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On-farm system performance in the Maricopa-Stanfield Irrigation and Drainage District area

A.J. CLEMMENS[1], A.R. DEDRICK[1], W. CLYMA[2] & R.E. WARE[3]
[1]*U.S. Water Conservation Lab., 4331 E. Broadway, Phoenix, AZ 85040, USA;* [2]*Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, CO, USA;* [3]*U.S.D.A. Soil Conservation Service, Casa Grade, AZ, USA*

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Abstract. A detailed Diagnostic Analysis (DA) was performed on an irrigation district in Central Arizona as part of a Management Improvement Program (MIP). The DA was conducted by an interdisciplinary team who focused their findings on performance of the irrigated agricultural system, on- and off-farm, rather than on disciplines. This paper reports on the findings related to on-farm management. Specific findings are presented relative to farm water use, soil sustainability, the interactions between the farm irrigation system and the water delivery system, and the adoption and transfer of new technology. The results point to the need for appropriate application of technology, ongoing farmer education, and coordination of farm and district operations and government agency programs. The interdisciplinary nature of the DA team was essential for properly assessing performance. Although this study was done in the state of Arizona in the USA, the methodology used and some of the general conclusions are applicable to other locations, both within and outside the United States.

Key words: farm irrigation, irrigated agriculture, management improvement, water delivery, coordination, interdisciplinary teams, integrated resource management

Introduction

For many irrigation projects around the world, the performance of irrigated agriculture is well below expected levels. Irrigated agriculture is a complex process that is influenced by weather, labor, irrigation and other farming practices, and the availability and management of inputs (e.g., seed, fertilizer, water, etc.). In irrigated areas, water availability, distribution, and application are often the major limiting factors for production. Further, these factors are frequently a mix of technical, social, and political issues that can be divided into two subsystems or components; those associated with the farm system and those associated with support to the farm system (e.g., irrigation project, cooperatives, farm credit availability, etc.).

Water management is but one part of farm management within an irrigated agricultural setting. Improvements in farm water management must be viewed in the context of overall farm management. Evaluations that deal only with the technical aspects of farm irrigation systems may not identify the range of constraints that hinder farm water management and performance. Interdisciplinary studies of farming practices are an effective way to identify both strengths and weaknesses in irrigation systems and their operation (Clyma and Lowdermilk 1988).

The Management Improvement Program (MIP) is a structured methodology for assessing performance and organizing interested parties to identify and address improvement opportunities. The Diagnostic Analysis phase of the MIP consists of assessing existing conditions and documenting areas of low and high performance. This assessment and documentation potentially includes a broad spectrum of agricultural production, such as water use, crop management, soil management, labor, water availability and delivery service, technical services from government agencies, and educational programs. More details on the MIP process, including the *Management Planning* and *Performance Improvement* phases can be found in Dedrick et al. (1992), Dedrick et al. (1993) and Dedrick et al. (2000a).

In 1990, the U.S. Water Conservation Laboratory of the U.S. Department of Agriculture-Agricultural Research Service proposed testing the Management Improvement Program (MIP) to a number of federal and state of Arizona agencies. They chose the Maricopa-Stanfield Irrigation and Drainage District (MSIDD), an irrigated area in central Arizona, USA, as a demonstration site. The MIP was conducted over a three-year period (April 1991 through January 1994). Further details can be found in a series of papers in this issue (for example, Dedrick, et al. 2000a). The Diagnostic Analysis (DA) phase of the demonstration MIP identified existing conditions during the summer of 1991, including strengths and weaknesses of irrigated agricultural performance in the MSIDD area, and resulted in a DA report (Dedrick et al. 1992).

In this paper, we present the results of the on-farm portion of the DA. Where appropriate we also consider the influence of support entities on the farming enterprise in the area, especially as they impact the farm irrigation systems and crop water use. During the course of the MIP, conditions changed within the district, some changes occurring as a result of the DA findings, while others were due to externalities. This paper reflects those conditions that existed during DA data collection.

Study area

The Maricopa-Stanfield Irrigation and Drainage District (MSIDD) is a financially autonomous, public utility sanctioned by the State of Arizona. It has the authority to tax land, sell municipal bonds, and charge for water delivered. It is comprised of roughly 35,000 ha of irrigated land within central Arizona, about 30 to 50 km south of Phoenix, Arizona, USA. Policy issues are the responsibility of a nine-person board of directors, elected from the local area. The district uses both Colorado River water from the Central Arizona Project (CAP) and groundwater. The CAP was developed to reduce groundwater overdraft in central Arizona. Groundwater mining had been occurring in this area for more than half a century, which prompted the Arizona Legislature to restrict the amount of groundwater pumping in the main agricultural areas in the central part of the state. Water duties placed a limit on annual pumping volume by each farm. Colorado River water from the CAP was intended to directly offset groundwater pumping.

The climate in the MSIDD area is arid with summer temperatures reaching 50°C. Annual rainfall is about 200 mm. Average land area managed by farmers is about 500 ha. Cotton is the predominant crop in the area ($>85\%$). Other main crops include alfalfa, wheat, grapes, melons, and pecans. Surface irrigation is used on more than 95% of the land area, with some micro and sprinkler irrigation. Prior to the CAP, irrigation was from farmer owned and operated wells. The district sold municipal bonds to help pay for construction of an open-channel distribution network to deliver Colorado River Water, which was completed in 1989. With the receipt of CAP water, MSIDD took over the existing farm wells to provide conjunctive use management of the ground and surface water supplies and more efficient use of electrical power. Groundwater in the area is deep, typically 100–200 m. In 1991, 60% of the delivered water was from groundwater, and 40% came from the CAP.

Because of the predominance of large surface irrigated fields, the turnout design capacity was 425 l/s, with one turnout serving roughly 250-ha. Most farmers had more than one turnout, although some turnouts served more than one farm. Water is supplied to farmers on request with a one-day lead time. The district employs about 35 people including a general manager, an administrative staff , and an operation and maintenance staff. Each district turnout has a single-path ultrasonic flow meter (measures velocity in a pipe) with both rate and volume readouts. The irrigation district controls and monitors the wells, and water is charged at the same rate per unit volume regardless of the source.

Prior to arrival of CAP water, many farmers had experienced water shortages due to limited well capacities. The district can be characterized as having relatively expensive water (35 to 40 US$ per megaliter or cubic dekameter). Thus, there have been significant incentives to limit water pumping or diversion. Groundwater recharge is not well documented in this area. During long period of groundwater mining, groundwater tables were dropping faster than deep percolation from agriculture was moving down. No credit on water duties for groundwater recharge is provided for agricultural deep percolation, since it is unclear whether or not this water actually reaches the groundwater (transit times are on the order of decades). Thus for this paper, there is no distinction between water delivered, applied, or used, since all water delivered is assumed lost to the system. Groundwater recharge has been primarily from major storm events in ephemeral stream that run through this area.

MSIDD-area diagnostic analysis

The interdisciplinary DA team consisted of specialists in on-farm water control, delivery water control, farm agronomic productivity, economics, social-organizational issues, and management science (process facilitation). The team had members from the local area as well as outside experts. Data were collected from interviews with farmers and their foremen and irrigators; district personnel, including key managers, dispatchers, and canal operators; and the board of directors. Information on many aspects of the farming operation was collected, including irrigation system, irrigation practices, labor practices, tillage, chemical applications, interactions with the irrigation district and other government agencies, farm budgets, yields, cotton prices, and debt. Data from district records on water delivered were used directly since they previously had been verified as accurate (i.e., within ± 3%).

Data on water use, yields, farming practices, etc., were collected for the land area serviced by an individual turnout from the district for the previous year, 1990. Turnouts were grouped by location along a lateral canal (head, middle, tail) and by land area farmed (i.e., not just by the land served by that turnout) by the farmer receiving water from that turnout (large, medium and small). Four turnouts, and the associated farmer, were selected randomly from these nine groupings (3×3). The intent was to interview three farmers from each group, with the fourth being an alternate. A total of 25 farmer interviews were eventually conducted. Further details of the sampling strategy can be found in Dedrick et al. (1992).

The DA results for the demonstration MIP were grouped into three areas:

- Overall economic viability of the irrigated agriculture system;
- Management of the farm enterprise and MSIDD;
- Technology upgrading and new technology adoption.

Each area had a set of objectives from which performance could be judged. Performance was described in terms of Performance Statements within these three areas. Each of these Performance Statements represented the DA team's interdisciplinary understanding of that aspect of performance at that time. These statements reflected observed conditions, including both quantitative and qualitative factors. The process for arriving at these statements is discussed in more detail in Dedrick et al. (2000b). Quantitative information was collected from various reports, district records, and interviews. Qualitative judgments were based on the collected data (i.e., existing records and interviews), field visits, and professional judgments. Such judgments made by individuals were challenged if they did not fit the understanding of all DA team members.

For each performance statement, statements of contributing factors were included in the report (Dedrick et al. 1992). These contributing factors included specific observations or specific conclusions reached by the team that supported the more general Performance Statement. The Performance Statements for the MSIDD-Area DA related to the on-farm system are provided in this paper, with supporting data where appropriate.

MSIDD-area diagnostic analysis results

The MSIDD-area DA performance statements dealing with on-farm management issues (other than economic viability) are given in Table 1. Other aspects of the DA are discussed in companion papers (Wilson and Gibson 2000 cover economic viability, and Bautista et al. 2000b cover district performance). Some of the more significant contributing factors and data analysis leading to these Performance Statements follow.

Water management

Because of limited time and resources, the analysis of water management practices primarily focused on cotton, since it was by far the major crop grown in the area. The seasonal water applied to cotton in 1990 varied from just under 900 mm to just over 2000 mm, with an average of 1260 mm and a standard deviation of 330 mm. Most farmers indicated that 1990 was a low water application year because of effective rainfall during the growing season. Consumptive use was estimated from local agricultural experiment station data to be about 1020 mm, with about 120 mm of effective rainfall and 50 mm of initial soil moisture, thus requiring about 850 mm from irrigation. Consumptive use can vary considerably depending on the growing

Table 1. MSIDD-area diagnostic analysis performance statements related to on-farm management (excluding economic viability issues) from Dedrick et al. (1992).

Performance area	Number	Performance statement
1. Overall economic viability of irrigated agriculture system		See Wilson and Gibson (2000)
2. Management of the farm enterprise and MSIDD[1]		
	M1	Water use for a given crop (e.g., cotton) varies widely within the district, depending on soils, irrigation system, and management practices; this implies there are opportunities for improvement.
	M2	Because of the standard water delivery service window (on and off), the flexibility and timing of water delivery service vary within the district; this influences farm irrigation operations, management practices and investment in technologies.
	M3	Soil-building conservation measures such as the use of small grains, alfalfa, cover crops, manure and reduced tillage systems are inadequately employed to sustain the farming system.
	M6	The ability of MSIDD operating staff to deliver the requested flow rate and maintain it over time without significant fluctuation varies within the district.
3. Technology upgrading and new technology adoption[1]		
	T1	Growers' adoption of new or improved irrigation technologies has been limited and in some cases, incomplete.
	T2	Agency technology transfer efforts have had only limited success in affecting the rate of technology upgrading or new technology adoption by growers.

season length chosen by the farmer (i.e., some farmers stop irrigating cotton in early August, others as late as the end of September). The water applied was obtained from MSIDD water delivery records. Land area farmed during 1990 for each turnout was obtained from the farmers (with approximate verification from local agency records). Weather conditions during 1990 also

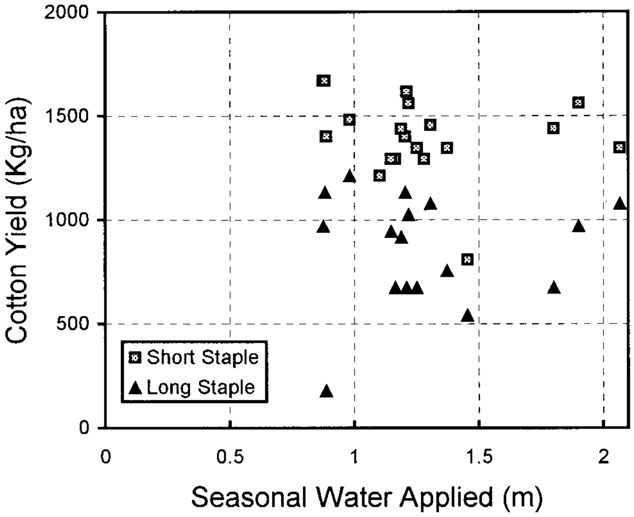

Figure 1. Cotton yield versus seasonal water applied for land supplied from sample turnouts in MSIDD during 1990.

caused relatively low yields (hot June and wet August). Yield records were obtained from farmer records (usually ginning receipts) and averaged 1400 and 870 kg/ha for short and long staple cotton, respectively. (See Dedrick et al. 1992 for further details).

Neither short- nor long-staple cotton yields were statistically related to seasonal water applied during 1990 (Figure 1). What is important to observe, for example for short-staple cotton, is that some farmers had relatively high yields (>1500 kg/ha) with low water application (<1 m applied), while others had yields that were significantly lower (<1200 kg/ha) with more water applied (>2 m in one case). Long-staple cotton responded similarly. Seasonal water applied was clearly not the cause of the yield variability, and other factors (e.g., timing of irrigations, pest and nutrient management, etc.) contributed significantly to the resulting yields.

The factors considered as potentially affecting seasonal water use for cotton are given in Table 2. Other factors were initially considered, but it was felt that there was insufficient detail to include them in the analysis. For other locations, the list would be modified. The General Linear Model (GLM) procedure of SAS (SAS/STAT 1991) was used to test the significance of the factors shown in Table 2 in describing the seasonal water applied to cotton during the 1990 growing season. Data on water applied were available for only 20 of the 25 farmers interviewed. The statistical model was developed by first including all the factors and then removing the least significant factor,

Table 2. Variables that were expected to be related to seasonal water use on cotton during 1990 for land serviced by a given turnout.

Factor	Definition	Quantification
AREA	Land area managed by farmer	$<$ 300, 300 to 600, or $>$ 600 ha
LOCAT	Location of farm offtake on lateral canal	$<$ 2, 2 to 5, $>$ 5 active turnouts upstream
TYPE	Irrigation system type	Sloping furrows with or without side fall ($>$ 60 mm fall in length-of-run), low gradient or level furrow with side fall (water distributed to individual furrows with siphons), or level basins, no slope in any direction (furrows connected by secondary ditch)
LENGTH	Average length of run in meters	Range 200 to 800 m
IFAM	SCS intake family averaged over area served by turnout	Range 0.3 to 1.3
OWN	Indicator of land ownership by farmer	Own, lease, or hired manager
YEARS	Years of farming the area of land in question	$<$ 10, or $\geq$ 10 years
WHEN-WHO	Who decides when it is time to irrigate?	Owner/consultant or Foreman/irrigator
WHEN-HOW	How is time to irrigate decided?	Visual observations only or other methods that may include visual and other methods
AMOUNT-WHO	Who determines how much water should be applied?	Owner/consultant or Foreman/irrigator
AMOUNT-HOW	How is the amount to apply determined?	More scientific method (e.g., soil moisture measurement) or strictly by experience/not at all
HOW	How are irrigation set changes decided on in the field?	By time only or by other methods
ADEQ	How is adequacy of irrigation checked?	Check with soil probe/other similar method or not checked/visual check only
CALC-H20	Is water applied calculated for each irrigation?	Yes or no
REC-E	Is water applied recorded for each irrigation event?	Yes or no
REC-S	Is water applied recorded seasonally?	Yes or no

one by one, until all remaining factors were significant at the 10% probability level. The final statistical model describing the remaining factors is

$$W = A + B \bullet LENGTH + C \bullet IFAM + D + E + F \tag{1}$$

where
W is the seasonal water applied in mm;
LENGTH is the length-of-run in meters, averaged over the land served by the turnout;
IFAM is the USDA, Soil Conservation Service (SCS[2]) intake family (USDA, 1974a); averaged over the land served by the turnout;
A is the intercept in mm;
B is the coefficient for LENGTH in mm/m;
C is the coefficient for IFAM in mm;
and D, E, and F are the coefficient for the class variables AREA, OWN and ADEQ, respectively (see Tables 2 and 5 for definitions and values) in mm.

The details of the model's statistical significance are shown in Tables 3 and 4. Equation 1 explains 79% of the variability in the amount of seasonal water applied during 1990 for the 20 farms analyzed (Table 3), with length-of-run the most statistically significant variable (see Table 4 probabilities), followed by the variable for soil intake family. The coefficients for the model are given in Table 5. Each of the analyzed factors is discussed below. Because of the small sample size, independence of the variables in Table 2 could not be determined. Thus, these results should be interpreted as providing general tendencies and not as precise relationships.

Factors that influenced water use

Irrigation length-of-run (LENGTH) Significantly more water was applied seasonally on irrigation systems with longer lengths-of-run. As noted earlier, it was the most statistically significant factor considered, accounting for 28% of the variability in seasonal water use. Average length-of-run (an average value was taken if the length-of-run varied for the area serviced by an individual turnout) ranged from about 200 to 800 m. The statistical analysis suggests that 119 mm more seasonal water was applied for each 100 m increase in furrow length (Table 5, B = 1.186), which results in a difference of roughly 700 mm for the range of lengths in the sample. Such differences indicate a potential for considerable water and cost savings. If lengths-of-run were shortened from 800 to 200 m, this analysis would indicate a savings in water cost of roughly $250/ha/year. [Note: shortening the length of run requires capital expenditures, more infrastructure, and more land taken out of production and may reduce machinery efficiency, which may offset these projected gains].

Table 3. Results of statistical analysis on water applied: Model significance. ($r^2 = 0.791$, Root mean square error = 190).

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
Model	7	1,633,334	233,333	6.48	0.0025
Error	12	431,854	35,988		
Total	19	2,065,188			

Table 4. Results of statistical analysis on water applied: Factor significance.

Source	Degrees of freedom	Sum of squares	Mean square[a]	F value	Probability[b]
AREA	2	324647	162324	4.51	0.0346
OWN	2	312730	156365	4.34	0.0381
ADEQ	1	161751	161752	4.49	0.0555
LENGTH	1	586028	586028	16.28	0.0017
IFAM	1	258352	258352	7.18	0.0201

[a] Because both continuous and class variables are used, Type III sums of squares are used.
[b] Factors with probability less than 0.10 are considered significant.

Table 5. Results of statistical analysis on water applied: Final statistical model.

Parameter	Case	Coefficient	Estimated value	Standard error of est.	Units
Intercept		A	586*	21	mm
LENGTH		B	1.186	0.294	mm/m
IFAM		C	564	210	mm
AREA	Large	D_L	–337*	125	mm
	Medium	D_M	–349*	127	mm
	Small	D_S	0**		mm
OWN	Own	E_O	–170*	155	mm
	Lease	E_L	116*	147	mm
	Hired	E_H	0**		mm
ADEQ	No	F_N	251*	118	mm
	Yes	F_Y	0**		mm

*Due to the unbalanced sample, these parameter estimates are biased.
** For class variables, one case is assigned a value of zero and is used as a reference.

Figure 2. Mean values and range of seasonal water applied to cotton in 1990 for different size farms in MSIDD.

Soil intake family (IFAM) Farmers in the sample applied more water in 1990 on higher intake soils. The average SCS intake family numbers (USDA, 1974a) for the area serviced by a turnout ranged from 0.3 to 1.3. The statistical analysis showed that IFAM explained about 13% of the variability in seasonal water applied, and that the difference in seasonal water use was approximately 560 mm for the range of intake families in the area (i.e., 564 × (1.3–0.3)), a significant amount. This translates to about 56 mm more seasonal water applied for every 0.1 increase in SCS intake family number. The interactions length-of-run by intake family and irrigation system type by intake family, although expected to be significant, were not.

Total land area managed (AREA) Farmers who farmed fewer than 300 ha on average used about 340 mm more water over their land than other farmers. They also showed the widest range of water applied, including both the smallest and largest amounts applied (880 to 2070 mm). Even though this factor shows up as statistically significant, it may have resulted from lack of data availability (i.e., differences in sample size). For example, it was difficult to obtain cropped area and yield records for a large farm that we suspected had high water use per unit area. However, if this relationship is real, it indicates that larger farms show less variability in water use, as shown in Figure 2.

Land ownership (OWN) Farmers in the sample who owned the land they farmed were more likely to apply less water than those who leased. Hired managers fell between these two groups. On average, owner-farmers applied 170 mm less water on cotton in 1990 compared to hired managers and almost 290 mm less than lessees. Factors that might contribute to this tendency include familiarity with the soils and irrigation system and the lack of lease continuity needed for incremental improvements in the irrigation system over the years.

Checking adequacy of irrigation (ADEQ) Farmers in the sample who used soil probes or related methods during or shortly after an irrigation to check the adequacy of water infiltrated at key spots within the field used an average of 250 mm less water compared to those who used simple visual checking or no checking at all. The magnitude of the difference in water use for this factor is somewhat surprising. Farmers appear to use observation of adequacy as feedback to adjust flow rates and application times for the remainder of the current irrigation and for future irrigations to avoid overirrigation of the lower end of the field (e.g., checking adequacy helps them stay right on the edge of over and under application).

Determining depth actually applied (CALC-H2O) This factor was the last one removed before reaching the final model given by Equation 1. Farmers who calculated depth applied after each irrigation tended to use less water, approximately 150 mm less. Again, the farmers appear to use this as feedback for adjustments to future irrigations. Determining depth actually applied was significant at the 16% level of significance, and so was beyond the original 10% limit established. However, it is considered significant enough that it should be given consideration when examining methods for inducing improvements in farm irrigation efficiency.

Factors that did not influence water use

While the following factors may influence the water use for a particular farm, they were not shown to be significant with the available data. This could have resulted from incomplete or erroneous data or from our inability to separate correlated variables. Further, it could be that the influence of these factors in this particular agricultural setting were less than the random variability observed (e.g., differences in farmer behavior).

Water supply (LOCAT) No differences in water use were found between head ($<$ 2 active offtakes upstream) and tailenders ($>$5 active offtakes upstream) on lateral canals, nor whether farmers had wells to use in addition to the canal delivery.

Irrigation system type (TYPE) Perhaps as a result of aggregating data by turnout, no relationships were found between irrigation system type and seasonal water applied. Turnouts often serviced several system types, several soil types, and several lengths-of-run. Three categories of system type were chosen and turnouts grouped by the dominant type (most area). There was a tendency for sloping furrows (greater than 60 mm fall in length-of-run) to use more water, but the differences were not statistically significant at the 10% level. Also, there is a tendency for flatter fields to have shorter run lengths, thus any relation between water applied and system type may have been masked by the effects of length-of-run. More detailed information would need to be collected to identify any relationship between water applied and system type.

Years of farming same land (YEARS) One of the least significant factors in determining water use was the number of years farming that piece of ground. There was some correlation with ownership and number of years, but it was not consistent. In addition, no data were collected on changes in irrigators and foreman, which could also influence performance.

Scheduling when to irrigate (WHEN-WHO, WHEN-HOW) The irrigation scheduling method used by farmers in the sample was not related statistically to seasonal water use. Simple visual methods and more scientific methods (e.g., soil moisture feel) of irrigation scheduling performed equally well. A number of groupings of methods were tried, and none were found to reflect significant differences in water use. Also, who schedules the irrigations was not shown to be significant. Farmers who use less water seem to have learned to apply the right amount for their method of timing irrigations. Also, farmers can receive water within 24 hours of request, making visual estimates of stress a more viable scheduling method.

Scheduling how much water to apply (AMOUNT-WHO, AMOUNT-WHEN) The answers to questions related to whether or how farmers determine how much water to apply during an irrigation were so varied that it was sometimes difficult to determine whether the farmers established a target amount to apply or not. Some used a general knowledge of consumptive use, others used soil hand/feel methods, many just irrigated and used their shutoff criteria to determine amount to apply (e.g., the minimum amount their irrigation system could apply with reasonable uniformity). None of these methods were correlated with differences in seasonal water applied. It also did not seem to matter who scheduled how much to apply.

Criteria for changing sets (HOW) The criteria for changing sets was not shown to cause significant differences in water use. Most used observations of the water in the field to change sets (e.g., how high the water is on the beds at the lower end). A few used time to change sets. However, fluctuating flow rates limit the benefits of using time as a criterion to change sets. Farmers appeared to make other adjustments to reduce water use so that the set-changing criteria could be kept the same.

Record keeping (REC-E, REC-S) Keeping records of water use, whether by irrigation or by season, appeared to have no impact on water use. Some farmers kept informal records or applied water close enough to their target levels that they felt that detailed records were unnecessary. Thus the indicator of record keeping was not sufficient to determine who kept close track of water applied and who did not.

Soil management

After reviewing the practices of crop rotation, tillage, and residue management, the DA team concluded the following:

> *The soil condition on district farms is rated by the SCS as being below the sustainable level. Decreased crop rotation, excessive tillage, and inadequate levels of organic matter reduce soil tilth and permeability, leading to soil compaction and interfering with root development. These factors can result in a less effective root zone which adversely affects the management of water and fertilizer. Overall, these negative long-term effects will limit the sustainability of the farming enterprises in the area.*

To evaluate soil sustainability in the area, the SCS Soil Condition Rating Index (USDA 1974b) was applied to grower practices over the years 1986–1990. This is an index that evaluates various practices for tillage, crop rotation, and the addition of amendments in terms of the long term health of the soil for maintaining crop production. A rating of zero is considered the minimum value for a sustainable soil resource. A rating above 1 is considered good, while 0 to 1 is fair. As an example, to achieve the minimum rating of 0, a grower currently raising continuous cotton either would need to change to an intensive minimum tillage program *or* use a certain level of minimum tillage plus cover crops/small grains/or legumes in rotation. Soil condition ratings for the grower sample are given in Figure 3. Values for the growers sampled ranged from –2.7 to +4.3 with a mean rating of –0.71. For this sample, 21 of 25 growers (84%) are experiencing a long-term degradation in soil condition.

Crop rotation

A number of factors contributed to the conditions observed. Cash-flow and economics played a key role. Only four of the 25 growers interviewed had a significant crop rotation plan. For the 21 growers not rotating, cotton represented 96% of their planted acreage over a four-year period. The potential

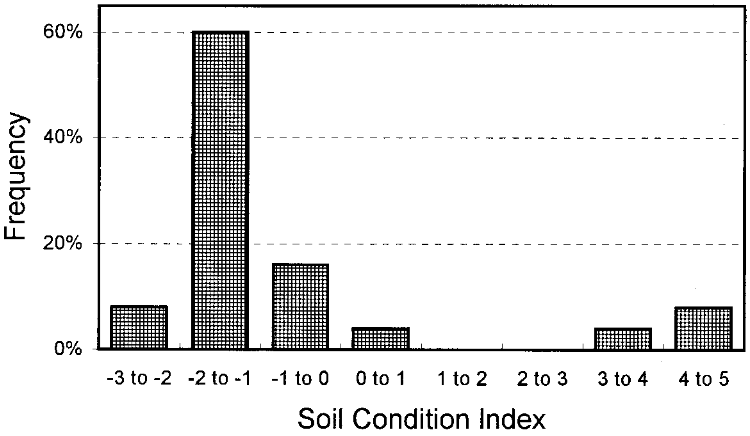

Figure 3. Frequency distribution for Soil Condition Index for period 1986 to 1990 for sample of MSIDD growers.

benefits of small grains often seem to be assessed only in terms of cash flow, rather than for their soil-enriching and other crop rotational values. As a result, soil maintenance is usually not a priority for lenders because they tend to operate only from a short-term (seasonal) cash flow perspective, and many growers indicate they cannot rotate crops without financing.

Tillage

Growers in the sample averaged 19 tillage operations on a cotton crop, with a range of 12 to 26 for the season. The frequency distribution of the number of tillage trips is shown in Figure 4. Cotton yields were not influenced by number of tillage operations. Though optimal numbers of tillage operations were not determined, the range suggests that tillage practices might be reduced, with attendant benefits for soils and reduced production costs. Also, for growers in the sample, there was a slight tendency for seasonal water applied to cotton in 1990 to increase with increasing numbers of tillage operations (Figure 5). With the available data, it could not be determined whether there was a physical reason for the change in water use (e.g., tillage operations increase infiltration rates, potentially contributing to deep percolation), or whether those who adopted reduced tillage practices also adopted improved water management practices (e.g., better overall management).

Soil amendments

Available methods to maintain adequate levels of soil organic matter were not being used. Though manure, used on a regular basis, adds organic matter to the soil, fewer than 25% of the growers in the sample regularly applied

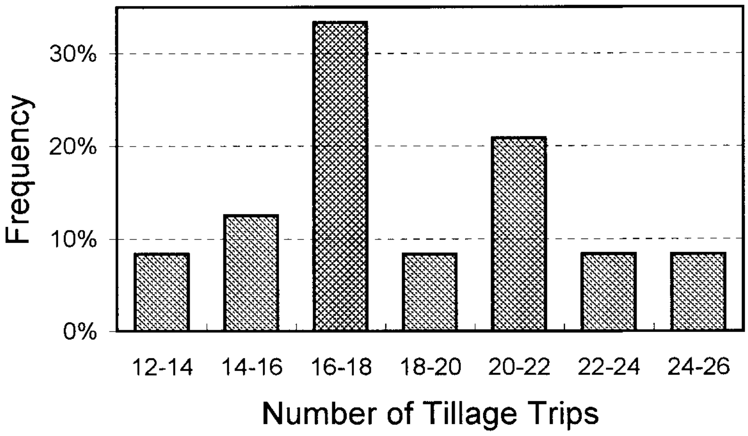

Figure 4. Frequency distribution of the number of tillage trips used to raise cotton by MSIDD growers.

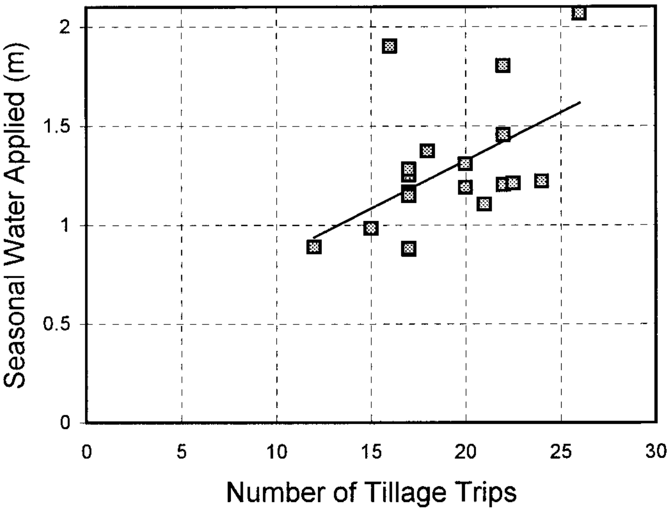

Figure 5. Seasonal water applied to cotton in 1990 versus number of tillage trips for land supplied from sampled turnouts in MSIDD.

manure. Though gypsum is considered to be a soil conditioner, over 60% of those who did not use either crop rotation or manure, incorrectly considered their use of gypsum or other soil additives to be soil building practices (i.e., to add organic matter).

Water delivery service

Some of the important findings of the Diagnostic Analysis dealt with the interactions between the irrigation district and the growers. While it has long been known that such interactions exist, they have been difficult to characterize. The results presented in this section provide some details on the conditions in this district for which district operations influence farm management. Sufficient data were not available to quantify this impact in terms of cost or water use. The description of irrigation district operational procedures given here pertain to those in effect at the time of the Diagnostic Analysis (i.e., 1991).

Delivery service window

The hours of 7:00 a.m.–3:00 p.m. are MSIDD’s standard operating time window. Though services may be requested to be performed anytime outside this window, the grower pays a $100 fee for such “special services”. In establishing the standard service window, the Board of Directors (BOD) (eight of whose nine members are active growers) analyzed the policy’s potential impacts on the cost of water and inequities in service. Nevertheless, some growers appeared not to understand the BOD’s decision and/or its weighing of the potential inequities. Also, it appeared that MSIDD staff and BOD did not understand fully the possible disincentive to on-farm irrigation system upgrading resulting from the policy, though they were actively pursuing some alternative cost-effective operating procedures to lessen the policy’s impacts (e.g., the increased use of supervisory control on the delivery system’s main canal). Overall, it seems that processes for analyzing issues, communicating the analyses to growers, and identifying and exploring possibilities for further changes needed strengthening at that time.

During interviews, the growers’ initial reactions to the delivery service window were neutral. Further discussion revealed that they used a variety of techniques to deal with it, including planning ahead to adjust flow rate or change set times, reirrigating fields that were just irrigated, irrigating fields (e.g., other crops) that did not need water, using wells or tailwater sumps, and paying the special services turn-off fee. These techniques represent a cost to the grower in terms of management effort, labor and/or increased water use, and likely increased production costs. In general, growers in the sample avoided the $100 special services turnoff fee without considering the actual economics or consciously made unfavorable economic decisions. (See Dedrick et al. 1992 for supporting data). Only 2 of the 25 growers interviewed opted, on a regular basis, to request a special services turnoff, paying the $100 fee. In addition, the delivery system rules acted as a disincentive to change

Table 6. Grower dissatisfaction with the service window based on location, number of on-farm wells, *or* irrigation distribution system type.

Location	Dissatisfied	Wells	Dissatisfied	System	Dissatisfied
Head	38% (3 of 8)	0	70% (7 of 10)	Siphon tube	42% (8 of 19)
Middle	33% (2 of 6)	1	38% (3 of 8)	Basin outlet	75% (3 of 4)
Tail	67% (6 of 9)	2 or more	20% (1 of 5)		

because of the lack of grower understanding of the overall economics of water use in relation to the special service fee.

Three factors were identified as influencing the farmers dissatisfaction with the service window; location along lateral canals, number of wells that the grower can use, and irrigation system type. The percentage of growers expressing dissatisfaction by these categories is shown in Table 6.

Growers in the sample at the end of long laterals (tailenders) have a shorter effective standard service window for turn-on and turn-off (e.g., two hours less on both ends of the service window). Shorter windows are caused by longer canal travel times and may be influenced by the particular canal operating procedures being used. MSIDD staff and growers both recognized that the service window is shorter at the end of long laterals under current operating rules.

Most of the active wells pump directly into MSIDD canals. In some cases, however, growers have wells that they can use directly on their farms when they request water (e.g., in addition to the canal delivery). Growers in the sample with on-farm wells had less management difficulty with the standard service window since they were able to complete an irrigation outside the standard service window with a well.

With siphon tube delivery, the farm inflow rate can be varied (on request) and the number of furrows irrigated adjusted to provide the same average flow rate per furrow. In this way, the total duration of the irrigation event can be adjusted so that it can be completed within the service window. Growers with fixed-dimensioned basins were less able to alter the total duration of the irrigation event, and thus have more difficulty with the service window. Also, growers who irrigated with siphon tubes could adjust set width to accommodate the lower flow rates available from wells. Growers with level basins typically could not take advantage of on-farm wells because of the relatively low well flow rates unless several wells were combined (Figure 6). Growers with mostly level basins (Figure 6) or tailenders (Figure 7) had significantly more difficulty with the standard service window if they had fewer wells (e.g.,

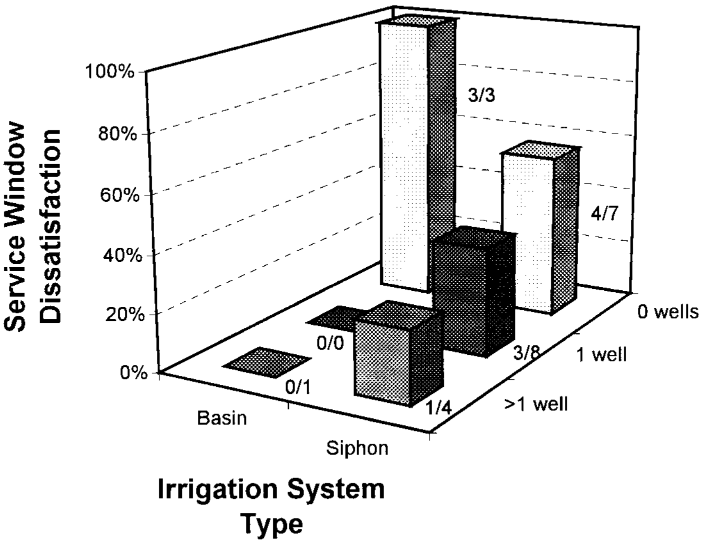

Figure 6. Grower dissatisfaction with MSIDD water delivery service window by irrigation system type and number of farm wells available.

less than one well for those with level basins and fewer than two wells for tailenders).

Further, growers in the sample reported that the 7 a.m. to 3 p.m. standard service window did not match their irrigators' schedules, causing altered set times and inefficient use of labor. When, for example, the grower's labor schedule was 6 a.m. to 6 p.m. and must be adjusted to match the time when water is actually received, irrigators might have been idle during part of their shift, resulting in increased labor costs for the grower.

Flow rate delivered Receiving a flow rate that is too high, too low, or varies over time, can represent a cost to the grower in terms of increased management effort, labor, time and/or water use. Only 5 of 21 growers expressed dissatisfaction with the delivered flow rate, although all growers experienced differences between ordered and delivered flows. Dissatisfaction varied with the location along the lateral canal and with the irrigation system type. [Note, this analysis assumes that the flow rate was ordered to match the irrigation system requirements].

Table 7 shows the results of the grower survey regarding dissatisfaction with delivered flow rates. Receiving a flow rate other than that ordered affected some farm irrigation systems more than others; it particularly affected level basin systems. While 67% of the sampled growers indicated that delivered flow rates frequently differed somewhat from ordered rates, only

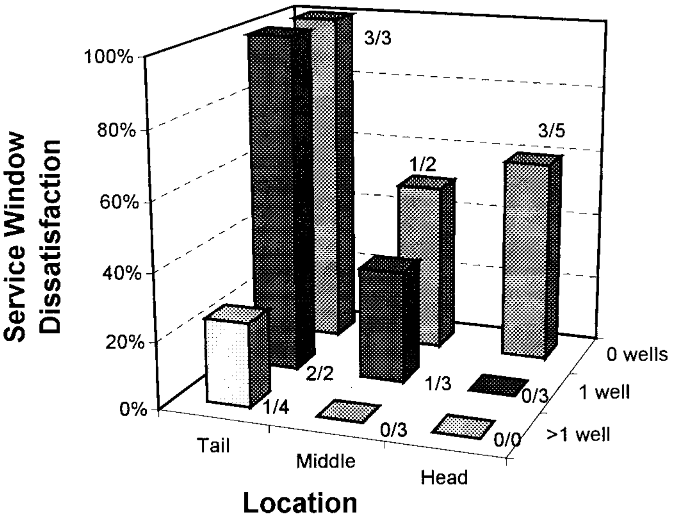

Figure 7. Grower dissatisfaction with MSIDD water delivery service window by location on lateral canal and number of farm wells available.

24% considered this a problem. Growers had earlier been convinced that the volumes recorded by their turnout water meters were accurate. Since they were charged for the actual volume delivered, variations in delivered rate were a minor concern, unless they influenced irrigation system performance. All growers with level basins who responded (3 of 3) indicated that this was a problem, while no growers with low gradient (or level) furrows did, and only 2 of 12 growers with sloping furrows did. Growers with level basins need high flow rates to maintain efficiency. Growers with sloping furrow systems are somewhat sensitive to flow rate as this affects the ponding of water at the end of the field. Excess flow rates may cause temporary dikes to break, leading to runoff. Growers with low-gradient and level furrows apply water to individual furrows with siphon tubes, but typically do not have problems with excessive water ponding. They are thus better able to handle a range of flow rates.

Some growers will take all the flow they can get as long as it stays constant; others order lower flows than they can handle to avoid the added labor costs and other problems that might accompany a higher-than-expected flow delivery; and still others order a higher flow than they need so they will be sure to have enough. Also, the number of wells did not appear to be a factor in grower dissatisfaction with delivered flow rates. District management did not provide canal operators with formalized procedures and/or training to achieve specific flow rate standards; nor did it systematically monitor the maintenance of delivered flow rates. Canal operating procedures and the use

Table 7. Grower dissatisfaction with the delivered flow rate by location and system type.

Location	Irrigation system type Level	Low-gradient	Sloping	Total
Head	–	0% (0 of 2)	25% (1 of 4)	17% (1 of 6)
Middle	–	0% (0 of 2)	25% (1 of 4)	17% (1 of 6)
Tail	100% (3 of 3)	0% (0 of 2)	0% (0 of 4)	33% (3 of 9)
Total	100% (3 of 3)	0% (0 of 6)	17% (2 of 12)	

Table 8. Grower dissatisfaction with flow rate fluctuations by location and system type.

Location	Irrigation system type Level	Low-gradient	Sloping	Total
Head	100% (1 of 1)	33% (1 of 3)	0% (0 of 5)	22% (2 of 9)
Middle	–	50% (1 of 2)	67% (2 of 3)	60% (3 of 5)
Tail	100% (3 of 3)	0% (0 of 2)	75% (3 of 4)	67% (6 of 9)
Total	100% (4 of 4)	29% (2 of 7)	42% (5 of 12)	

of meters did not guarantee that canal operators would be very precise in delivering the ordered flows. The hydraulics associated with relatively long laterals created control problems for the operators. Flow rate changes made at lateral headings are damped as they move downstream. These changes arrive gradually, making balancing of inflow and outflow a time-consuming process for the canal operators.

Flow fluctuations While 80% of the growers sampled said they experienced some flow fluctuations, only about half of them considered this a problem. It is assumed that fluctuating flows occur more often and have greater magnitude toward the tail end of the canal. Table 8 shows that growers with level basins considered fluctuating flows a problem regardless of location (i.e., regardless of how severe the fluctuations or how often they occurred). Those with level furrows (i.e., those who use siphon tubes and have side fall) or low gradient furrows did not generally consider fluctuating flows a problem (no trend by location). Those with sloping furrows considered fluctuating flows more of a problem the closer they were to the tail end of a long lateral, or the more often or severe the fluctuations.

Because of the travel time down the canal, fluctuations during the 7 a.m. to 3 p.m. standard service window often reached tailenders at night. This made it more difficult for irrigators to adjust for the fluctuations, since fewer irrigators work at night. Some growers reported ordering less water than their irrigators could manage so that an increase in flow would not cause difficulties for their irrigators. Some growers were satisfied with whatever they got, as long as it did not fluctuate.

New technology adoption

From the grower interviews, a number of factors have limited the adoption of new technologies over the four years since CAP water arrived in the district. The factors include: capital investment requirements; inadequate understanding by growers of the relative advantages, suitabilities, and management and operations requirements of the various options available; inadequate analysis of both the overall economic impact on farm operations and the cost-effectiveness of the particular technology; and grower uncertainty about the future.

Adoption of improved irrigation methods Changes in the irrigation systems in the area have been minimal since the start of CAP water deliveries. Currently, about 1% of the irrigated area per year is being converted to level basins, and about 1% per year is being converted to level or low gradient furrows with side fall. About one-fourth of the overall irrigated area in the district is currently in level basins, one-fourth in level or low gradient furrows, and about one-half in sloping furrows. However, these improved technologies do not seem to be having the impact on productivity or water conservation that had been anticipated (i.e., system type was not a significant factor affecting seasonal water use on cotton, Table 2). In some instances, the specific physical changes carried out on the farm seem to have been improperly selected, poorly or incompletely designed, incorrectly implemented, or most frequently, inadequately integrated with management requirements (e.g., irrigation practices were not changed to match the new irrigation system).

The expense of going from a traditional graded furrow system to a high-flow level-basin system can exceed $180 per hectare. In addition, for new technology to reach its potential, the physical changes must be accompanied by new and, in general, initially more intensive management practices, particularly until appropriate system operation is learned. Success requires this continuing commitment to management from the grower over enough time to reach full adoption.

Given the small amount of change in system type in the sample, there is not enough information to determine whether owned or leased land is more likely to be converted to another system type. It appears that land owners who were going to change from sloping furrows did so prior to CAP water arrival, while more change in irrigation systems has occurred on leased land since the arrival of CAP water.

Finally, the economic situation during the late 1980's and early 1990's, along with uncertainty about the future, reduced growers' incentive to consider carefully the cost-effectiveness or overall economic impacts of irrigation technology changes. These factors reduce the growers' willingness to invest either the required time or the relatively scarce capital. To achieve their potential performance, new or upgraded technologies require specific tailoring to actual farm conditions, active management, and better control of the water supply, including improved management coordination between the growers and MSIDD. Level basin performance, for example, is lowered with reductions in flow rate. Further, the possibility of fluctuations in flow rate often creates an otherwise unnecessary requirement for consistent and careful attention by the grower to each irrigation. In general, new or upgraded technologies may also place additional water delivery requirements on MSIDD Management and may have implications for current delivery policies.

Technology transfer programs of government support agencies The DA core team did not specifically interview government agency personnel during the Diagnostic Analysis. However, a number of questions were asked of farmers about their use of agency programs and services, about which ones they used, and about whether they found them useful. The core team had members from various agencies; thus when the DA interview results were compared against personal experiences, a fairly clear picture emerged. The MSIDD-area Diagnostic Analysis concluded that the agencies that support irrigated agriculture in the area could benefit from better coordination of programs. These agencies appeared to lack common program goals and foci for promoting, selecting, and managing new or upgraded irrigation technology. This appeared to be a negative influence on technology adoption. For example, personnel from different agencies often used different terminology for the same irrigation system or used the same terminology when talking about different irrigation systems. Further, they often seemed to lack a shared perception of what is needed to upgrade a current system and of when their suggestions constitute a "technology". They also seem to disagree on the management requirements of some of their recommendations.

Often, even if a grower is not interested in or cannot afford to adopt a new irrigation system, options may still be available for upgrading the current system and reducing water use through improved management. There appears to be a lack of agency consensus as to what to recommend in these situations, whether those recommendations are or are not "technology", and what the available options are for different grower situations. Many agency personnel appear to have only a limited understanding of, and experience with, these options as well as with the new technologies; many seem to have uneven and only partial understanding of them. This lack of understanding may lead to inadequate presentation to growers of available options to upgrade their systems or improve their management and missed opportunities to reduce water use and costs. Overall, these circumstances may result in grower confusion and contribute to the reduced levels of technology upgrading and adoption.

In response to budget constraints and additional program demands, most agencies seem to be providing fewer services to growers on an individual basis, focusing more on contact with large groups. This limited individual grower contact minimizes the identification and limits the transfer of technology specific to the grower's needs. Thus, technology transfer programs often may not be targeted to grower interests, nor be supported by adequate resources. Over time, growers may lose confidence in the likelihood that agencies will support technology transfer effectively. One reflection of this perception may be the limited utilization of agency cost-sharing programs. For example, two of three of the sampled farm units have not utilized the ASCS LTA (Agricultural Stabilization and Conservation Service Long-Term Agreement[3]) program, and less than 10% of the acreage in the DA sample has been affected by ASCS-LTA funds.

Discussion

The findings of this study are specific to the conditions within this district. While some general understanding of irrigation systems, irrigation practices, and farmer views can be gained from these results, the main purpose was to provide an understanding for the individuals involved. The understanding provided by the Diagnostic Analysis served as a catalyst for local cooperation and the planning of improvements. The breadth of issues and the interdisciplinary focus on describing current conditions (i.e., rather than focusing on narrow performance measures) promoted acceptance of and commitment to the need for change by key stakeholders, including farmers. During management planning activities, these findings were reformulated around specific action programs (see Dedrick et al. 2000a). The success of these programs is discussed in Bautista et al. (2000a).

One of the criticisms of this diagnostic analysis was that it did not provide much hard data on farm irrigation performance, such as irrigation efficiency, nor on quantitative measures regarding district delivery performance. Much more data would have been required to determine individual irrigation efficiencies, crop water use efficiencies, the economics of potential irrigation system modifications, etc. So from an outsiders perspective, particularly government regulatory agencies, the DA results were too qualitative. However, failure of irrigation system modernization programs can result from too strong a focus on quantitative measures and a lack of understanding provided by such qualitative relationships. Most of the DA participants wanted more quantitative data, however the resources for obtaining such data were simply not available for this demonstration of the methodology.

Further, this irrigation district was not chosen because there were serious performance problems that needed to be corrected. In general, farming practices and district operations were considered above average for Arizona by the DA team and the interagency group that oversaw the demonstration MIP. However, averages can be misleading. This study quanitified some of the diversity in farming conditions and practices that can exist within an irrigation district. While some growers are performing very well, there are areas in which many growers can improve significantly. This study also documents the need for cooperation and understanding in the application of technology and management practices to irrigated agriculture, regardless of the level of education (e.g., MSIDD growers' average education level was three years of college) and the technology being used. While the need for such coordination and planning is clear for poorly performing irrigated areas (whether in developing or developed countries), this study shows that irrigated areas that are performing relatively well can also gain by such a program.

Summary and conclusions

The Diagnostic Analysis identified several areas where performance varied and could be improved within the MSIDD area. These areas were related to farm water management, soil management and sustainability, interactions between farm irrigation systems and water delivery constraints, and technology transfer mechanisms.

The following factors were identified as contributing to the amount of water applied to cotton over the growing season:

- Irrigation length-of-run,
- Soil type (intake family),
- Farm size,
- Land ownership,
- Checking the adequacy of irrigation, and
- Determining the depth of water applied after the irrigation.

Other factors such as location along lateral canal, irrigation system type, and irrigation scheduling methods were not found to significantly influence the amount of water applied.

At the time of the DA, the trend in the district was to grow continuous cotton without rotation which was leading to the degradation of soil productivity. Further, many growers incorrectly thought that their soil amendment practices were sufficient to maintain proper soil condition and organic matter.

Growers tended to be more dissatisfied with the delivery service window (7 am to 3 pm) if they fit the following conditions;

- at the tail end of a lateral,
- no on-farm wells to operate, and
- farm irrigation systems sensitive to low or high flow rates or not able to adjust irrigation set width.

Growers with the following conditions were more dissatisfied with the delivered flow rate:

- at the tail end of a lateral, and
- farm irrigation systems sensitive to low or high flow rates or not able to adjust irrigation set width.

Growers dissatisfaction with flow rate fluctuations was related to the same conditions as delivered flow rate; however, irrigation systems with zero or very small slopes resulted in less dissatisfaction.

Recent adoption of new on-farm irrigation technology (e.g., level basins) was extremely limited. This was influenced by:

- the current poor economic conditions and lack of capital for improvements,
- low success ratio with recently improved irrigation systems because of lack of management adjustment,
- high relative cost of some improved irrigation systems,
- district water delivery policies and practices that limit the potential of improved farm irrigation systems, and
- uncoordinated, incomplete technology transfer programs by local agencies.

The Diagnostic Analysis, although not as quantitative as desired, provided a good picture of farm irrigation practices within the MSIDD area and opportunities for improvement.

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Notes

1. See Bautista et al. 1999b for details on other performance statements.
2. Now called the Natural Resources Conservation Service (NRCS).
3. Now called the Farm Service Agency (FSA).

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