Field Irrigation Practice and the Performance of Smallholder Irrigation in Zimbabwe: Case Studies from Chakohwa and Mpudzi Irrigation Schemes

A. Senzanje[1], I. Samakande[1], E. Chidenga[2] and D. Mugutso[3]

[1]Agricultural Engineering, University of Zimbabwe, P.O. Box MP167, Mt Pleasant, Zimbabwe, 263-4-303211; [2]Irrigation Division, Ministry of Water and Rural Resources, Harare, Zimbabwe; [3]Ambineers Pvt. Ltd., Workington, Harare, Zimbabwe.

ABSTRACT

Developing economies have often regarded smallholder irrigation as a means to ensure food security, create employment and promote agro-based industries in rural areas. However, of late smallholder irrigation has come under scrutiny as its performance has fallen short of expectations. This has prompted the need for an understanding of irrigation practices and their impact on performance so that remedial measures can be implemented. An analysis of smallholder irrigation practices and the subsequent impact on performance for two irrigation schemes located in the drier parts of Zimbabwe are presented. One is a surface irrigated scheme (Chakohwa scheme) measuring 90 ha while the other is drag hose sprinkler irrigated scheme (Mpudzi scheme) measuring 48 ha. Farmer practices were assessed through observation and use of structured interviews. Technical performance measures relating to the efficiency, adequacy and uniformity of irrigation events were assessed using standard field evaluation methods. To a large extent, the farmers' practices were determined by their perceptions and understanding of irrigation events. An assortment of irrigation scheduling methods was practised, water application approaches were not as per system design and there was a general tendency to over irrigate. The performance of both schemes was generally poor as the technical performance measures did not match the expected irrigation standards. At Chakohwa irrigation scheme, application efficiency averaged a low 24.7%, deep percolation losses a high 75%, and requirement efficiency a high of 87.3%. At Mpudzi drag hose irrigation scheme, the distribution uniformity was 44.9%, application efficiency of the lower quarter was low at 26.4%, and Christiansen's uniformity coefficient averaged 62.6%. These results indicated that the effectiveness of irrigation was low to medium implying an inefficient utilisation of resources, especially

water, in irrigation. This has implications on sustainability of smallholder irrigation. Despite these technical performance shortcomings the irrigation schemes contributed significantly to the livelihoods of the irrigators.

1.0 INTRODUCTION

The challenge for most developing countries like Zimbabwe is to close the gap between agricultural production and population increases. Irrigated agriculture plays a vital role in increasing agricultural productivity. It is estimated that over the next 20 or so years, 80% of the additional food supplies required to feed the world will depend on irrigation (FAO, 1997), with the same or lesser amount of water (Burt and Styles, 1999). In developing countries, smallholder irrigation is often touted as a vehicle for rural development, and Zimbabwe with about 12900 ha under smallholder irrigation, is no exception to this concept. It is generally claimed that smallholder irrigation enables intensification of agriculture, provides local food security, alleviates rural poverty, promotes agro-based rural industries and creates employment (Rukuni, *et. al.*, 1994, Makadho, 1994). These benefits can only be realised continually if smallholder irrigation performance is satisfactory and the irrigation systems are sustainably managed.

Over the past decade, there has been some concern over the performance of smallholder irrigation. These schemes have been performing below expectations, and thus failing to meet their development objectives and justifying the investment that went into them. There is an even more urgent need to improve the performance of smallholder irrigated agriculture because as we move into the future, there is limited scope for continued development, at reasonable cost, of new water sources and irrigation schemes (Burt and Styles, 1999). Performance can only be improved, through appropriate interventions, if the current levels of performance are known and an analysis is made as to why they are low or poor. Performance evaluations allow the comparison of actual irrigation performance to the broad design expectations, both initially and even after a rehabilitation exercise. Assessment of irrigation performance is important to irrigators, irrigation managers, researchers and those who allocate public funds for irrigation development and management (Small and Svendsen, 1990). Performance evaluation calls for the use of appropriate performance indicators, and typically, the choice of performance indicators for a given evaluation is related to the water delivery system, the irrigated agriculture system, and the agricultural economic system (Small and Svendsen, 1990, 1992).

In Zimbabwe, a number of comparative studies have been undertaken to assess irrigation schemes at the system level and specific aspects relating to management (Makadho, 1994; Makombe, *et. al.*, 1998; Manzungu, 1999; FAO, 2000; Gotosa, *et. al.*, 2003). There have been very few studies, if any, undertaken to quantify irrigation performance at the field level and relate this to field irrigation practices (Zirebwa, 1997; Motsi *et. al.*, 2001). It is such performance data and information that is required to improve the operation and management of smallholder irrigation schemes so that they can achieve their development objectives. It was with this requirement in mind that the study reported here was undertaken. The broad objective of the study was to evaluate the performance of some smallholder irrigation schemes in Zimbabwe. This was achieved through the specific objectives of documenting farmer irrigation practices, and assessing the technical performance at the field level. While there is a wide choice of indicators, the ones used here for the technical performance assessment related to the efficiency, adequacy and uniformity of irrigation events over the season at the field level. The study was based on the hypothesis that farmers' perceptions and understanding of irrigation events determines their irrigation practices that in turn impacts on irrigation technical performance.

2.0 MATERIALS AND METHODS

The research was conducted during the 1999/2000 irrigation season in the Manicaland province of Zimbabwe (Fig. 1). Manicaland province has the highest number of irrigation schemes per given province in Zimbabwe with a wide variety of irrigation issues, such as age of scheme, irrigation technology applied, agro-climatic conditions, and land holding sizes. Two smallholder schemes were studied, one was a surface irrigated scheme using water diverted from a river (Chakohwa irrigation scheme), and the other was a gravity fed drag-hose sprinkle irrigated scheme (Mpudzi irrigation scheme). These schemes were chosen so as to bring out irrigation technological differences, implications on farmer practices and hence impact on irrigation technical performance.

Chakohwa surface irrigation scheme was established in 1948 and currently it irrigates 90 ha in 4 blocks out of a possible total command of 102 ha. Water is diverted from the Umvumvumvu River via a weir and fed into two night storage dams. The scheme has a 60 l/s water permit. Basic details about the scheme are given in Table 1.

The scheme is government managed through AREX (Agricultural Research and Extension Department of the Ministry of Lands and Rural Settlement) department, and has a 3-person maintenance team. There is a 13 member irrigation management committee (IMC) responsible for the day to day running of the scheme. Mpudzi is a 48 ha drag hose sprinkler irrigated scheme located in the Clydesdale Resettlement Area about 60 km south of Mutare.

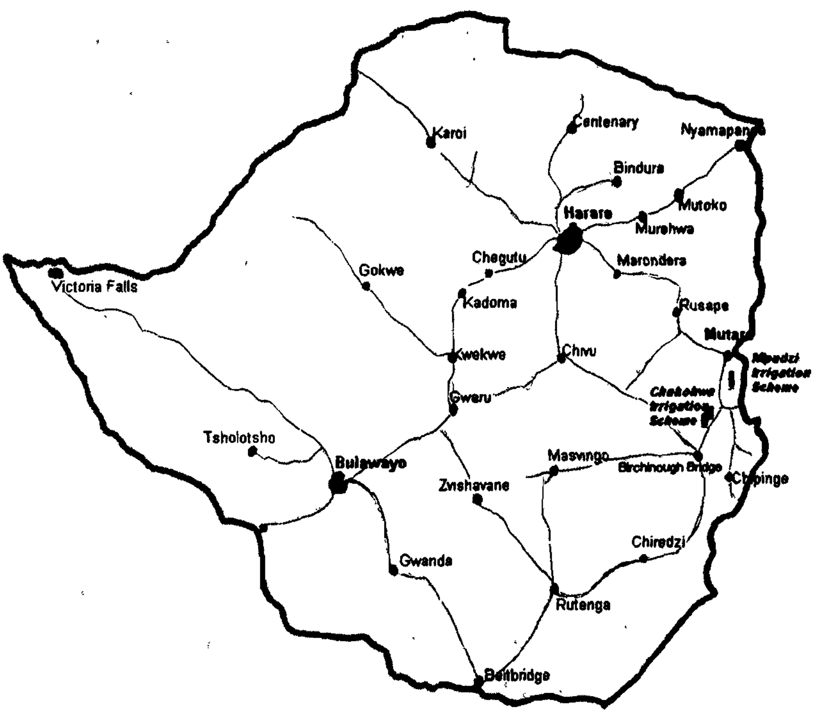


Figure 1. Map of study area showing Chakohwa and Mpudzi irrigation schemes

The scheme draws its water from a dam on the Chitora River with a total annual amount of 754 600 m^3 and allowable maximum abstraction rate of 51 l/s. The water from the dam flows by gravity (80m head) down hill to drive the sprinkler irrigation system. The drag hose system design is a square 12m x 12m layout. Basic details about the scheme are given in Table 2. Mpudzi can be considered to be a more recent type of scheme using drag hose irrigation technology that was not applied in Zimbabwe until about 1988 (Chidenga, 1997; Deimer, 2000).

Table 1: Basic details about Chakohwa irrigation scheme

BLOCK	A	B	C	D	TOTAL
Area (ha)	48,5	12,7	15,3	13,1	89.6
No. of plots	60	17	29	23	129
Avg. plot size (ha)	0,81	0,75	0,53	0,57	0.67
Soil type	Mainly sandy clay	Sandy loams and sands	Sands and patchy loams	Sandy soils	
Summer crops	Groundnuts, Maize, Okra, and Tomatoes	Groundnuts, Maize and Tomatoes	Groundnuts and Maize	Groundnuts and Maize	
Winter crops	Beans	Beans	Beans	Beans	
No. of irrigators per day	(9+3)	2	3	3	20
Irrigation Frequency (days)	7-14	6-7	8-14	8-14	

The day to day responsibility of scheme management rests with an irrigation management committee comprising a chairperson, vice chairperson, secretary and 4 committee members (2 from each of the 2 blocks).

Table 2: Basic details about Mpudzi irrigation scheme.

BLOCK	I	II	TOTAL
Area (ha)	24	24	48
No. of plots	24	24	48
Avg. plot size (ha)	1	1	1
Soil type	Mainly Loamy Sand	Sandy loams and sands	
Summer crops	Groundnuts, Maize, and Tomatoes.	Groundnuts, Maize and Tomatoes	
Winter crops	Beans, Onions	Beans, onions	
No. of irrigators per day	2-3	2-3	4-6
Irrigation Frequency (days)	7-14	7-14	

2.1 Farmer practices

Determining farmer operation and practices involved interviews with the farmers on a one-to-one basis. This was coupled with a questionnaire, which addressed issues that included the following; how do farmers decide when to irrigate, what is the irrigation frequency and how does it vary during the season, how does the farmer decide how much water to apply, what are the farmer's agronomic practices, and what is the farmer's perceived sense of ownership of the irrigation scheme and its assets? This was intended to; understand how and why farmers do certain things, and determine farmer's knowledge on irrigation principles and practices, as these could be constraints to achieving high irrigation performance.

2.2 Performance indicators used

The set of performance indicators used for surface and sprinkler irrigation system evaluation were the same except for the differences in interpretation. The performance measures were the efficiency, adequacy and uniformity of irrigation events (James, 1988; Bos and Nugteren, 1990). Due to the nature of irrigation, the performance measures were quantified both spatially and temporally (Bos, *et. al.*, 1994). Efficiency gives an indication of how effective water is applied, whereas adequacy gives an indication of the proportion of the field receiving sufficient water to maintain the quantity and quality of crop production. Uniformity of application describes how evenly an application method distributes water over an irrigated field. Effectiveness of irrigation is a term that qualitatively describes the application efficiency, uniformity and adequacy of irrigation.

The specific measures used to quantify efficiency were field water application efficiency including deep percolation and tail water runoff ratios. Adequacy was quantified through measuring irrigation requirement efficiency, and uniformity was assessed through determining distribution uniformity and application efficiency of the lower quarter (Merriam and Keller, 1978; Bos and Nugteren 1990). The choice of performance indicators used in this study does not in any way detract from other performance indicators for irrigation.

Water application efficiency (E_a) is the ratio of the amount of water beneficially used in irrigation to the amount of water delivered to the field (Eq. 1). Any inefficiency is a result of deep percolation (DPR) and tail water runoff (TWR) losses, and these have to be quantified as well (Eq. 2 and 3, respectively). DPR and TWR are components of E_a such that, expressed as ratios, the sum of E_a + DPR + TWR equals unit.

Application efficiency (E_a) $= (V_{I+L} / V_T)\ 100$ 1

Deep percolation ratio (DPR) $= (V_{DP} / V_T)$ 2

Tail water runoff ratio (TWR) $= (V_{TW} / V_T)$ 3

Where V_T = total volume applied, V_{I+L} = volume beneficially used (for crop and leaching requirements), V_{DP} = volume of deep percolation, V_{TW} = volume of tail water runoff.

Irrigation requirement efficiency (E_r), which is an index of adequacy, is the ratio of the amount of water stored in the root zone during irrigation to that required in the same root zone prior to irrigation (Eq. 4). E_r serves as an indicator of how well irrigation meets the objective of refilling the root zone to field capacity. Naturally, E_r cannot exceed 100%, and it should be noted that a high E_r does not necessarily imply a high level of irrigation performance.

Requirement efficiency (E_r) $= (V_{RZ} / V_{FC})\ 100$ 4

Where V_{RZ} = volume stored in root zone during irrigation, V_{FC} = volume of water required in the root zone prior to irrigation, e.g. to bring it to field capacity.

The applicable uniformity indices are application uniformity or Christiansen's uniformity coefficient (UC) (Eq.5), distribution uniformity (DU) (Eq.6) and application efficiency of the lower quarter (AELQ). In general, AELQ is the average low quarter depth of water stored in the root zone as a ratio of the depth of water supplied, but for sprinkler irrigation this is determined using sprinkler application rates (Eq. 7). Implicit in the AELQ is a measure of uniformity, but it does not indicate adequacy of the irrigation event – it merely shows that, for any given value greater than zero, all the irrigated area is receiving water. DU and UC give an indication of how evenly the applied water is distributed over the irrigated area.

$$\text{Uniformity coefficient (UC)} = (1 - (\Sigma|d|/N\,X_m))\,100 \quad \ldots\ldots 5$$

$$\text{Distribution uniformity (DU)} = (X_{mLQ} / X_m)\,100 \quad \ldots\ldots 6$$

$$\text{Application Efficiency of the Low Quarter (AELQ)} = (R_{mLQ}/R_m)100 \quad \ldots\ldots 7$$

Where, $\Sigma|d|$ = sum of the absolute deviations $(X_i - X_m)$, X_i = depth of water caught in catch-can at point i, X_m = average depth of water caught in catch-cans at all sampled points, N = number of sampled points, X_{mLQ} = average depth of the low-quarter of water caught in catch-cans, R_{mLQ} = average low quarter rate applied, and R_m = average rate of water application.

2.3 Data collection

The data collection approaches used for performance assessments were as per procedures described in the ASAE standards (1999a, 1999b), Merriam and Keller (1978) and Ley and Clyma (1983), but with some slight modifications to suit conditions in the field. For surface irrigation at Chakohwa irrigation scheme, water diverted into a border was quantified from measuring siphon operating head, siphon diameter and number of siphons serving a border. Siphon calibration was done using the basic approach of measuring discharge into a container of known volume dug into a border so that its rim was at the same level as the irrigated border. Water application along a border was quantified using the advance–recession approach coupled with data from infiltration tests. Advance-recession measurements determined the intake opportunity time (or contact time) per given point along a border and this contact time was input into the infiltration equation to calculate water applied per point (Walker and Skogerboe, 1987). This was compared to the water required to bring soil to field capacity as well as determining deep percolation losses. Tail water runoff losses were monitored using a small WSC (Washington State College) flume.

Data collection and procedures for the drag-hose sprinkler system were mainly as per the procedures outlined in Merriam and Keller (1978) and ASAE standards (1999b). Application efficiency and uniformity were determined using the standard catch-can test as described in the above references. Data were also collected on sprinkler nozzle diameter, sprinkler discharge, operating pressure, and wind speed (using a hand held wind vane) and wind direction.

3.0 Results

3.1 Chakohwa irrigation scheme

3.1.1 Farmer practices

In Chakohwa irrigation scheme, it was noted that the day to day running of the scheme was done by the IMC. The IMC sets irrigation rotations in the scheme, levy a fine on those who violate the irrigation rotation, and monitor the operations of the water bailiff, whieh include opening of water from night storage dams, allocating water to farmers and the monitoring of all water control structures.

Irrigation was by rotation following a top-down sequence, i.e. the rotation starts with farmers near the water source, going down to those at the tail reaches of the scheme. The rotation duration varied between blocks from 7 to 14 days. Each farmer is strictly bound by the rotation hence one could not effect proper scheduling based on crop water requirements and better scheduling techniques, a problem also reported by Manzungu (1999) at Chibuwe irrigation. These rigid rotations have led to water poaching, vandalism of some gates and checks, and pre-emptive over irrigating.

Water application to the borders was through the use of siphons. The water was siphoned from the head ditch into the border using 40 and 50 mm diameter siphons. Mostly PVC poly-pipes siphons were used but of late they have been getting grey mine suction hoses, which are believed to have a longer life compared to PVC poly-pipe. The poly-pipe easily wore out during priming as it rubbed against the canal. As the water flowed along the border the experienced farmer monitored it as it advanced and directed it to achieve greater application uniformity and stop it from crossing into another border. In most cases water was opened into the end of the next border when they felt it has ponded long enough.

The amount of water applied depended on availability and the time it took for the advancing front to reach a certain point along the border when they effected cut-off. It was observed that cut-off practices were poorly employed because, in some cases, crops at the end of the border appeared to suffer stress earlier than the rest of the crops in the same field, and yet at other times, there was excessive ponding at the end of the border.

There were basically not much run-off losses as water was simply transferred from one border to the next. The run-off that was existent was diverted into a drain in which sugar cane and bananas were planted. Some of the run-off was also directed into orchards and fishponds.

3.1.2 Technical performance

The performance measures for blocks A1, A2, B and C of Chakohwa irrigation scheme are given in Table 3. Overall it was noted that the application efficiency for Chakohwa irrigation scheme was very low as a greater portion of the volume applied was lost through deep percolation. Tail water ratio was zero in most instances as a result of the farmers blocking the end of the border. The distribution uniformity was fairly high as can be seen from Table 3.

Table 3: Performance measures for 3 blocks in Chakohwa irrigation scheme

Performance indicator/Block	A1	A2	B	C	Avg
E_a (%)	10.7	17.8	36.1	34.3	24.7
E_r (%)	69.9	100	90.4	88.8	87.3
DPR (%)	89.2	82.6	63.1	65	75
TWR (%)	0.2	0.6	0.8	1.1	0.7

The application efficiencies (E_a) observed in the scheme were very low, ranging from 10.7% to 36.1%, with a scheme average of 24.7%. This level of performance was lower than the average obtained by Zirebwa (1997) of 59% at Musikavanhu irrigation scheme. The deep percolation ratios were very high, in the order of 63.1% to 89.2%, the average for the scheme being 75%. Tail water losses, as measured by TWR were very low, averaging 0.7%, because of the farmers' practice of blocking the end of the borders. Irrigation requirement efficiency was fairly high across the scheme as it averaged 87.3%.

3.2 Mpudzi irrigation scheme

3.2.1 Farmer practices

All the farmers interviewed in Mpudzi irrigation scheme indicated that they used subjective methods to determine how much water to apply and when to apply it. They decided when to irrigate by observing the state of the crop. If it was beginning to wilt then they would come in to irrigate. Some dug a small hole to determine the depth of moisture while others said they now had experience and could tell by the appearance of the soil that irrigation was needed. They also estimated when to irrigate by using the time when they last irrigated or when it last rained, meaning if they had last irrigated or it last rained 14 days ago, they would then irrigate their crops. Two farmers out of 48 said they also used the crop growth stage, e.g., seedlings required light frequent irrigations. They said they also use subjective methods when it came to the amount to apply. Some said they stopped irrigating when ponding was just about to begin. Others insisted that they were taught to stop irrigating after a set time of six hours. One farmer said that he used the crop growth stage and gave the example of maize at tasseling stage, which he said required more water. Another also added that the sandy soil type saturated much faster than heavy textured soils, so he took less time on sandy soils. The results indicated that farmers are literally using some of the known irrigation scheduling techniques, but for various reasons.

In the management of sprinkler equipment, at least 75% of the farmers indicated they had replaced their sprinkler heads (from the design size of 2.5 mm) with bigger sized nozzles (3.5 mm or bigger). This was because, the farmers felt, large nozzle sprinkler heads were able to discharge and throw large amounts of water further if there was enough pressure in the system, thus satisfying their crop water needs. Another surprising development is that most farmers have since removed the pressure regulators on the risers claiming that these throttled water from coming out. The pressure regulators were designed to compensate for the slightly undulating topography in Mpudzi irrigation. Fifty-two per cent (52%) of the farmers have either replaced a burst pipe or a leaking Tee-junction at the hydrant. This has been most evident on the down slope plot-holders. The cause could be attributed to water quality after rainstorms, which contains debris, which scour the Tee-junctions. However two of the farmers confirmed that they had damaged the pipes during ploughing. One farmer has so far replaced 9 Tee-junctions.

With regard to water shortages in Mpudzi irrigation, farmers adopt various approaches to this problem at plot level, block level and scheme level. At scheme level, Block I farmers negotiated with Block II farmers so that they could alternate their irrigation. They gave each other 1-week to irrigate. The severity of water shortage has not been as bad as that of the 1994-1995 season, so farmers have not gone to this exercise again. At block level, the farmers of Block I demarcate their scheme into two during the dry period of September to October. The demarcated sides are allowed two days use of water each, i.e., effect their irrigation for two days then turn over the irrigation to the other side. Individual farmers have devised various methods to conserve water at individual plot level. Methods used range from night irrigation, use of smaller sprinklers, cropping pattern and use of hoses without sprinklers. Figure 2 shows the proportions of the various approaches used at plot level to manage water shortage.

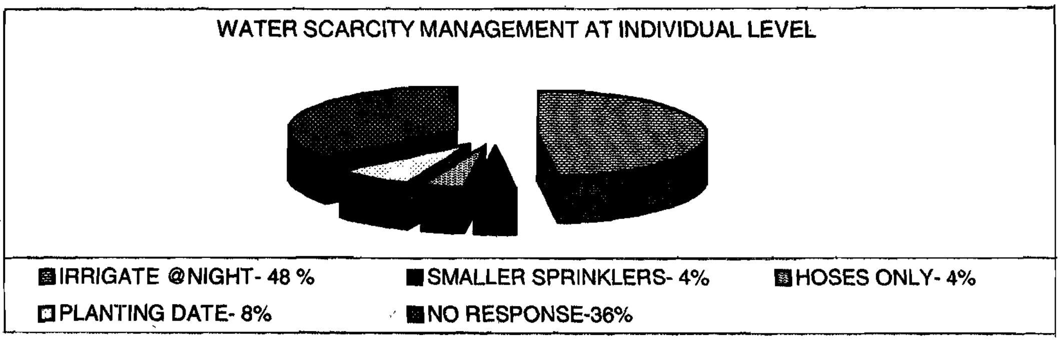


Figure 2: Approaches to managing water shortage at Mpudzi irrigation scheme

On equipment and scheme ownership, most farmers indicated that they believed that these belonged to them because they derived their livelihoods from the irrigation scheme. The equipment was installed at scheme development by government. The only sticky point was that of ownership of land. Some farmers felt that since they did not have title deeds, then they did not own the irrigated land.

3.2.2 Technical performance

The performance measures for Mpudzi irrigation scheme Block I are given in Table 4. The results indicate the performance of the drag-hose sprinkler system to be on the lower side compared to expected standards.

During the performance evaluation period (December 1999 to February 2000), the sprinkler operating pressure averaged 231 kPa. There were marked pressure variations throughout the system and these gave an efficiency reduction factor of 0.125, i.e., the variation in pressure in the system during the evaluation reduced overall system efficiency by 12.5%. A further interesting result was the measured wind speed compared to the design values. Wind speeds averaged 219 km/day during the evaluation period compared to a design value of 115 km/day. The variable operating pressure and high wind speeds most likely have an impact on the performance of the drag hose sprinkle system.

Table 4. Performance measures for Block I of Mpudzi drag-hose sprinkle irrigation scheme

Performance Indicator	Result	Standard Deviation
Christiansen's Uniformity Coefficient (UC)	62.6%	11.5%
Distribution Uniformity (DU)	44.9%	17.9%
Application Efficiency of the Lower Quarter (AELQ)	26.4%	15.9%
Sprinkler Operating Pressure	231.3 kPa	39.7 kPa
Sprinkler Discharge	0.26 l/s	0.06 l/s
Nozzle Size	3.7 mm	0.54 mm

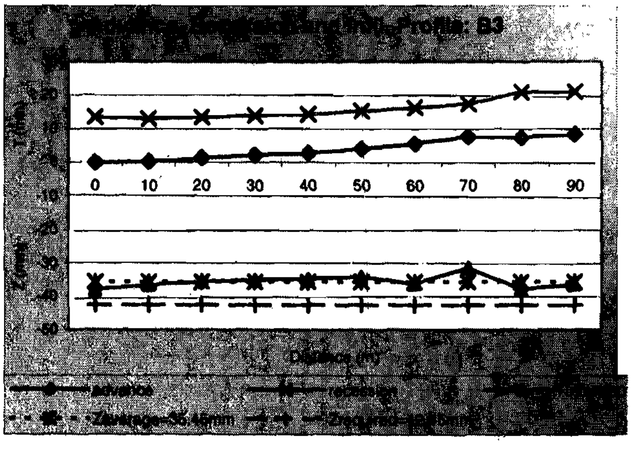
DU averaged 44.9% and the UC values averaged 62.6%, with a range of 40.6% to 77.5%. The technical performance measure AELQ is equally low averaging 26.4%

4.0 DISCUSSION

4.1 Chakohwa irrigation scheme

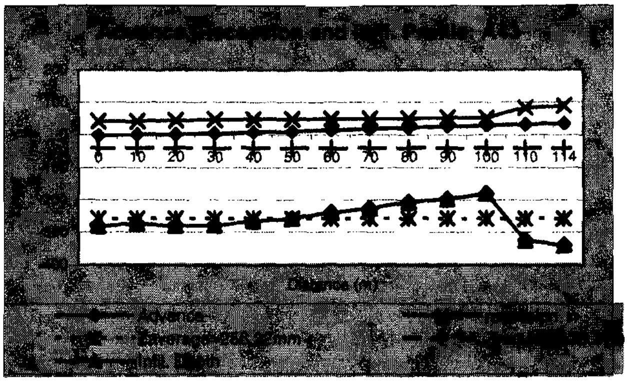
Performance of irrigation events is governed by design variables such as border length, slope, soil type and leveling of borders, as well as by management variables such as inflow stream size, times of cut-off and water control. An irrigator has to balance these in order to effect a good irrigation resulting in high performance.

The results of the technical performance of Chakohwa irrigation scheme clearly indicate the implications of farmer practices on irrigation performance. Farmers irrigated in rotation and this constrained them from being able to practice proper irrigation scheduling, also reported by Manzungu (1999), resulting in under (Fig. 3) or over (Fig. 4) irrigation. The practice of blocking the end of the border, while reducing tail end water run off, increased the intake opportunity time at this part of the border resulting in excessive infiltration (Fig. 5). This led to deep percolation and leaching of nutrients, as similarly observed by Zirebwa (1997). Leaching was evidenced by the yellowing of maize at the end of the border compared to the rest of the border. Blocking the end of the border is a common practice used to eliminate tail end run off, but it needs to be managed properly to minimise excessive infiltration in this part of the border. The most common approach to achieve this is to cut back the inflow stream size (Cuenca, 1989).



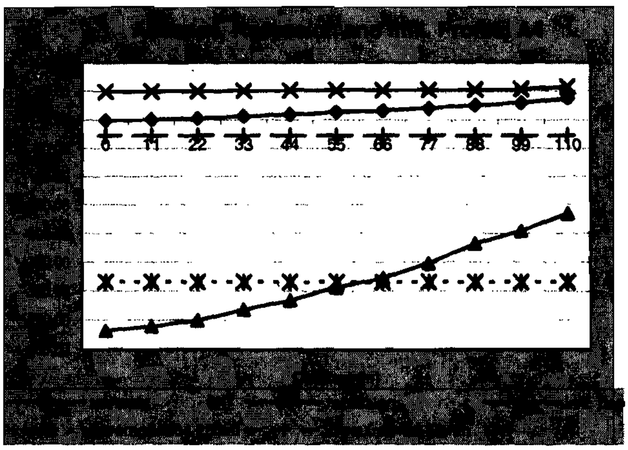
Ea=100%, Er=83.5%, DPR=0%, TWR=0% and DU=93.9%

Figure 3. Infiltration profile derived from advance recession for plot B3: Sandy Loam



E_a=9.9%, E_r=100%, DPR=90.1%, TWR=0% and DU=75.4%

Figure 4. Infiltration profile derived from advanced recession by the measurements for Plot A43: Clay Loam



E_a=9.1%, E_r=100%, DPR=90.9%, TWR=0% and DU=86.6%

Figure 5. Infiltration profile derived from advance recession measurements for Plot A4: Sandy Soil

The inflow stream sizes used by farmers were not adequately large to drive water towards the end of the border. This was most prevalent in the sandy soils of some sections of Blocks B and C tested. The farmers used 9 – 10 siphons per border, giving an average stream size per border ranging from about 2.2 l/s/m to 3.4 l/s/m. This stream size turned out to be small for the medium grained sandy soils when compared to the recommended values of 10 – 15 l/s/m, and barely adequate for the sandy clay soils of Block A where the recommended stream sizes are 3 – 6 l/s/m (Booher, 1974; Kay, 1986).

In Block A, the stream size was effected for a long time (44 min) and this resulted in over application (Fig. 5) and resultant low application efficiency. This over application was a result of farmers' perceptions of irrigation and soil water content.

Border length, a design variable, affected application efficiency. The borders for the sandy blocks were too long for this type of soil. The lengths ranged from 60 m to 150 m when the recommended length should be less than 70 m for borders on sandy soils (Kay, 1986). This tended to increase the intake opportunity time resulting in gross over applications; and subsequent low application efficiencies. Using the unit inflow rate concept (Cuenca, 1989), from the advance, recession and infiltration data, and at an optimistic application efficiency of say 60% (Bos and Nugteren, 1990), the optimum border lengths would have been 34 m for A4, 29 m for A43 and 6 m for B3. However, in everyday irrigation management border length is not a variable that can be manipulated, so what is important and practical is to manage the inflow stream size and cutoff time. As an example of this, taking block A with an average 100 m border length, the ideal cutoff time (to achieve a realistic 60% application efficiency) for the given stream sizes would have been 10 min for A4 and 11 min for A43, instead of the 44 min used by farmers. Information on appropriate cut off time comes from experience and evaluations such as conducted in this study.

Farmer's perception of adequacy revealed a clear lack of knowledge on irrigation principles on which design aspects are based. Farmers were much more satisfied with a saturated field than with an adequately irrigated field. Most farmers deliberately increased the intake opportunity time to get the satisfaction that their crops had received all the water they need. Requirement efficiency perhaps is what the farmers worry about and not the application efficiency. Farmers generally worry about the wetness of the field and less about the efficiency of the operation. The observed high requirement efficiency (Table 3) meant that the soil was recharged to field capacity. This resulted in the high requirement efficiency of over 85% on average, but not necessarily indicating an efficient irrigation. The impression from the farmers was that the soil was able to handle any amount of water applied to it, i.e., it could store extra water for future use. This revealed lack of knowledge of such aspects as field capacity, leaching and deep percolation, leading to farmer practices that impacted on performance of the irrigation events and ultimately of the whole system.

4.2 Mpudzi irrigation scheme

The technical performance recorded at Mpudzi for the sprinkler irrigation system was poor. The DU at an average of 44.9% was quite low compared to the expected range of 70% to 80% for typical field crops on medium textured soils (Merriam and Keller, 1978). UC was also poor compared to a standard of >80% (Merriam and Keller, 1978; ASAE, 1999b). A further analysis of UC values from Mpudzi scheme showed that only about 17% of the results were in the fair performance range (of 70% - 80%) and 83% of the results were in the poor performance category (of <70%) according to ASAE (1999b) and Merriam and Keller (1978). Low UC values are a result of sprinkler operating pressure variation and wind speed and direction changes. It has been noted already that at Mpudzi scheme, farmers removed pressure regulators resulting in marked pressure variations in the system, leading to an efficiency reduction factor of 0.125. Similarly, the AELQ results are low and far below the expected 50%. Low values of the AELQ indicate problems with sprinkler system operation and management at Mpudzi scheme.

The levels of technical performance recorded for Mpudzi irrigation scheme are a direct result of farmers' practices and how they try to react to prevailing conditions when they are irrigating. First, although the technical design of Mpudzi is such that each farmer can irrigate as and when they desire, water supply limited the farmers ability to practice proper irrigation scheduling, leading to adoption of practices that allowed the limited water to go a bit further. Most farmers used a variety of well documented scheduling methods governed by soil and crop conditions rather than climatic conditions. It is interesting to note that there was a mini weather station at Mpudzi which would have allowed farmers to use Class A pan irrigation scheduling method but no one practiced it. The adoption of various practices and operational procedures during water shortages at the plot, block and scheme level indicate that farmers share the same concern of trying to effect irrigation under adverse times, and are thus inclined to cooperate for their common good. Some of this collaboration between irrigators facing a common problem in irrigation was also noted and reported by Deimer (2000).

The practice of replacing nozzles and removing pressure regulators on the sprinkler system led to varying discharges at different points in the field, thus affecting the performance of the system, as indicated by the low uniformity results. These practices or behaviour by farmers could be attributed to farmers' perceptions that the more water you apply to your field the better. However, this behaviour could be defended by the fact that the farmers were probably never informed on the consequences of changing nozzle sizes or removing the pressure regulators. These undertakings by farmers are not surprising and seem to indicate that farmers where not properly instructed on how to best operate the system when it was commissioned. This is generally an oversight of irrigation agencies in that after scheme design and construction, there is no proper hand over of equipment. As such, this behaviour would seem perfectly logical.

Although the system design was a 12 m x 12 m square layout, farmers barely followed this format. In some cases, especially when water was not limiting, farmers used a closer spacing. They did this as a reaction to high wind speeds and the varying wind direction. However, when water was limiting, farmers tended to increase the sprinkler spacing to wider than design. It was observed that they did this trying to wet as much of the field as possible with the available water. This practice led to poor overlap leading to under irrigation in some spots in the fields and low uniformity levels.

5.0 CONCLUSION

The technical performance of the two smallholder schemes was found to be quite low as indicated by the low application efficiency for Chakohwa and low uniformity coefficient for Mpudzi. The recorded levels of performance were far below the expected standards. Technically, the effectiveness of irrigation – qualitatively described by the application efficiency, uniformity and adequacy – in both cases was rated low to medium. This means the schemes were not effectively using the resources, especially water, through irrigation. However, from a socio-economic perspective, the schemes are contributing significantly to the livelihoods of the irrigators through food and cash crop production. This contribution is being done in a manner that is not effectively utilising the water resource, implying that long term attainment of development goals and sustainability could be compromised. This is important considering that very soon all water users in Zimbabwe will be expected to pay for it at about Z$350/megalitre (WRMS, n.d.).

Farmers' practices were found to be adaptive to the conditions exerted by their circumstances. In Mpudzi irrigation scheme, farmers adapted to water shortage by altering their usual practices of irrigation in order to be able to effect irrigation the best way they could. In Chakohwa farmers circumvented unreliable water supply by over irrigating their plots so as to conserve water in the soil.

In both smallholder irrigation schemes, it has been shown that farmer practices to a large extent determined the technical performance of the schemes. The farmers' practices were in turn influenced by the farmers' perceptions and understanding of irrigation events. If the performance of the irrigation schemes is to be improved, it is important that the farmers' perceptions and understanding of irrigation are changed. As an example, farmers need to understand that the soil can only take in and hold a given amount of water, thus water application and frequency of that application has to take this into account. It should, however, be appreciated that some of the observed cases are not due entirely to the farmer, but a case of design limitations. Some of the border lengths are too long, which is a case of poor design. This prompts for the need to revisit some of the designs and make adjustments where these are feasible.

ACKNOWLEDGEMENTS

We acknowledge the assistance given by the extension workers, farmers, and irrigation management committees in the two irrigation schemes and the Zimwesi II project – a joint university cooperation project between the University of Zimbabwe and Wagenigen University of the Netherlands for the funds.

REFERENCES

ASAE 1999a. Evaluation of irrigation furrows. ASAE Standards EP419. ASAE, St. Joseph, MI, USA.

ASAE 1999b. Procedure for sprinkler testing and performance reporting. ASAE Standards S398. ASAE, St. Joseph, MI, USA.

Booher L. J. 1974. Surface Irrigation. Food and Agricultural Organization, Agricultural Development Paper No. 95. Rome, Italy.

Bos M. G. and Nugteren J. 1990. On Irrigation Efficiencies. ILRI Publ. No. 19. Wagenigen, The Netherlands.

Bos M. G., Murray-Rust D. H., Merrey D. J, Johnson H. G. and Snellen W. B. 1994. Methodologies for assessing performance of irrigation and drainage management. *Irrigation and Drainage Systems, 7, 231 – 261.*

Burt C. M., and Styles S. W. 1999. Modern water control and management practices in irrigation – Impact on performance. Water Reports No.19. FAO/IPTRID/World Bank. Rome, Italy.

Chidenga E. 1997. Water delivery systems in smallholder irrigation schemes in Zimbabwe – The place for drag hose sprinkler systems. A discussion paper for Agritex, Ministry of Lands and Rural Resettlements, Harare, Zimbabwe.

Cuenca R. H. 1989. Irrigation System Design – An Engineering Approach. Publ. Prentice Hall, New Jersey, USA.

Deimer G. 2000. Management processes on two smallholder sprinkler layouts – A case study from Zimbabwe. *Irrigation and Drainage Systems, 14(3), 183 – 198.*

FAO 1997. Food production – The critical role of water. Technical background document No.7. World Food Summit, 13 – 17 November 1996. Rome, Italy.

FAO 2000. The Socio-economic impact of smallholder irrigation development in Zimbabwe – Case studies from 10 irrigation schemes. FAO/SAFR, Harare, Zimbabwe.

Gotosa J., Gichuki F. N. and Senzanje A. 2003. Performance assessment of water delivery to a smallholder irrigation scheme in Zimbabwe – Nyanyadzi case study. *Journal of Applied Science in Southern Africa*, (In press).

James L. G. 1988. Design and Operation of Farm Irrigation Systems. Publ. J. Wiley, NY, USA.

Kay M 1986. Surface Irrigation – Systems and Practice. Cranfield Press, UK.

Ley T. and Clyma W.1983. Evaluation of graded border irrigation systems. In Diagnostic Analysis of Irrigation Systems, Vol. 2 – Evaluation Techniques. Eds. C.A. Padmore and D. G. Eyon. Water Management Synthesis Project, Colorado State University, Ft. Collins, USA.

Makadho J. M. 1994. An Analysis of Water Management Performance in Smallholder Irrigation Schemes in Zimbabwe. Unpublished D.Phil. Thesis, Faculty of Agriculture, University of Zimbabwe. Harare, Zimbabwe.

Makombe G., Makadho J. M. and Sampath R. K. 1998. An analysis of the water management performance of small holder irrigation schemes in Zimbabwe. *Irrigation and Drainage Systems, 12(3), 253 – 263.*

Manzungu E. 1999. Strategies for Smallholder Irrigation Management in Zimbabwe. Published Ph.D. Thesis, Wagenigen University, The Netherlands.

Merriam J. L, and Keller J.1978. Farm Irrigation System Evaluation – A Guide for Management. Utah State University, Logan, USA.

Motsi K. E., Zirebwa J. and Machingambi E. 2001. Assessment of smallholder irrigation performance – Management of conveyance and distribution infrastructure (at Murara and Nyamatanda, North East Zimbabwe). *Journal of Applied Science in Southern Africa. 7(1), 9 – 22.*

Rukuni M., Svendsen M., Meinzen-Dick R. with Makombe G. 1994. Irrigation Performance in Zimbabwe. UZ/AGRITEX/IFPRI Project, University of Zimbabwe, Harare, Zimbabwe.

Small L. E. and Svendsen M. 1990. A framework for assessing irrigation performance. *Irrigation and Drainage Systems, 4 (4), 283 – 312.*

Small L. E. and Svendsen M. 1992. A framework for assessing irrigation performance. IFPRI Working Papers on Irrigation Performance No. 1 IFPRI, Washington D.C. USA.

Walker W. and Skogerboe G. V. 1987. Surface Irrigation – Theory and Practice. Pub. Prentice Hall, New Jersey, USA.

WRMS (Water Resources Management Strategy) (n.d). Towards integrated water resources management. Government of Zimbabwe Printers. Harare, Zimbabwe.

Zirebwa J. 1997. Evaluation of the technical performance of smallholder irrigation schemes in Zimbabwe – Musikavanhu case study. Unpublished M.Sc. Thesis, IHE, Delft, The Netherlands.