

EXPERIENCE WITH DRIP IRRIGATION ON SMALLHOLDER SUGARCANE IRRIGATION SCHEMES IN SWAZILAND

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Abstract

The problems encountered by smallholder drip irrigation users in Swaziland are discussed. The continuing drought, rapid population growth and mounting environmental concerns, have resulted in irrigated agriculture being expected and often required to operate with less water than previously allocated. Water supplies have become scarcer and more expensive due to increased pumping costs, and therefore agricultural productivity has to improve. In addition, an expanding population continually exerts new water demands on agriculture. These constraints have forced irrigation farmers to re-evaluate their systems and adopt new technologies such as drip irrigation to maximise water use efficiency. It is for these reasons that smallholder farmers in the Swaziland sugar industry have opted for drip irrigation as a means of expanding their irrigated area rather than because it is a technology they feel comfortable working with. The performance of drip irrigation systems on smallholder grower farms was compared with overhead systems. The cane yields obtained by farmers using drip irrigation are on average lower than those achieved with the dominant overhead systems such as sprinklers and center pivots. Drip irrigation has high installation costs and requires a high level of management to be successful. Field evaluation exercises have highlighted inherent problems caused by poor pressure distribution, leaks and incorrect operation.

Keywords: smallholder growers, drip irrigation, water use efficiency, irrigation system evaluation

Introduction

Drip irrigation systems

Drip irrigation has steadily increased in popularity since the first large commercial installations of the early 1970s (Burt and Styles, 1999). Since the late 1980s there have been steady improvements in drip irrigation products and quality. In the late 1990s there were many innovations, such as pulsating emitters, completely new designs of pressure compensating emitters, new large pressure regulators that operate with low pressure loss yet maintain the low pressures needed for drip tape, and some new filter designs. Drip irrigation generally refers to systems that use low flow rate emitters, from which water drips onto or into the soil.

Drip irrigation delivers water directly to small areas adjacent to individual plants through emitters placed along a water delivery line, the lateral. Typical requirements for a drip system include a pump, filters, chemical/fertiliser injectors, main and sub-main lines, laterals and emitters. Equipment such as laterals and emission devices typically remain in one place during the growing season. Systems are typically permanently installed for trees and vines and for some row/field crops, but for other row/field crops such as lettuce and cotton, they may be portable and moved to a different field after an irrigation season is complete.

Drip irrigation systems require very clean water to avoid clogging of the emitters, and hence filtration components represents a major portion of the purchase and maintenance costs of a drip system. Chemicals injected into the system are usually required to avoid clogging, due to bacterial growth and/or chemical precipitation in the laterals and emission devices. Filtration and chemical application for the prevention of clogging can be minimized only if the water is very clean and if the laterals with the emitters are discarded after a short life.

Flow rates for individual emitters are typically very small, ranging from about 1.5-8.0 litres per hour. Most drip systems are easily automated where the water supply is readily available. Drip irrigation systems are ideal for irrigation managers who are interested in fine-tuning the applications of water and fertilisers (fertigation) through the irrigation system. Some drip systems are designed to irrigate a whole field at once. However, the universal trend toward higher emitter flow rates or more closely spaced emitters usually requires that the full pump flow rate be rotated between two to eight blocks within a single field.

The purpose of this paper is to discuss some of the problems encountered by smallholder farmers using drip irrigation technology for sugarcane production, and to highlight some precautionary measures that need to be taken to ensure a more efficient irrigation system.

Water usage

One of the most important characteristics of drip irrigation is that water can be applied frequently in small quantities directly related to crop water requirements and soil properties (Svehlik, 1987). Under such conditions, the irrigation and soil moisture regimes can be closely controlled and, as a result, there is potential to achieve high water application efficiencies. In subsurface drip irrigation only a small part of the area is wetted, with the consequence that the evaporation component of the total water usage is reduced. With surface drip, the surface is constantly wet, hence evaporation can be high prior to canopy development.

Significant water savings in comparison with other irrigation methods in terms of irrigation water requirements have been widely reported (Hanks, 1974; Abbot, 1984). It has been reported that savings of as much as 30% of irrigation water compared with sprinkler irrigation and up to 75% compared with poorly managed surface methods have been made.

Savings of water, however, have not been achieved in all cases. Svehlik (1987) reported that in Australia and the USA there was no significant reduction in water use compared with sprinkler irrigation, and in some cases the use of drip irrigation resulted in the opposite – an increase in water use, but with consequent higher yield per unit volume of irrigation water. Can these differences be explained? Does drip irrigation then really save water?

Some researchers have suggested that, for mature crops, water requirements are similar for all methods of irrigation and water savings from drip irrigation would depend largely on the inefficiency of the methods it replaces (Bernstein and Francois, 1973). The opinion of the author is that any reduction in water requirements for drip irrigation over another method result primarily from an improvement in on-farm irrigation management. It can be argued that the efficiency of drip irrigation depends equally on the skills of the operator, and its potential efficiency under well-managed conditions should not be compared, for water saving purposes, with the inefficiency of the method it replaces. An inefficient well-managed drip system may use more water than a well-managed surface irrigation system.

Most farmers use drip as a means of expanding their irrigated land. An example can be made by looking at the Maplotini Farmers' Association, who were allocated water of 113.2 L/s by Government. Taking a yearly water requirement of about 1400 mm, under drip irrigation they could irrigate about 231 hectares (90% efficiency), 193 hectares under sprinkler (75% efficiency) and 154 hectares under furrow (60% efficiency).

It can also be argued that the efficiency is based on evapotranspiration and losses of water, which are often unknown quantities, particularly when the system is not designed for maximum yields.

Materials and Methods

Data collection

Cane yield data was obtained from the Swaziland Crop Statistics booklet that is compiled annually by the Swaziland Sugar Association, and summarised from 1999 to the present. The data was grouped per the various irrigation system types: sprinkler, furrow, center pivot and drip. Data analysis was done using the Excel spreadsheet. Some of the drip irrigated fields were evaluated as described by Pitts (1997) for water application efficiency and distribution uniformity, as part of the annual system evaluation exercise. The hydraulic uniformity was estimated by measuring pressures at points distributed throughout the field. Pressures were measured to the nearest kPa using a portable pressure gauge connected to a flexible tube. These pressures were measured at the beginning and end of the laterals for the one closer to the hydraulic control valve, and at every 50 m until the last lateral. Some of the results from the evaluation exercise are summarised.

Determining drip irrigation performance

The first requirement for efficient drip irrigation is uniform water application, without which irrigation scheduling is problematic. One of the main objectives of an irrigation system evaluation is therefore the determination of water application uniformity. With drip irrigation systems, non-uniformities are repeated in subsequent irrigations and tend to accumulate, whereas with overhead (sprinkler and center pivot) and furrow irrigation, non-uniformities vary somewhat from irrigation to irrigation and thus there may be some compensation. A highly uniform water application does not ensure high efficiency, since water can be uniformly over-applied; however, a highly efficient irrigation system along with good crop yields requires uniform water application. Irrigation efficiency is a measure of (i) the effectiveness of an irrigation system in delivering water to a crop, or (ii) the effectiveness of irrigation in improving crop quality.

The effectiveness of a drip irrigation system in delivering water and hence improving crop quality is dependent on the emitter discharge. The response of a specific emitter depends on its design and construction. The relationship between the emitter operating pressure and flow rate is given by the following equation:

$$Q = kP^x \quad (1)$$

where

- | | | |
|---|---|---------------------------------------|
| Q | = | flow rate (L/h), |
| P | = | pressure at the emitter (kPa), |
| k | = | is a constant dependent on the units, |
| x | = | pressure discharge exponent. |

Measures of drip irrigation system performance include the determination of distribution uniformity (DU), standard deviation (S_d), coefficient of variation (Cv), statistical uniformity (SU), and emission uniformity (EU).

These are defined in the following equations:

$$DU = \frac{L_q}{X_m} 100 \quad (2)$$

where

L_q = average discharge of the lower quarter
 X_m = average discharge of all the observations

$$S_d = \left[\frac{\text{sum}(X_i - X_m)^2}{N - 1} \right]^{0.5} \quad (3)$$

where

X_i = observed depth or collected volume/ (flow rate),
 X_m = mean of observations (flow rate),
 N = number of observations.

$$C_v = \frac{S_d}{X_m} \quad (4)$$

where

C_v = coefficient of variation
 S_d = standard deviation

$$SU = \left[1 - \frac{S_d}{X_m} \right] 100 \quad (5)$$

Alternatively the DU can be expressed in terms of standard deviation as:

$$DU = \left[1 - \frac{1.27 S_d}{X_m} \right] 100 \quad (6)$$

$$EU = \left[1 - \frac{1.27 C_v}{n^{0.5}} \right] \frac{q_m}{q_a} 100 \quad (7)$$

where

n = number of emitters,
 q_m = minimum emitter discharge for minimum pressure,
 q_a = average of design emitter discharge.

The statistical uniformity is an important measure for drip irrigation systems. The major advantage of using this measure is that sources of non-uniformity can be separated and thus identified because it takes into account the observed discharges. Knowing the contribution of the various factors that contribute to non-uniformity is of great value in determining what corrective action is needed to improve water application uniformity. For example, if the differences between observations and the mean of all the observations are too great, then the

standard deviation will be high and result in a high coefficient of variation, which is a sign that the laterals must be replaced.

In Table 1, criteria for rating the statistical uniformity estimate are provided. Generally, uniformities below 80% become unacceptable.

Table 1. Criteria for rating uniformity (Pitts, 1997).

Rating	Statistical uniformity (SU)	Distribution uniformity (DU)
Excellent	>90%	>87%
Good	80-90	75-87
Fair	70-80	62-75
Poor	<70	<62

Results

Irrigated area

The trend in irrigated area in the entire Swaziland Sugar industry since 1984 to 2004 is shown in Figure 1. The increase was steady in the irrigated areas until about 1998, when there was a sharp increase due to the large number of smallholder growers joining the industry.

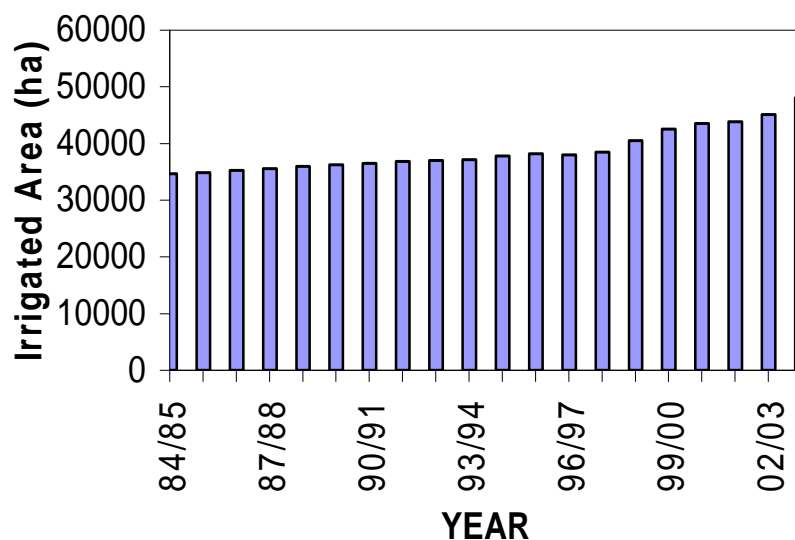


Figure 1. Trends in irrigated area in the Swaziland sugar industry from 1984 to 2004.

Cane yield

The average cane yield in tons cane per hectare obtained by smallholder farmers comparing the various irrigation systems is shown in Figure 2. The lowest average cane yields were obtained in furrow irrigation and then drip irrigation systems. The highest average is from sprinkler irrigation systems.

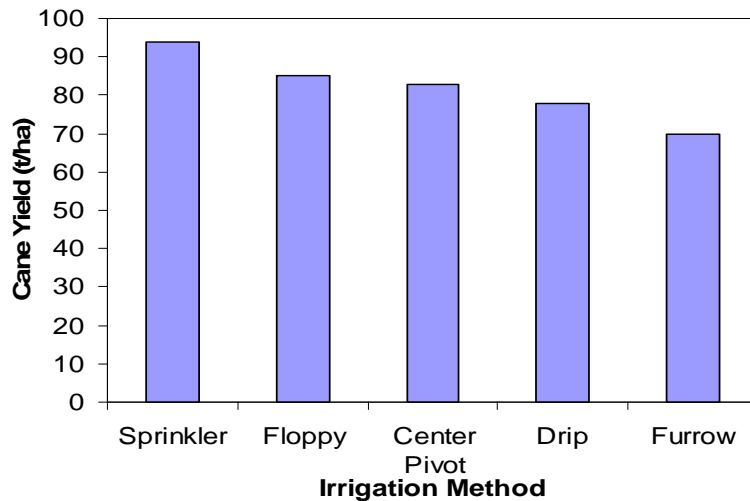


Figure 2. Average cane yield obtained by smallholder farmers with the various irrigation systems.

In Figure 3 the average cane yields obtained by smallholder farmers using drip irrigation system are compared with those obtained by larger, more experienced growers (RSSC). The yields obtained by smallholder growers are generally lower than those achieved by larger scale growers and the gap is mostly attributed to constraining factors at technological and management levels. Examples of such factors include:

- management skills which tend to affect the timing of operations.
- lack of finances compared to large scale operations. These farmers depend on the willingness of financial institutions to give them advance loans, which at times are approved late, and even where approved they are restricted. This then delays the timing of essential operations such as application of fertilisers, chemicals, weeding, and, of course, irrigation and maintenance.

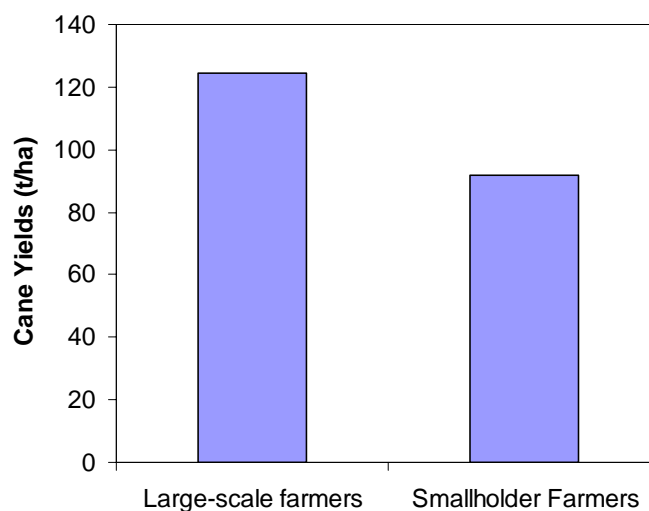


Figure 3. Comparison of average cane yield obtained by smallholder farmers and large scale estate growers.

Results of a performance evaluation of drip irrigation monitored on two smallholder farms over a two-year period are given in Tables 2 and 3.

Table 2. Drip performance as measured at Manzana Farmers' Association for the 2002 and 2004 seasons.

Field number	2002 season		2004 season	
	13	20	13	20
Emitter design flow (L/h)	1.60	1.60	1.60	1.60
Average flow (L/h)	1.70	1.60	1.60	1.60
Standard deviation (L/h)	0.10	0.10	0.50	0.10
Average of lower quarter (L/h)	1.60	1.50	1.10	1.40
Statistical uniformity (%)	94	92	71	93
Distribution uniformity (%)	94	91	71	88
Blocked emitters (%)	0	0	6	0

Table 3. Drip performance as measured at Maplotini Farmers' Association for the 2001 and 2003 seasons.

Field number	2001-season		2003-season	
	A1	A2	A1	A2
Emitter design flow (L/h)	1.65	1.65	1.65	1.65
Average flow (L/h)	0.90	0.90	1.40	1.30
Standard deviation (L/h)	0.20	0.40	0.20	0.30
Average of lower quarter (L/h)	0.60	0.30	1.10	1.00
Statistical uniformity (%)	76.0	56.0	83.9	80.5
Distribution uniformity (%)	67.0	37.0	78.3	74.0
Blocked emitters (%)	0	2.2	0	0

The performance rating at Manzana Farmers' Association declined from excellent to fair for both SU and DU over a year. During the second evaluation a number of emitters were found to be blocked. It is important to note that the discharge through the emitters was found to be higher than the design discharge, mainly because the laterals were facing downhill and hence there was a gain in pressure. The Maplotini system was near collapse when the first evaluation was done. After following recommendations for improvement, the system improved from fair to good. The biggest question is for how long they can sustain the 'good' performance.

Discussion

Observed problems

The most serious problems in drip irrigation have been root intrusion and silt/sand deposition. Uncontrolled weeds were found to be responsible for root intrusion. In most cases, chemical treatment cannot be applied because the water supply is also used for domestic purposes. Drip tubes with large emitter outlets are more vulnerable to root intrusion than smaller ones. Oron *et al.* (1990), state that temporary neglect of system maintenance may cause irreversible damage. Poor filtration resulted in sand deposition inside dripper lines. Neglect during installation has also contributed to the build-up of sand. Water pumped directly from the river

contains a lot of silt; if fed directly to the field the silt gets deposited along the emitters. River water should be stored in a reservoir to allow the silt to settle before use in drip irrigation systems.

There is great difficulty in assessing subsurface drip irrigation emitter performance as holes have to be dug in the process, disturbing the cane stool. Also, the pattern of irrigation is not easy to see, making it difficult to detect emitter blockages, and there are problems in effecting repairs. There is a tendency with growers to replace pieces of laterals with piping of different emitter configuration than those originally designed, which alters the hydraulics of the system. In Swaziland poor germination is often observed when drip irrigation is used on rapidly draining soils. There is difficulty in land preparation when subsurface drip is used over more than one crop cycle. There is a need for correct placement of the tape, correct emitter spacing and correct filtration.

Various problems have also been encountered during harvesting such as accidental burning, cutting by cane cutters and kinking of dripper lines caused by harvesting machinery. During harvesting, drip irrigated fields are usually irrigated to avoid compression of the laterals by harvesting equipment, and also to prevent the burning of the tubes. However, this is not done as it leaves the soil soft and moist, thus causing tires to create ruts deep enough to force replacement of the tubes. Continuous wetting of the topsoil is a disadvantage as it reduces the efficiency of water penetration by rainfall and causes cane stools to be susceptible to lodging during strong windstorms.

Emitters are generally sensitive to plugging, indicating that all emitters require some type of water treatment. Cyclonic separators and screen filters are used to remove inorganic contaminants. Chemical treatment of water may also be required to control biological activity in the water, to adjust pH, or to prevent chemical precipitation, which could plug emitters. Proper design and care of the water treatment system is vital to the successful use of the drip irrigation.

Drip irrigation can be used successfully with poor quality water, although some special cautions are necessary. Salts will tend to concentrate at the perimeter of the wetted soil volume. If too much time passes between irrigations, the movement of soil water may reverse itself by capillary rise, bringing salts back into the root zone. Salts concentrating on the surface of the wetted area can be moved down into the root zone by light rain. For this reason irrigations should continue unless heavy rainfall is forecast.

Installation costs

The cost of drip irrigation systems can vary greatly, depending on the source of water, the type of hose selected for laterals, and the type and spacing of the emitters. Table 4 compares the installation cost of drip irrigation with the other systems used in Swaziland.

These cost figures are for high quality systems and include pumps, filters (for drip irrigation) and controls, mainlines, manifolds and laterals.

Table 4. Average initial cost of a drip irrigation system compared with other irrigation systems in the Swaziland sugar industry during the 2003/04 season.

Irrigation system type	Installation cost (R/ha)
Drip	29 000 - 35 000
Semi-solid	21 000 - 27 000
Floppy	18 000 - 30 000
Dragline	15 000 - 25 000
Center pivot	16 000 - 24 000
Furrow	10 000 - 15 000

Typical operation and maintenance costs for drip irrigation systems also vary greatly, depending on local circumstances and irrigation efficiencies achieved. A most basic approach that helps in planning, is to estimate the operation and maintenance costs as a percentage of the initial capital costs, as shown in Table 5.

Table 5. Estimate of annual operation and maintenance costs for a drip irrigation system as a percentage of initial capital cost.

Expense category	Percentage estimate
Labour	1.5
Power*	3-7
Maintenance	3

*Depends on system efficiency

There are perceptions that projected yield increments are not large enough to recoup what is considered to be a high-cost investment on smallholder farms. It is obvious that drip irrigation has a high relative installation cost. Yet another major hindrance to adoption of drip is the fear of the irregularity of water applications.

Conclusions

Drip irrigation is a relatively new and rapidly expanding method of irrigation. Well designed and properly operated, this system has the potential to create favorable plant growth conditions by controlling the soil moisture and salt concentration in the root zone, as well as plant nutrition, plant diseases and weed growth. In such a situation, a high yield and high effectiveness of water use can be achieved.

However, the use of drip irrigation does not guarantee high yields and high efficiency. The method, as any other methods of irrigation, is not immune to failures. The efficiency of the method depends equally on the skills and art of the operator, and its potential efficiency under well-managed conditions should not be compared, for water saving purposes, with the management inefficiencies of the method it replaces, e.g. furrow.

The physical, chemical and biological processes on drip-irrigated fields are more complex than on fields where irrigation is by other, conventional methods. Research has provided some insights into the phenomena involved, but many questions on the behavior of the soil-

water-plant-atmosphere relationship under conditions of drip irrigation have not yet been answered, e.g. the impacts of shallow wetting. It has however, been shown that the multi-dimensional movement of water and a partial soil wetting under drip irrigation have a considerable impact on the field energy balance, on the pattern of wetting, water extraction, salt distribution in the root zone, plant rooting and, finally, on the yield.

In subsurface drip irrigation, the wetting pattern is hidden underground and not often seen, making it the most difficult method to manage under irrigation. Farmer training to understand the principle governing this method is essential if misuse of the method is to be minimised.

The choice of irrigation system selection should be left with the farmer and where expert advice has been sort, such should consider the level of 'art' of the farmer in handling the type of irrigation system.

Further research is needed to improve knowledge and understanding of the complex processes taking place on drip irrigated fields. This will enable the improvement of design and operation of drip irrigation systems, so that the method can be used to its full potential.

Acknowledgements

This paper has been made possible through the help of colleagues at SSA Technical Services. Many thanks to Dr Mike Clowes and to Mr Peter Turner for their encouragement. Special thanks goes to Mr Patrick Mkhalihi for data collection and to Mr Duma Zwane.

REFERENCES

- Abbott JS (1984). Micro-irrigation – World wide usage, 1984. Bulletin de la CIID, janvier. 36 pp.
- Bernstein LE and Francois LE (1973). Comparison of drip, furrow and sprinkler irrigation. *Soil Science* 115: 73-86.
- Burt CM and Styles SW (1999). Drip and micro irrigation for trees, vines, and row crops. California Polytechnic State University (Cal Poly), San Luis Obispo, CA 93407, USA. 292 pp.
- Hanks RJ (1974). Modeling for predicting plant yield as influenced by water use. *Agron J* 66(5): 660-664.
- Oron G, de Malach J and Hoffman Z (1990). Subsurface trickle irrigation of domestic crops with domestic effluent. pp 243-257 In: Proceedings of AGRITECH, 5th International Conference on Irrigation, Israel.
- Pitts DJ (1997). Evaluation of micro-irrigation systems. South West Florida Research and Education Center, University of Florida, USA. 46 pp.
- Svehlik SJ (1987). The impact of micro-irrigation techniques on water usage and crop yield. *ICID Bulletin* 36(1): 38-50.