
Maximum Pipe Length	=	200 m
Head Loss in Pipe	=	4.0 m/100 m in 127 mm (5 inch) diameter pipe
Total Head (m)	=	80 + 8 + 10 = 98 = 100
Recommended Farm Size	=	21.0 ha = 50.0 acres

<u>Power Requirement</u>

Q = 30 lps
H = 100 m
WHP - 39.5 hp
Engine HP - 79 - 80 hp

The size of farm recommended considering peak demand of 5 mm and 10 hours of operation is 50 acres. The LDPE black carbon pipe is recommended for delivery and suction purposes. The PTO driven system with 80 hp tractor can be used for irrigation of a 50-acres farm.

2.2.1.5. Manufacturing Specifications

Electric Motor Operated Systems

The PARC has already developed production capability with MECO Pvt. Ltd. Lahore to use their available facility for manufacturing of mono-block or direct coupled pumping systems for sprinkler irrigation. The manufacturing specifications recommended are:

Raingun PY1 20 System For 2 Acres Farm

Discharge of pump	=	1.3 lps
Pressure Head	=	52 meters
Motor Size	=	1.5 HP
Delivery Pipe Diameter	=	50 mm or 2 inch

Raingun PY1 30 System For 5 Acres Farm

Discharge of pump	=	3.0 lps
Pressure Head	=	60 meters
Motor Size	=	4.0 HP
Delivery Pipe Diameter	=	50 mm or 2 inch

Raingun PY1 40 System For 10 Acres Farm

Discharge of pump	=	6.0 lps
Pressure Head	=	60 meters
Motor Size	=	8 HP
Delivery Pipe Diameter	=	76 mm or 3 inch

Raingun PY1 50 System For 15 Acres Farm

Discharge of pump	=	8.5 lps
Pressure Head	=	70 meters
Motor Size	=	13 HP
Delivery Pipe Diameter	=	76 mm or 3 inch

Raingun PY1 60 System For 20 Acres Farm

Discharge of pump	=	12.0 lps
Pressure Head	=	76.0 meters
Motor Size	=	20 HP
Delivery Pipe Diameter	=	102 mm or 4 inch

Raingun PY1 60 System For 25 Acres Farm

Discharge of pump	=	14 lps
Pressure Head	=	80 meters

Motor Size	=	25 HP
Delivery Pipe Diameter	=	102 mm or 4 inch

Diesel Engine Operated Systems

PARC has designed portable sprinkler irrigation systems using Chinese engine and MECO pumps. The MECO Pvt. Ltd. Lahore is now providing complete units. The detailed specifications of portable sprinkler pumping systems in respect of pump and engine size are:

Diesel operated sprinkler irrigation portable system, multi-stage pump (as per requirement), pressure head and discharge (as per requirement) with desired size Chinese engine, installed on an adjustable trolley with 2 wheels and 12-inch new tires or desired rim size, 2 stands, towing hook, 6 m LDPE black carbon suction pipe with check valve, coupler at pump outlet with connection for desired size lateral flexible pipe and pressure gauge. All assembly work should be properly aligned, safe and pads should be used at engine and pump foundation to reduce vibrations. All couplings must be leak proof. MECO Pvt. Ltd. Kot Lakhpat, Lahore now fabricates these systems.

<u>Raingun PY1 20 System For 2 Acres Farm</u>

Discharge of pump	=	2.0 lps
Pressure Head	=	57 meters
Engine Size	=	3.0 HP
Delivery Pipe Diameter	=	50 mm or 2 inch

<u>Raingun PY1 30 System For 5 Acres Farm</u>

Discharge of pump	=	3.0 lps
Pressure Head	=	63 meters
Engine Size	=	5.0 HP
Delivery Pipe Diameter	=	50 mm or 2 inch

<u>Raingun PY1 40 System For 10 Acres Farm</u>

Discharge of pump	=	5.0 lps
Pressure Head	=	60 meters
Engine Size	=	8 HP
Delivery Pipe Diameter	=	76 mm or 3 inch

<u>Raingun PY1 50 System For 15 Acres Farm</u>

Discharge of pump	=	8.5 lps
Pressure Head	=	70 meters
Engine Size	=	16 HP
Delivery Pipe Diameter	=	76 mm or 3 inch

Tractor PTO Driven Systems

When the size of the engine exceeds 16 hp or 24 hp, it is recommended using the PTO-driven systems because the cost of the engine pumping systems is very high. Therefore, for farmers who own 25 hp, 32 hp, 45 hp or 80 hp tractors, the following systems are recommended with specifications:

Raingun Sprinkler System For 20 Acres Farm

Pump Discharge	=	12 lps
Pressure Head	=	76 meters
Engine Size	=	24 hp (use 25 hp tractor TOP
Delivery Pipe Diameter	=	102 m or 4 inch

Raingun Sprinkler System For 25 Acres Farm

Pump Discharge	=	14 lps
Pressure Head	=	80 meters
Engine Size	=	30 hp (use 32 hp tractor PTO)
Delivery Pipe Diameter	=	102 m or 4 inch

Raingun Sprinkler System For 30 Acres Farm

Pump Discharge	=	17 lps
Pressure Head	=	90 meters
Engine Size	=	41 hp (use 45 hp tractor PTO)
Delivery Pipe Diameter	=	102 m or 4 inch

Raingun Sprinkler System For 50 Acres Farm

Pump Discharge	=	30 lps
Pressure Head	=	100 meters
Engine Size	=	80 hp (use 80 hp tractor PTO)
Delivery Pipe Diameter	=	102 m or 4 inch

2.2.1.6. Testing of Raingun Systems

The uniformity coefficient and effective diameter of coverage were evaluated in relation to pressure and discharge of PY_1-30 raingun. The details are presented in Table 23.

The standard nozzle for PY_1-30 raingun system is 10 mm, whereas the design nozzle recommended for manufacturing pumping systems is 12 mm. The irrigation evaluation indicated that the effective radius of coverage is 23 maters compared to 29 meters of the potential radius of coverage.

The effective radius of coverage is based on the desirable uniformity of 80% or more. The evaluation also indicated that the best operating pressure for PY_1-30 raingun is in the range of 50-60 psi with discharge range of 2.75-3.25 lps.

2.2.1.7. Conclusions

The irrigation evaluation conducted for PY_1-30 raingun sprinkler system indicated that a reasonably high uniformity coefficient of 80% can be achieved for locally manufactured systems. The smaller rainguns are recommended if the uniformity coefficient exceeds 75%. However, the uniformity will vary with wind speed. The data presented in the evaluation represent the permissible wind speed. The uniformity will be reduced if the operating pressure is less than 50 psi.

The selection of nozzle size cal also help to have the desired drop size. Farmers can select nozzles considering the crop and its growth stage. At sensitive growth stages like flowering, smaller nozzles can be used to have smaller drop size. Such nozzles have been produced locally and are available at a cost of Rs. 20.00 per nozzle. Farmers may keep 3-4 nozzles and use them according to their requirements.

The design and layout of raingun sprinkler systems should be made in such a way that the unit cost does not exceed Rs. 5000 - Rs. 6000 and Rs. 3000 - Rs. 4000 per acre for diesel and electric operated pumping systems, respectively. Otherwise, the design may be revised as an effort to achieve balance between efficiency and cost effectiveness. Furthermore, no significant information is available regarding the relationship of uniformity with crop yield.

2.2.2. INDIGENIZATION OF TRICKLE IRRIGATION TECHNOLOGY

2.2.2.1. Feasibility in Pakistan

The initial capital cost of standard trickle irrigation equipment is considered the limiting factor against its large-scale adoption in Pakistan, particularly for high value fruit trees and vegetables grown in specific areas. These areas include the following.

- Areas of Balochistan province where the value of water is high and high value crops are grown;
- Green belts around urban centres where high value vegetables, fruits and ornamental plants are grown;
- Undulated sandy lands in the Thal, Thar and Cholistan deserts which are underlain with groundwater of acceptable quality;
- Sandy and undulating riverine areas;

- Uncommanded sandy high areas within the Indus basin which require huge investments for surface irrigation;

- Fringe areas or where water is either saline or extremely scarce; and

- Northern Areas and Pothwar plateau where high value crops are grown.

The inefficiency of surface irrigation, probably 20 percent or less on sandy rough lands is well known. Thus, the attractiveness of highly controlled trickle irrigation which has the potential to increase efficiency to 85 percent or more is obvious. Further, the use of trickle irrigation which utilizes pipes to convey the water directly to the plants makes the development of the most sandy lands and rough topography practical even with relatively saline water. Thus, existing water supplies can be greatly extended and a totally new class of lands becomes available for irrigation and development. The technical feasibility of trickle irrigation systems has already been substantiated extensively throughout the world. The question that should be adressed in Pakistan is whether such systems or their special adaptations are sociologically and economically cost-effective at present.

The cost of the unit and the net return from the crop should be compared before a decision is made on installing a trickle irrigation system. The main item of expenditure is the lateral lines; the wider the row spacing, the lesser the initial cost.

Crops like grapes, almonds, apples, papayas, guavas, citrus, coconut and other fruit trees can be grown well with trickle irrigation whereas sprinkler irrigation is more suitable for high value vegetables.

2.2.2.2. State of Trickle Irrigation in Pakistan

Initial efforts were made by the Balochistan Forest Department to introduce trickle irrigation in orchards in Quetta. Thereafter, efforts continued throughout the country in a less organized manner. Other organizations which attempted to introduce trickle irrigation were the Pakistan Council of Appropriate Technology (ATDO) in collaboration with the Pakistan Council of Research in Water Resources (PCRWR): Agricultural Development Bank of Pakistan (ADBP); WAPDA: Provincial OFWM Departments; and Irrigation Departments. The FAO, UNDP and ADB also funded projects for the promotion of trickle irrigation for orchards in Balochistan.

At present, the Deciduous Fruit Department Centre is the premier and pioneering agency for the introduction of trickle irrigation in Balochistan. The Pakistan Agricultural Research

Council (PARC) is collaborating with this institution since inception of the programme. However, active collaboration was initiated during 1990 under the ISM-R programme.

Realizing the potential of trickle irrigation systems, some private enterprises like Hoechst Pakistan Ltd., Drip Irrigation, Merin Pvt. Ltd., Galaxy, Rainmakers and many other companies entered the marketing of imported trickle irrigation systems. However, Merin Pvt. Ltd. initiated the indigenization of trickle components in Pakistan but could not produce the required quality due to lack of scientific knowledge.

Despite the above mentioned efforts, there was very little progress in the adoption and promotion of trickle irrigation systems in Pakistan. Thus, the PARC was entrusted with the responsibility to initiate research in the area of trickle and sprinkler irrigation in 1982-83. In 1990 PARC critically analysed previous efforts and developments to determine the causes of failure and came up with the following:

- Discontinued and piecemeal efforts;
- Lack of coordination among research and development agencies;
- High cost of imported systems;
- Lack of back up facilities for service, maintenance and spares;
- Lack of scientific knowledge and skills; and
- Absence of linkages and advisory service for the local industries.

To overcome the difficulties and ensure continuity, PARC realized that the systems must be produced with local skills, technology and materials, that is, the whole process of trickle irrigation technology should be indigenized. In recognition of the importance of this thrust area, PARC accorded to it high priority and sufficient financial and manpower resources in 1990-91.

2.2.2.3. Indigenization

For the indigenization of trickle irrigation systems, the most difficult part was where to begin. The economic viability dictated the use of this system in fruit orchards and high value vegetables in areas where water is at premium.

The cost of the system depends on the distance between rows and plants. Thus, the main cost is the cost of lateral. Since normally fruit plants are planted with 6mx6m spacing,

trickle irrigation systems is recommended for plants grown with 6m x 6m spacing or more. Therefore, efforts were made to produce plastic tubings for laterals, manifold and main lines. The other important element is the emitter which also requires indigenization. Although in the beginning it was considered difficult to produce a wide range of emitters locally, a simple and general purpose emitter was selected for indigenization. The connections, filters and pumps were also considered for indignization.

Laterals

Samples of plastic tubings were collected from the local market. These were low pressure PVC flexible pipes, high pressure PVC flexible pipes, low pressure rubber pipes and high pressure rubber pipes. The first three items were found unsuitable as they could not maintain their shape due to lack of ultraviolet resistance. The high pressure rubber pipes were comparatively better in performance but uneconomical and difficult to handle. However, none of the materials were found economical in terms of the durability criterion.

PVC flexible pipes of 13 mm diameter reinforced with linen thread were later chosen for the trickle laterals. These pipes retained their shape under field conditions but within three months the dark colour faded away. However, the pipes were serviceable for one season only. As this attempt also did not produce the desired results in technical and economical feasibility, it was concluded that none of the pipes readily available in the local market are suitable for trickle irrigation laterals.

Imported plastic tubings were analysed to find their constituents. It was found that black carbon and UV stabilizers are essential components of low density polyethylene resin for making trickle irrigation lateral pipes. After determining the right composition of the materials, the following specifications were recommended for local production.

Pipe Diameter (mm)	Wall Thickness (mm)
13	1.40
25	1.80
50	2.80

The pipes were tested and found suitable for use under Pakistani conditions. They were also tested by the Plastic Technology Centre (PTC), Karachi and found to conform to ASTM standards. A prototype system was installed at the Water Resources Research Institute Field Station, NARC and its performance evaluated on orchards. After the materials were found suitable, the production process was geared to further

reduce the cost by reducing the wall thickness. The reduction of wall thickness required better dies and production techniques. The latest plastic tubings produced are:

Pipe Diameter (mm)	Wall Thickness (mm)
13	1.0
25	1.5
50	2.0

Emitters

The emitters are important components of the system. Copper tubings of 1 mm diameter used in refrigeration and PVC flexible pipes of the same diameter were selected from the local market to to determine their suitability as dripers. Some electric wire covers after pulling out the copper wires were also tested for their suitability as emitters. The variation in flow was very high due to the non-uniformity of the inner diameter of these tubings.

The next step was to produce proper emitters with relatively higher density polyethylene materials. The following emitters were successfully produced:

Pressure compensating turbo emitters
Variable flow spiral emitters
LDPE micro-tubings of 1 mm diameter

The accuracy level of these emitters in terms of flow and manufacturing precision is being studied at WRRI Field Station, NARC. Preliminary results showed that spiral emitters are within the acceptable range and discharge rating is 0.5-4.0 lph. The micro-tubings also performed satisfactorily. However, the pressure compensating emitters require further refinement.

Fitting and Accessories

Fittings and accessories, although required in lesser quantity, are nevertheless important in making the system functional. After a careful analysis of the materials for fittings, it was recommended that they be manufactured using carbon black ABX or high density polyethylene (HDPE). The following fittings are being commercially manufactured:

Pushfit connectors for 13 mm pipe
Pushfit reducer adapter for 13 mm diameter laterals
Quick couplers for 25 mm pipe
Quick couplers for 50 mm pipe

The most common problem of the trickle irrigation system is the clogging of emitters. It is not always possible to have sediment free water. Therefore, filters for 25 and 50 mm

diameter pipes were developed, which are commonly used for manifolds or mainlines. Two different sizes of mesh screens of 140 and 200 mesh were also developed to filter waters.

Other fittings such as gate valves, tees, elbows, etc. will be obtained from the local market which are available for GI pipes. Pumping sets of various capacities and various brands are already available throughout the country. A few commonly used pumps manufactured by MECO Pvt. Ltd. Lahore are standardized.

Fertilizer and chemical injectors will be developed in the near future.

Economics

A typical one acre layout is used for cost estimates. The cost estimate is as under:

Component	Quantity		Cost (Rs) Rate	Amount	% of total cost
- Main line 25 mm diameter and 18 mm walls thickness	60 m	21.00	1260.00		14.0
- Laterals 13 mm diameter and 1.4 mm wall thickness	670 m	9.00	6030.00		67.2
Emitters	220 Nos.	5.00	1100.00		12.3
Reducer Adopter (25 x 13 mm)	10 Nos.	4.00	40.00		
Connections	10 Nos.	5.00	50.00		
End plugs	10 Nos.	4.00	40.00		
Filter (25 mm)	1 No.	300	300.00		3.3
Gate valve (13 mm)	1 No.	150	150.00		
Total Cost Rs/acre			8970		

Therefore, the cost of one acre trickle installation for 6m x 6m spacing is approximately Rs. 9000. However, the cost will be reduced if laterals and mainline of 1.0 and 1.5 mm wall thickness are used. Furthermore, since the cost of gate valve and filter is not exclusively for one acre only, in effect, the cost of trickle irrigation ranges from Rs. 8000 to

Rs. 9000 per acre. However, these estimates are based on the Ex. Factory prices of the GRIFFON Industrial Corporation, Lahore. The actual installed cost will vary from location to location.

2.2.2.4. Conclusions

At present, the technology, skills and materials are available to install standard trickle irrigation systems. The cost of standard trickle irrigation system based on Ex.Factory prices comes to Rs. 9000 per acre. This cost will be reduced further in the future with increasing demand as is the tendency with the introduction of new technology. However, with about 75% duty and taxes on the import of polyethylene raisin, it is necessary to arrange sanctions for the rebate of import duty and taxes for agricultural purposes. This is a policy issue which should be addressed in the near future. Meanwhile, to overcome this discrepancy the government has enforced a subsidy program for the installation of trickle irrigation systems in the country.

For the successful introduction of trickle irrigation systems in the country, it is imperative to have appropriate design, layout and installation to achieve cost-effectiveness. The quality of polyethylene used in the manufacture of plastic tubing is another major issue which must be considered. The NARC-WRRI is trying to develop and strengthen the National Irrigation Systems Testing Laboratories recently established at WRRI, NARC, Islamabad to continue monitoring the quality of locally produced materials.

2.2.3. DEMONSTRATION OF SPECIALIZED SYSTEMS

Trickle irrigation systems have been installed at farmers fields at DFDC, Quetta and KARINA, Gilgit to evaluate the techno-economics of these systems. Farmers participated and shared some of the cost of installation of these systems.

2.3. WATER APPLICATION PRACTICES

2.3.1. SUPPLEMENTAL IRRIGATION FOR WHEAT IN BARANI ENVIRONMENT

2.3.1.1. Materials and Methods

The supplemental irrigation study for wheat crop was conducted at the Water Resources Research Institute (WRRI). Field Station, NARC, Islamabad when the Rabi rainfall ranges between 123 mm to 650 mm. The study was done during the 1989-90 to 1991-92 growing seasons. The soil texture of the experimental site was sandy-loam. The soil moisture characteristics were studied. The field capacity and wilting

point were determined as 17.5% and 7.4% on dry weight basis, respectively. The bulk density was 1.53 $gm.cm^{-3}$. The dugwell water was used for irrigation. The EC of well water ranges 0.54-0.94 $mmhos.Cm^{-2}$. These four supplemental irrigation treatments were employed:

- Barani treatment where only incident rainfall was used for crop water requirement
- Barani treatment except one Rauni irrigation of 10 mm applied prior to crop planting
- Irrigations of 10 mm each were applied when soil moisture deficiency reaches to 50% of MAD
- Irrigations each of 25 mm were applied when soil moisture deficiency reaches 75% of MAD

Wheat variety of PAK-81 was planted the first week of November during the three selected wheat growing seasons. Seed rate of 100 kg per hectare was used. The recommended fertilizer rate of 115-85 (NP) kg/ha was used for all the treatments. Sowing was done using tractor drawn drill. Row to row spacing was 20 cm.

Soil samples were taken at 0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm depth at sowing and harvest. Soil moisture contents were calculated by gravimetric method. The CROPWAT model was used to calculate crop water requirement and irrigation water requirement using climatic and crop data. The average climatic data used for prediction of required crop water are presented in Table 24.

2.3.1.2. Results and Discussion

The supplemental irrigations were applied based on predictions made using CROPWAT model for Islamabad using climatic data, soil moisture characteristics and wheat crop growth stages. The rainfall received during the growing seasons was sufficient to meet seasonal crop water requirement. The monthly and seasonal rainfall, and supplemental irrigation depth for wheat crop during 1989-90 to 1991-92 growing seasons are presented in Tables 25, 26 and 27, respectively.

Crop data such as germination, plant height, number of tillers per plant, number of plants per unit area, yield and yield components were recorded (Tables 28, 29 and 30).

The seasonal rainfall received during the wheat growing season of 1989-90 was more than the seasonal crop evapotranspiration, therefore crop did not respond to supplemental irrigation and there was no significant difference in crop yield. During the wheat growing season of 1990-91, the seasonal rainfall was more than the seasonal crop

evapotranspiration but the distribution was a little different than 1989-90. However, supplemental irrigation increased the yield significantly over Barani. An increase in yield of about 44% was achieved with Rauni irrigation of 10 mm only. The benefits of supplemental irrigation range Rs.3952 to Rs. 6583 per hectare during 1990-91 wheat growing season.

During the 1991-92 wheat growing season, the seasonal rainfall was almost equal to the seasonal crop evapotranspiration but it was not well spread. Most of the rainfall occurred at the final stage of tillering and flowering. The booting to flowering stage is the most sensitive for growth but not that sensitive for yield, and rainfall was received during this period. The irrigation was applied at node formation to booting stage based on predictions of CROPWAT model. An increase of 95% and 117% in yield was achieved when supplemental irrigation of 80 mm and 135 mm was applied, respectively. The net benefits of supplemental irrigation were Rs. 5556, Rs. 8785 and Rs. 9651 per hectare at 10 mm, 80 mm and 135 mm of supplemental irrigation, respectively, during 1991-92 wheat growing season.

The gross benefits, supplemental irrigation costs and net benefits from wheat during 1989-90 to 1991-92 growing seasons are presented in Tables 31 and 32.

The net benefits during 1991-92 wheat growing season indicated that the cost of system hardware for a 2-hectare farm can be recovered in one crop season of wheat under optimum management conditions. Under farmers' conditions, the cost of system hardware can easily be recovered in two cropping seasons. The benefits will increase in dry years and in dry regions.

The study was conducted in high rainfall zone of the Barani lands. This indicates that benefits are expected to increase in areas with low to medium rainfall. Taking into account this aspect the supplemental irrigation studies have been extended to Fatehjang area where experiments are underway to verify this expectation.

2.3.1.3. Conclusions and Recommendations

- By using raingun sprinkler for supplemental irrigation of wheat, when compared with that for barani crop, the yield increased 45% and 117% during the 1990-91 and 1991-92 wheat seasons in Islamabad, respectively. An unevenly distributed seasonal rainfall of 523 mm and 354 mm was received for the two respective seasons.

- The highest net benefits obtained from supplemental irrigation were Rs. 6583 and Rs. 9651 per hectare during the 1990-91 and 1991-92 growing seasons, respectively.

- The benefits from supplemental irrigation are expected to be greater in dry years and/or dry regions.

2.3.2. IRRIGATION SCHEDULING FOR WHEAT AND MAIZE

At KARINA experiments have been conducted to develop irrigation schedules for wheat and maize crops using irrigation frequency, streamsize and field length. The data are still under collection and/or compilation. The crop will be harvested in June, 1993. The report will be prepared in July-August as second volume to this report.

2.4. TRAININGS

The Water Resources Research Institute, NARC organized three training courses, which are:

- Border Irrigation - one week training course organized for ISM/R PIs and OFWM-Punjab engineers during 1991 at University of Agriculture, Faisalabad.

- Sprinkler and Trickle Irrigation - On-Job Training for engineers and scientists in Pakistan at NARC during late 1992. This course was attended by 41 participants.

- Surface Irrigation Systems - On-Job Training Course organized for engineers and scientists from various agencies at NARC during 17-22 April, 1993. The course was attended by 43 participants.

The most important part of these trainings was to impart practical training to engineers and scientists engaged in research and development activities. All the important national and provincial agencies participated in these trainings.

2.5. PUBLICATIONS

Six papers have been presented in the symposium organized by IIMI-Pak during April, 1993. Two handbooks on sprinkler and trickle irrigation systems were prepared by Dr. Shahid Ahmad and distributed to the trainees. In future, with the addition of some more data about 4-6 papers will be published in journals of international repute.

2.6. COMPUTER SOFTWARE LIBRARY

Six computer softwares were selected and procured under ISM/R and included in the software library of the Water

Resources Research Institute, NARC, Islamabad. In future, these softwares will be used for the development of management strategies. The 'VOLBAL' and 'BASCAD' softwares were provided to all the collaborators and training was imparted to the users.

2.7. EQUIPMENTS

Laboratory and field equipments were procured under ISM-R and provided to various collaborating agencies. These equipments strengthened the capability of the collaborating agencies in soil moisture estimation, soil moisture characteristics and irrigation practices. Sprinkler and trickle irrigation system components were also provided to DFDC, Quetta, KARINA and NARC.

Table 1. Physicochemical properties of experimental fields

Properties	Peshawar	UAF	AUT
Texture	Clay loam	Sandy clay loam	Clay loam
Bulk density	1.60	1.66	1.42
Field Capacity	32%	23%	35%
Permanent Wilting	18%	11%	19%
Ec	< 5	1.12 to 3.32	0.75-4.75
SAR	-	1.89-4.05	9
ESP	-	1.51-4.5	-
pH	-	8.15-8.4	> 7

The soils at three experimental sites are Non-saline non-sodic soils.

UAF: University of Agriculture, Faisalabad.

AUT: Agricultural University, Tandojam.

Table 2. Storage efficiencies for different border lengths with three stream sizes (NWFP)

Border Length (m)	Stream Size (l/s/m) 1	2	3	Mean
30	91.06 92.73 92.14 78.11 98.67 92.32	96.88 85.95 91.46 83.10 91.44 93.01	95.61 84.06 95.23 88.49 92.3 87.12	90.54
60	89.29 95.38 92.43 82.30 96.93 97.54	98.87 87.64 79.34 91.18 89.12 83.76	96.87 89.8 90.24 82.12 96.85 92.31	90.67
90	90.73 93.35 91.66 82.37 88.66 91.75	94.38 95.54 96.54 85.67 90.74 96.64	96.79 95.91 98.33 96.52 85.32 87.64	92.14
Mean	90.97	90.63	91.75	

Table 3. Storage efficiencies for different border lengths with three stream sizes (UAF)

Border Length (m)	Stream Size (l/s/m) 1	2	3	Mean
30	71.10 93.61 90.61	74.38 84.68 86.65	70.32 71.82 87.73	81.21 A
60	81.97 77.65 76.84	84.78 87.30 86.40	90.46 88.45 92.71	85.17 A
90	73.61 72.32 78.62	56.15 76.82 60.94	76.38 74.05 77.03	71.77 B
Mean	79.59 A	77.57 A	80.99 A	

Table 4. Statistical analysis of storage efficiency (NWFP)

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value
Replication	5	400.32	80.064	3.47
Length (L)	2	11.94	5.972	0.26^{NS}
Discharge (Q)	2	28.57	14.284	0.62^{NS}
L x Q	4	92.45	23.113	1.00^{NS}
Error	10	922.76	23.069	

NS : Non-significant

Table 5. Statistical analysis of storage efficiency (UAF)

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value
Replication	2	214.32	107.158	2.65
Length (L)	2	853.60	426.801	10.56**
Discharge (Q)	2	53.46	26.728	0.66^{NS}
L x Q	4	497.39	124.347	3.07*
Error	16	646.21	40.388	

** : Highly significant
* : Significant
NS : Non-significant

Table 6. Observed and predicted storage efficiencies for different border lengths with three stream sizes (NWFP).

Border Leng `L´ (m)	Stream Si `Q´ (l/s/m)	Cutoff Ti `Tc´ (min)	Storage Efficie Observed	Predicted
30	1	43.5	88.32	91.07
	2	17.7	90.46	91.36
	3	12.3	92.31	91.07
60	1	86.3	89.75	89.75
	2	37.5	90.84	91.07
	3	25.1	93.22	93.30
90	1	125.9	90.31	91.07
	2	62.3	91.37	91.36
	3	35.8	93.42	93.34

Table 7. Observed and predicted storage efficiencies for different border lengths with three stream sizes (UAF)

Border Leng `L´ (m)	Stream Si `Q´ (l/s/m)	Cutoff Ti `Tc´ (min)	Storage Efficie Observed	Predicted
30	1	38	85.10	82.31
	2	16	81.90	78.72
	3	11	76.62	77.22
60	1	80	78.82	85.53
	2	42	86.16	82.74
	3	20	90.54	79.63
90	1	112	74.85	71.86
	2	50	64.63	68.93
	3	38	75.82	67.97

Table 8. Distribution efficiencies for different border lengths with three stream sizes (NWFP)

Border Length (m)	Stream Size (l/s/m) 1	2	3	Mean
30	98.80	97.99	98.03	98.25
	98.80	98.50	98.15	
	98.40	99.06	97.53	
	98.62	99.29	98.57	
	98.70	99.13	99.00	
	96.60	99.24	94.00	
60	98.45	98.46	96.85	98.25
	98.26	97.21	96.82	
	98.60	98.52	97.74	
	99.33	99.15	98.32	
	98.15	98.93	97.42	
	98.33	99.35	98.89	
90	98.28	97.56	97.00	98.45
	99.92	98.38	96.69	
	99.28	98.19	97.55	
	99.10	99.18	98.17	
	99.70	99.06	98.05	
	98.99	99.18	97.80	
Mean	98.67	98.69	97.59	

Table 9. Distribution efficiencies for different border lengths with three stream sizes (UAF)

Border Length (m)	Stream Size (l/s/m) 1	2	3	Mean
30	89.21	91.88	88.24	90.81 A
	92.41	85.87	95.33	
	93.03	88.79	92.50	
60	81.79	87.66	91.80	89.36 A
	85.46	92.51	96.18	
	81.72	87.83	93.32	
90	73.80	71.12	84.13	75.69 B
	68.93	74.87	82.69	
	73.70	75.00	76.92	
Mean	82.90 A	83.95 A	89.01 B	

Table 10. Statistical analysis of distribution efficiency (NWFP)

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value
Replicate	5	7.01	1.402	1.96
Length (L)	2	13.05	6.524	9.10**
Discharge (Q)	2	0.10	0.048	0.07NS
L x Q	4	1.25	0.312	0.44NS
Error	10	28.67	0.717	

** : Highly significant

NS : Non-significant

Table 11. Statistical Analysis of Distribution Efficiency (UAF)

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value
Replication	2	8.06	4.028	0.52
Length (L)	2	1253.00	626.501	81.41**
Discharge (Q)	2	192.17	96.087	12.48**
L x Q	4	83.38	20.844	2.70NS
Error	16	123.13	7.696	

** : Highly significant

NS : Non-significant

Table 12. Observed and predicted distribution efficiencies for different border lengths with three stream sizes (NWFP)

Border Leng `L' (m)	Stream Si `Q' (l/s/m)	Cutoff Ti `Tc' (min)	Storage Efficie Observed	Storage Efficie Predicted
30	1	43.5	97.54	97.57
	2	17.7	98.32	98.58
	3	12.3	98.60	98.58
60	1	86.3	97.55	97.59
	2	37.5	98.49	98.58
	3	25.1	98.87	98.58
90	1	125.9	97.67	97.59
	2	62.3	98.59	98.56
	3	35.8	99.05	98.05

Table 13. Observed and predicted distribution efficiencies for different border lengths with three stream sizes (UAF)

Border Leng `L' (m)	Stream Si `Q' (l/s/m)	Cutoff Ti `Tc' (min)	Storage Efficie Observed	Storage Efficie Predicted
30	1	38	91.56	88.00
	2	16	88.84	89.17
	3	11	92.02	89.68
60	1	80	84.99	87.01
	2	42	89.33	87.87
	3	20	93.76	88.87
90	1	112	72.16	73.32
	2	50	73.66	74.23
	3	38	81.24	74.54

Table 14. Application efficiencies for three different soil surface conditions, stream sizes and border lengths

BORDER STRIP	FRESH TILTH			POST IRRIGATION			CROP CONDITION		
	STREAM SIZE (l/s/m)								
	1	2	3	1	2	3	1	2	3
	%								
A1(90mx8m)	94.46	94.23	95.33	93.79	96.08	95.55	94.82	95.14	95.94
A2(90mx8m)	94.65	93.95	93.84	93.71	95.86	95.25	94.82	95.16	95.86
A3(90mx8m)	94.78	93.76	95.46	93.63	96.30	94.94	94.82	95.17	95.90
AVG	94.63	93.98	94.88	93.71	96.08	95.25	94.82	95.16	95.90
B1(60mx8m)	95.35	94.56	95.00	94.04	95.72	95.52	95.40	95.48	96.56
B2(60mx8m)	95.19	93.52	95.28	94.76	95.83	95.61	95.43	95.43	96.50
B3(60mx8m)	95.41	93.90	94.51	94.19	96.12	95.51	95.43	95.41	96.22
AVG	95.32	94.00	94.93	94.33	95.89	95.55	95.42	95.44	96.76
C1(30mx8m)	96.38	94.65	95.45	94.91	96.39	95.97	[illegible]	95.71	96.57
C2(30mx8m)	96.11	93.99	95.00	95.07	96.03	96.34	95.98	95.70	96.38
C3(30mx8m)	96.24	95.07	95.23	94.74	96.52	95.06	95.71	95.67	96.38
AVG	96.24	94.57	95.23	94.91	96.31	95.79	95.88	95.70	96.44

Table 15. Analysis of variance for application efficiencies for three different soil surface conditions, stream sizes and border lengths

CONDITIONS	U. Limit	Means	L. Limit	
CROP- POST IRRIGATION	-0.017	0.411	0.838	
CROP- FRESH TILTH	0.433	0.860	1.288	***
POST IRRIGATION - CROP	-0.838	-0.411	0.017	
POST IRRIGATION - FRESH TILTH	0.022	0.450	0.877	***
FRESH TILTH-CROP	-1.288	-0.860	-0.433	***
FRESH TILTH-POST IRRIGATION	-0.877	-0.450	-0.022	***
STREAM SIZES				
3 l/s/m - 2 l/s/m	-0.027	0.400	0.828	
3 l/s/m - 1 l/s/m	0.180	0.607	1.035	***
2 l/s/m - 3 l/s/m	-0.828	-0.400	0.027	
2 l/s/m - 1 l/s/m	-0.220	0.207	0.635	
1 l/s/m - 3 l/s/m	-1.035	-0.607	-0.180	***
1 l/s/m - 2 l/s/m	-0.635	-0.207	0.220	
BORDER LENGTHS				
(30mx8m)-(60mx8m)	-0.045	0.382	0.810	
(30mx8m)-(90mx8m)	0.314	0.741	1.169	***
(60mx8m)-(30mx8m)	-0.810	-0.382	0.045	
(60mx8m)-(90mx8m)	-0.069	0.359	0.786	
(90mx8m)-(30mx8m)	-1.169	-0.741	-0.314	***
(90mx8m)-(60mx8m)	-0.786	-0.359	0.069	

Table 16. Distribution uniformities for three different soil surface conditions, stream sizes and border lengths

BORDER STRIP	FRESH TILTH			POST IRRIGATION			CROP CONDITION		
	STREAM SIZE (l/s/m)								
	1	2	3	1	2	3	1	2	3
	%								
A1(90mx8m)	92.62	95.14	97.13	94.86	98.41	98.33	95.88	97.76	98.57
A2(90mx8m)	93.02	95.27	95.79	98.80	98.35	98.28	95.99	97.78	98.67
A3(90mx8m)	93.94	94.82	97.36	94.73	98.47	98.23	95.77	97.77	98.61
AVG	93.19	95.08	96.76	96.13	98.41	98.28	95.88	97.77	98.62
B1(60mx8m)	95.77	96.95	97.51	96.97	98.74	98.85	97.08	98.42	98.82
B2(60x8m)	95.88	95.92	97.52	97.67	98.72	98.65	97.13	98.39	98.98
B3(60mx8m)	95.87	96.00	97.46	96.98	99.16	98.80	97.13	98.46	98.98
AVG	95.84	96.29	97.50	97.21	98.87	98.77	97.11	98.42	98.93
C1(30mx8m)	98.30	98.53	99.09	98.65	99.56	99.58	98.75	99.37	99.55
C2(30mx8m)	98.25	98.10	98.93	98.87	99.60	99.60	98.81	99.32	99.47
C3(30mx8m)	98.27	99.76	98.85	98.42	99.59	99.24	98.85	99.26	99.58
AVG	98.27	98.80	98.96	98.65	99.58	99.47	98.80	99.32	99.53

Table 17. Analysis of variance for distribution uniformity for three different soil surface conditions, stream sizes and border lengths

CONDITIONS	U. Limit	Means	L. Limit	
CROP- POST IRRIGATION	-0.176	0.237	0.650	
CROP- FRESH TILTH	1.346	1.759	2.172	***
CROP- FRESH TILTH	1.109	1.522	1.935	***
FRESH TILTH-POST IRRIGATION	-2.172	-1.759	-1.346	***
FRESH TILTH-CROP	-1.935	-1.522	-1.109	***
STREAM SIZES				
3 l/s/m - 2 l/s/m	0.106	0.601	1.097	***
3 l/s/m - 1 l/s/m	1.378	1.874	2.370	***
2 l/s/m - 3 l/s/m	-1.097	-0.601	-0.106	***
2 l/s/m - 1 l/s/m	0.777	1.273	1.769	***
1 l/s/m - 3 l/s/m	-2.370	-1.874	-1.378	***
1 l/s/m - 2 l/s/m	-1.769	-1.273	-0.777	***
BORDER LENGTHS				
(30mx8m)-(60mx8m)	0.855	1.351	1.847	***
(30mx8m)-(90mx8m)	1.816	2.312	2.808	***
(60mx8m)-(30mx8m)	-1.847	-1.351	-0.855	***
(60mx8m)-(90mx8m)	0.465	0.961	1.457	***
(90mx8m)-(30mx8m)	-2.808	-2.312	-1.816	***
(90mx8m)-(30mx8m)	-1.457	-0.961	-0.465	***

Table 18. Coefficient of uniformity for three different soil surface conditions, stream sizes and border lengths

BORDER STRIP	FRESH TILTH			POST IRRIGATION			CROP CONDITION		
	STREAM SIZE (l/s/m)								
	1	2	3	1	2	3	1	2	3
	%								
A1(90mx8m)	94.44	96.78	98.11	96.72	98.98	98.90	97.22	98.41	99.01
A2(90mx8m)	95.42	96.87	97.21	96.39	98.96	98.87	97.29	98.38	99.08
A3(90mx8m)	95.93	96.52	98.25	96.05	99.00	98.84	97.14	98.46	99.04
AVG	95.26	96.72	97.86	96.39	98.98	98.87	97.22	98.42	99.04
B1(60mx8m)	97.54	98.06	98.42	98.28	99.22	99.28	98.06	99.07	99.27
B2(60mx8m)	97.59	97.27	98.39	98.60	99.17	99.12	98.07	98.99	99.31
B3(60mx8m)	97.58	97.51	98.30	98.25	99.46	99.16	98.08	98.95	99.33
AVG	97.57	97.61	98.37	98.38	99.28	99.19	98.07	99.00	99.30
C1(30mx8m)	98.72	98.92	99.32	98.97	99.65	99.68	99.09	99.55	99.67
C2(30mx8m)	98.74	98.76	99.21	99.19	99.73	99.70	99.16	99.53	99.62
C3(30mx8m)	98.63	98.11	99.14	98.74	99.69	99.44	99.16	99.46	99.70
AVG	98.70	98.60	99.22	98.97	99.69	99.61	99.14	99.51	99.66

Table 19. Analysis of variance for coefficient of uniformity for three different soil surface conditions, stream sizes and border lengths

CONDITIONS	U. Limit	Means	L. Limit	
CROP- POST IRRIGATION	-0.322	0.002	0.327	
CROP- FRESH TILTH	0.726	1.050	1.375	***
POST IRRIGATION- CROP	-0.327	-0.002	0.322	
POST IRRIGATION- FRESH TILTH	0.724	1.048	1.373	***
FESH TILTH- CROP	-1.375	-1.050	-0.726	***
FRESH TILTH-POST IRRIGATION	-1.373	-1.048	-0.724	***
STREAM SIZES				
3 l/s/m - 2 l/s/m	0.043	0.367	0.692	***
3 l/s/m - 1 l/s/m	0.947	1.271	1.596	***
2 l/s/m - 3 l/s/m	-0.692	-0.367	-0.043	***
2 l/s/m - 1 l/s/m	0.580	0.904	1.229	***
1 l/s/m - 3 l/s/m	-1.596	-1.271	-0.947	***
1 l/s/m - 2 l/s/m	-1.229	-0.904	-0.580	***
BORDER LENGTHS				
(30mx8m)-(60mx8m)	0.377	0.702	1.026	***
(30mx8m)-(90mx8m)	1.268	1.593	1.917	***
(60mx8m)-(30mx8m)	-1.026	-0.702	-0.377	***
(60mx8m)-(90mx8m)	0.567	0.891	1.216	***
(90mx8m)-(30mx8m)	-1.917	-1.593	-1.268	***
(90mx8m)-(60mx8m)	-1.216	-0.891	-0.567	***

Table 20. Average volume of water and time of irrigation for different irrigation methods

Date of Irrigation	Border		Round Basin		Modified Round Basin		Modified Furrow	
	Vw (m^3)	Ti (min)	Vw (m^3)	Ti (min)	Vw (m^3)	Ti (min)	Vw (m^3)	Ti (min)
7.10.91	8.42	46.5	1.36	7.5	2.45	13.0	1.28	8.0
5.11.91	7.44	41.0	1.32	7.25	1.79	9.50	1.40	8.75
3.12.91	5.37	29.5	1.18	6.5	1.67	9.0	1.12	7.0
4.6.92	8.58	47.25	1.22	6.73	1.90	10.09	1.41	8.85
9.6.92	6.54	36.0	1.14	6.27	2.31	12.25	1.24	7.75
Average	7.27	40.05	1.24	6.85	2.02	10.77	1.29	8.07

Vw- Volume of water applied
Ti- Irrigation duration

<u>Percent Saving</u>

Volume of Water			486	-	260	-	464	-
Time of Irrigation			-	485	-	272	-	396

Table 21. Advance, recession and infiltration opportunity time

	Borders			Round Basin			Modified Round Basin			Modified Furrow		
Distance (meter)	Ta	Tr	Tz	Ta	Tr	Tz	Ta	Tr	Tz	Ta	Tr	Tz
3	1.23	46	44.77	0.43	40	39.56	0.68	82	81.32	0.55	60	59.45
9	4.06	49	44.93	1.37	64	62.63	1.70	84	82.30	1.33	61	59.67
15	8.20	53	44.80	2.42	69	66.58	2.77	94	91.23	2.28	59	56.72
21	12.57	55	42.43	3.38	67	63.62	3.88	85	81.12	3.43	64	60.57
27	17.62	58	40.38	4.42	66	61.58	5.13	89	83.87	4.57	65	60.43
33	22.75	62	39.25	5.52	70	64.48	6.33	105	98.67	5.68	65	60.68
39	28.18	67	38.82	6.58	81	64.42	7.63	107	99.37	6.73	70	63.27
45	34.62	79	44.38	7.40	91	83.60	8.87	118	109.13	7.95	71	63.05
51	40.68	115	74.32	8.72	85	76.26	10.02	136	126.00	9.22	72	62.78
60	48.38	141	92.62	9.93	95	85.07	11.63	156	144.37	10.22	78	67.78

Ta- Advance time, minutes;

Tr- Recession time, minutes;

Tz- Infiltration opportunity time, minutes.

Table 22. Recommended raingun sprinkler systems for various physical and socio-economic conditions in Barani areas.

Farm Size (acres)	Raingun Model	Working Pressure	Prime Mover	Area Coverage Per Setting (acres)
2.0	PY_1-20	40	Electric diesel	0.40
5.0	PY_1-30	40	Electric diesel	0.64
10.0	PY_1-40	45	Electric diesel	1.00
15.0	PY_1-50	50	Electric diesel	1.40
20.0	PY_1-60	60	Electric diesel	1.83
25.0	PY_1-60	60	Electric PTO driven	2.10
30.0	PY_1-80	70	PTO driven	2.50
50.0	PY_1-80	80	PTO driven	3.80

Table 23. **Christiansen coefficient of uniformity and effective diameter of coverage for raingun model PY1-30**

Nozzle Diameter (mm)	Pressure (psi)	Discharge (lps)	Coefficient of Uniformity (%)	Effective Diameter of Coverage (m)
5	50	0.47	73.4	22
	60	0.51	74.3	24
	70	0.55	79.2	23
	80	0.57	81.1	22
6	50	0.72	75.4	26
	60	0.80	82.6	27
	70	0.86	80.6	29
	80	0.92	79.4	27
8.6	50	0.94	79.0	34
	60	1.22	82.0	34
	70	1.92	79.7	34
	80	2.11	76.7	36
10	50	1.91	80.6	38
	60	2.08	80.3	40
	70	2.40	79.5	40
	80	2.50	78.7	39
12	50	2.79	80.0	46
	60	3.28	81.4	47
	70	3.5	78.7	40
	80	3.86	77.5	40

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Table 24. Average climatic data and reference crop evapotranspiration, National Agricultural Research Centre, Islamabad

Month	Temp. °C	Humidity %	Windspeed km/day	Sunshine hours	Radiation mm/day	ETo-Penman mm/day
Jan.	10.9	67	73	6.3	1.5	1.71
Feb.	13.1	65	90	6.3	2.3	2.44
March	16.1	60	96	5.9	3.2	3.43
April	22.4	54	94	7.8	4.5	5.08
May	26.1	41	123	9.6	5.4	6.96
June	30.0	42	135	8.9	5.5	7.60
July	29.1	65	110	7.5	5.4	5.95
Aug.	28.4	71	82	7.5	5.1	5.19
Sep.	27.3	61	85	8.4	4.4	5.02
Oct.	22.0	57	81	8.3	3.0	3.73
Nov.	17.3	60	67	7.9	1.9	2.43
Dec.	11.9	69	67	5.4	1.3	1.55

Table 25. Rainfall and supplemental irrigation during wheat growing season, 1989-90

Period	Rainfall (mm)	Supplemental Irrigation (mm)			
		TO	T1	T2	T3
Before sowing irrigation	-	-	10	-	-
Nov. 1989	-	-	-	-	-
Dec. 1989	49.9	-	-	-	-
Jan. 1990	41.4	-	-	10	-
Feb. 1990	104.9	-	-	-	25
Mar. 1990	170.3	-	-	10	25
Apr. 1990	49.8	-	-	10	25
May. 1990	-	-	-	-	-
Total	416.3	-	10	30	

Sowing date : 21-11-89
Harvesting date : 14-5-90
Growing season length : 175 days
Seasonal Rainfall : 416.0 mm
Seasonal Evapotranspiration : 382.5 mm

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Table 26. Rainfall and supplemental irrigation during wheat growing season 1990-91

Period	Rainfall (mm)	Supplemental Irrigation (mm)			
		To	T1	T2	T3
Before sowing irrigation	-	-	10	10	10
Nov. 1990	-	-	-	-	35
Dec. 1990	171.00	-	-	10	-
Jan. 1991	8.70	-	-	10	25
Feb. 1991	119.1	-	-	10	-
Mar. 1991	91.3	-	-	-	-
Apr. 1991	131.1	-	-	-	-
May. 1991	1.50	-	-	-	-
Total	522.7	-	10	40	60

Sowing Date : 3-11-90
Harvesting Date : 12-5-91
Growing Seasons Length : 191 days
Seasonal Rainfall : 523.0 mm
Seasonal Evapotranspiration : 315.0 mm

Table 27. Rainfall and supplemental irrigation during wheat growing season 1991-92

Period	Rainfall (mm)	Supplemental Irrigation (mm)			
		To	T1	T2	T3
Before sowing irrigation	-	-	10	10	10
Nov. 1991	-	-	-	10	35
Dec. 1991	25.0	-	-	10	35
Jan. 1992	123.0	-	-	10	25
Feb. 1992	34.0	-	-	10	35
Mar. 1992	109.0	-	-	10+10+10	25
Apr. 1992	47.0	-	-	-	-
May. 1992	16.0	-	-	-	-
Total	354.0	-	10	80	135

Sowing Date : 28-10-91
Harvesting Date : 08-5-92
Growing Season Length : 194 days
Seasonal Rainfall : 354.0mm
Seasonal Evapotranspiration : 360 mm

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Table 28. Yield and yield components of wheat during Rabi 1989-90, NARC, Islamabad

Description	Barani	Supplemental Irrigation Rauni Only	10 mm Application	25 mm Application
No. of plants/m²	189	166	158	195
No. of tillers/plant	3	3	4	4
Ear length (cm)	9.52	9.30	9.30	9.20
No. of grains/ear	55	55	51	52
Height of plant (cm)	98.66	93.57	96.14	100.34
Weight of 1000 grains(gm)	38.44	38.85	36.51	38.00
Grain wt. (gm m^{-2})	450.40	466.36	427.78	458.93
Straw wt. (gm m^{-2})	745.97	703.56	629.92	750.36
Grain straw ratio	1:1.66	1:1.51	1:1.47	1:1.64
Crop yield (t/ha)	4.50	4.66	4.28	4.59

Table 29. Yield and yield components of wheat during Rabi 1990-91, NARC, Islamabad

Description	Barani	Supplemental Irrigation Rauni Only	10 mm Application	25 mm Application
No. of plants/m²	185	175	168	215
No. of tillers/plant	3	3	4	4
Ear length (cm)	12.78	13.00	13.35	13.34
No. of grains/ear	48	49	51	52
Height of plant (cm)	88.00	100.00	99.00	99.00
Weight of 1000 grains(gm)	38.44	36.00	40.00	38.00
Grain wt. (gm m^{-2})	436.00	626.00	575.00	630.00
Straw wt. (gm m^{-2})	536.00	735.00	766.00	764.00
Grain straw ratio	1:1.23	1:1.17	1:1.13	1:1.21
Crop yield (t/ha)	4.36	6.26	5.75	6.30

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Table 30. Yield and yield components of wheat during Rabi 1991-92, NARC, Islamabad

Description	Baroni	Supplemental Irrigation Rauni Only	10 mm Application	25 mm Application
No. of plants/m²	180	195	171	205
No. of tillers/plant	4	4	4	4
Ear length (cm)	9.6	8.90	10.81	10.59
No. of grains/ear	40	49	54	53
Height of plant (cm)	96.70	97.73	98.30	98.33
1000 grain wt. (gm)	39.37	41.94	40.94	39.28
Grain wt. (gm m^{-2})	301.74	445.56	595.03	659.98
Straw wt. (gm m^{-2})	844.7	614.93	1096.45	1103.74
Grain straw ratio	1:2.80	1:1.35	1:1.84	1:1.64
Crop yield (t/ha)	3.04	4.56	5.95	6.60

Table 31. Cost of supplemental irrigation

1. Cost of the system — Rs. 18,000
2. Expected life — 8 years
3. Total operation/year — 1000 hours

4. 10mm/ha can be applied in 19 hours (with provision of one hour for adjustment, movement of machinery, etc., using 80% efficiency of the system).

5. Annual fixed cost

Interest @ 13%	18000 x 0.13 =	Rs. 2340.00
Depreciation @ 10%	(18000-1800)/8=	Rs. 2025.00
Total fixed cost		Rs. 4365

6. Operational cost per hour

Fixed cost	4.37
Fuel	5.05
Lubrication (15% of fuel cost)	0.76
Labor	5.00
Total operational cost per hour	Rs. 15.18

7. Total cost per hectare

- 10 mm application depth	288
- 40 mm application depth	1154
- 60 mm application depth	1731
- 80 mm application depth	2307
- 135 mm application depth	3894

Table 32. Benefits of supplemental irrigation

Particulars	Growing Seasons 1989-90	1990-91	1991-92
Gross benefits			
- 10 mm application as Rauni	280	6871	5844
- 10 mm application each at 50% MAD	-	5106	11092
- 25 mm application each at 75% MAD	-	7144	13545
Cost of Supplemental Irrigation			
- 10 mm application as Rauni	288	288	288
- 10 mm application each at 50% MAD	-	1154	2307
- 25 mm applications at 75% MAD	-	1728	3894
Net Benefits			
- 10 mm application as Rauni	Nil	6583	5556
- 10 mm application each at 50% MAD	-	3952	8785
- 25 mm application each at 75% MAD	-	5413	9651

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