AUTOMATIC SHORT FURROW IRRIGATION

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LITERATURE REVIEW AND PROJECT PROPOSAL

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ABSTRACT

Automated short furrow irrigation is a new and innovative approach to irrigation. The aim of this literature review and project proposal is to, therefore, assess and refine automated short furrow irrigation. The literature review focuses on the need for automated short furrow irrigation. This document contains an investigation into a range of irrigation systems but focuses on automated short furrow irrigation. The investigation shows the need for automated short furrow irrigation, as automated short furrow irrigation is potentially able to achieve high efficiencies at a fraction of the initial and operating costs of other irrigation systems such as sprinkler and drip irrigation.

The automation of short furrow irrigation systems is also reviewed, with an emphasis on the control mechanism. The control mechanisms include a tilt valve and riser system proposed by Austin (2003b), three way valves developed by Fischbach and Goodding (1971) and Humpherys and Stacey (1975), surge valves and a piston valve. Comparisons of the mechanisms lead to the conclusion that the piston valve shows the most potential to automate short furrow irrigation as the other valves were either too expensive or did not fulfil the required function adequately. However, the piston valve is still in a developmental phase and requires further development. These developments will be an integral part of the project as discussed in the Project Proposal.
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1. INTRODUCTION

South Africa is classified as a water scarce and semi-arid country (Perret, 2002; Badenhorst et al., 2002). South Africa has been delineated into 19 water management areas. In 2000, 10 of these water management areas demand exceeds supply (DWAF, 2004a). The agriculture sector currently accounts for approximately 62% of the total water use in South Africa (DWAF, 2004b). Irrigation systems can be delineated into three categories as illustrated in Figure 1.1. These are flood or surface irrigation, mobile irrigation such as centre pivot and static irrigation such as sprinkler and drip irrigation. Surface irrigation accounts for 90% of irrigation worldwide (ARC, 2003). Surface irrigation is the introduction and delivery of water in a field by the gravity flow of water over the soil surface. Typical application efficiencies for regular surface irrigation systems range from 45% to 60%. These efficiencies can be increased to range from 70% to 85% by using careful management and improved water control (Ley, 2003). These efficiencies can also be improved by using shorter furrow lengths as in short furrow irrigation (Austin, 2003b).

Figure 1.1 Classification of systems (ARC, 2003).
The main objective of this literature review is to determine the potential and feasibility of ASFI. Chapter 2 contains experiments on short furrow irrigation (SFI), which has been implemented extensively in South Africa and throughout the world with tests done in South Africa by Crosby et al. (2000). SFI uses a system of canals to deliver water to the furrows. The water is diverted down each of the supply canals by manually placing an obstacle in the canal where the flow must be blocked (Crosby et al., 2000). SFI is an efficient and low cost means of delivering water to plants (Austin, 2003b). SFI is, however, labour intensive (ARC, 2003). Therefore, the development of automated short furrow irrigation (ASFI) could prove valuable. ASFI is a new concept proposed by Colin Austin. ASFI uses a system of pipelines with water being diverted down the required pipeline by a flow control mechanism (Austin, 2003b). However, ASFI requires a cheap and simple valve system to automate the distribution of water (Austin, 2003a). Chapter 3 will therefore introduce the ASFI concepts and the different valve options. Chapter 4 contains a comparison of ASFI to sprinkler and drip irrigation, the most common replacement for flood irrigation, to help attain the main objective of the literature review. However, the ASFI system needs to be properly designed if it is to compete with sprinkler and drip irrigation. Chapter 5, therefore, includes the design considerations and computer models for ASFI to enable the ASFI design to be optimal for given conditions such as soil type and field slope. From the literature reviewed, conclusions are drawn, which leads onto the requirements for the project proposal in Chapter 7.

Chapter 2 focuses specifically on assessing the performance of SFI. This assessment is based on the possible application efficiencies (AE) and distribution uniformities (DU). The DU is an indication of how evenly the distribution of irrigation water is throughout the block (Koegelenberg, 2006). The AE applies to a single irrigation event (Lecler, 2005b). The AE is based on the concept of meeting a target irrigation depth (the soil moisture depletion, SMD, or a smaller amount to accommodate potential rainfall) for that event (Burt et al., 1997) and is given by the following formula:

\[
AE = \left[ \frac{\text{Ave. depth of irrig. water contrib. to target}}{\text{Ave. depth of irrig. water applied}} \right] \times 100\%
\]
2. SHORT FURROW IRRIGATION

A number of experiments have been conducted with regards to short furrow irrigation and the effects on changing field length. Eldeiry et al. (2004) conducted field experiments in Egypt for furrow irrigation for clay soils in Arid Regions. The results in Figure 2.1 show that short furrow lengths with relatively low discharges can achieve high efficiencies whereby, increasing the furrow length results in higher discharge requirements. The optimum furrow length for a given discharge on clay soils in arid regions can be determined from Figure 2.1 (Eldeiry et al., 2004).

![Figure 2.1 Application efficiencies at different furrow lengths for given discharges where Qo is the discharge in m³/min (Eldeiry et al., 2004).](image)

Figure 2.2 represents the efficiency as a function of discharge for particular furrow lengths. High efficiencies can be achieved for the 25 and 50 m furrows using a very small discharge. However, small errors in applying the required discharges can result in a dramatic decrease in the efficiency as a result of the distinct peak in the graph. Longer furrows have a higher security factor for clay soils in arid regions as the peak is less pronounced (Eldeiry et al., 2004). Eldeiry et al. (2004) therefore concluded that
even though short furrows have a higher maximum efficiency, the overall efficiency of the long furrows is a more practical design as it is less dependent on the application rates. Figures 2.1 and 2.2 can therefore be a guide to farmers on clay soil in arid regions on the correct furrow length and discharge combination (Eldeiry et al., 2004).

![Figure 2.2 Application efficiencies for different discharges at given lengths (Eldeiry et al., 2004).](image)

However, Crosby et al. (2000) conducted a number of experiments in South Africa and shows in Table 2.1 and 2.2 that high distribution uniformities are possible for short furrow irrigation at two different flow rates. Crosby et al. (2000) states that for most flood irrigation systems, it is crucial that the land is well prepared and cultivated every season so as to ensure uniform gradients and to remove hollows, furrows and ridges which will impede the flow. For small scale farmers, ensuring uniform slopes is exceptionally difficult as there is a lack of power for tillage purposes. However, short furrow irrigation is not nearly as sensitive to these factors as conventional flood irrigation is. Short furrow irrigation has the advantage that water advances rapidly down the furrow, ensuring even distribution in even sandy soils with a high infiltration rate (Crosby et al., 2000). Therefore, short furrow irrigation results in a very uniform water distribution across the field, even where the gradient varies or
there is an inconsistent flow rate. These variations in flow rate and gradient would make the more conventional methods of flood irrigation extremely difficult (de Lange, 1997).

Table 2.1 Possible distribution uniformities (DU) on a loam soil at two different flow rates (Crosby et al., 2000).

<table>
<thead>
<tr>
<th>Soil: Loam</th>
<th>Gradient</th>
<th>1m:300m</th>
<th>Zero</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L = 10 m</td>
<td>L = 20 m</td>
<td>L = 10 m</td>
</tr>
<tr>
<td>Flow Rate (m$^3$h$^{-1}$)</td>
<td>DU (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 m$^3$h$^{-1}$</td>
<td>72</td>
<td>89</td>
<td>86</td>
</tr>
<tr>
<td>10 m$^3$h$^{-1}$</td>
<td>90</td>
<td>80</td>
<td>91</td>
</tr>
</tbody>
</table>

Table 2.2 Possible distribution uniformities (DU) on a sandy soil at two different flow rates (Crosby et al., 2000).

<table>
<thead>
<tr>
<th>Soil: Sand</th>
<th>Gradient</th>
<th>1m:300m</th>
<th>Zero</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L = 10 m</td>
<td>L = 20 m</td>
<td>L = 10 m</td>
</tr>
<tr>
<td>Flow Rate (m$^3$h$^{-1}$)</td>
<td>DU (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 m$^3$h$^{-1}$</td>
<td>80</td>
<td>82</td>
<td>95</td>
</tr>
<tr>
<td>10 m$^3$h$^{-1}$</td>
<td>75</td>
<td>90</td>
<td>98</td>
</tr>
</tbody>
</table>

However, there are a number of disadvantages to using short furrow irrigation. These are that mechanised cultivation for short furrow irrigation is difficult, water losses occur in the supply furrow and it is a relatively labour intensive system (ARC, 2003). These disadvantages can be overcome by automating the short furrow irrigation system. Water losses in the conveyance system of ASFI are minimal as pipes are used rather than supply furrows (Lecler, 2006). This is due to the use of pipes becoming economically feasible as a result of the smaller flow rates and therefore smaller pipes required. As a result of the pressure being low, low cost flexible piping can be used (Austin, 2003a). In addition, with automated short furrow irrigation, operation is largely automated and there are no pipes that need to be moved between irrigations or siphons that need to be primed and thus labour requirements are low (Lecler, 2005a). The hydraulic design of ASFI is also more rigorous with an improved flow rate control (Lecler, 2006).
3. AUTOMATIC SHORT FURROW IRRIGATION

Traditional flood irrigation systems usually apply large volumes of about 50 mm of water every 5 to 10 days. However, plants respond better to smaller and more regular irrigation events, associated with ASFI, resulting in an increased productivity. ASFI systems are designed to apply a fixed amount of water of approximately 5 mm per irrigation event, depending on the water holding capacity of the soil (Austin, 2003a). ASFI irrigates short sections at a time, in sequence, resulting in no water passing beyond the root zone. Evaporation losses are low as the irrigation time for each furrow set is only a few minutes and only a small portion of the soil surface is wetted (Austin, 2003c).

Summarising the above, reducing the furrow length results in a high efficiency and distribution uniformity, even at very low flow rates (Austin, 2003b). The low water requirements results in many water sources which are too small for effective flood irrigation now being able to be used. Small, low cost pipes can now replace the large open channels resulting in significant water saving. Any soils can be irrigated using ASFI (Austin, 2003a).

Small-scale technology is required in South Africa to improve the ability to design and develop new and appropriate SFI systems (de Lange, 1997). Colin Austin, a retired mechanical engineer from Australia, addresses this problem during a visit to Ethiopia. The outcome of this was the development of Micro-flood, a benchmark to ASFI (Lecler, 2006).

3.1 Colin Austin’s ASFI Concepts

The ASFI concept is extremely simple. Water supply is from the mainline, a pipe running down the bay with tap off points at specific points along the length. Laterals with emitters are used to distribute the water across the bay. Initially the system works like a conventional flood system with water being distributed to the first tap off point as illustrated in Figure 3.1. However, when the flow enters the next section, the water is diverted down the mainline to the next tap off point. Only small amounts of water are applied during each irrigation event. The soil is not totally saturated resulting in
no water loss with the soil moisture being maintained resulting in optimum production. The use of ASFI can increase production by 40%. However, the furrow lengths should be much less than the equilibrium flow length, ensuring a high distribution uniformity. The flow must be switched to the next set of furrows once the flow has entered the next set of furrows. This will ensure a uniform distribution across the field (Austin, 2003b).

Figure 3.1 Systematic progression of irrigation with a) flow down the first lateral, b) flow down the second lateral and c) flow down the third lateral (Austin, 2003b).

3.2 Colin Austin’s Tilt Valve and Riser System

The system mention in Section 3.1 requires a cheap and simple valve system, used at the tap off points so that each set of furrows can be irrigated in turn (Austin, 2003a). Colin Austin proposed a system of tilt valves and risers. The risers direct the water into the tertiary line by elevating the pipe so that the water needs to overcome a head. This is done by using an inverted U. The flow is diverted to the next block by using the valve to block the flow down the tertiary line, forcing the water over the riser. The total area is therefore irrigated by each valve closing in turn once each set of furrows has received sufficient water (Austin, 2003b). The valve, known as the tilt valve, works as follows. A small bleed tube, attached to the tertiary line, is used to fill the L or U shaped tilt valve. Before irrigation, the valve is balanced in the open position. When the irrigation event commences, the water starts to fill Section A, thus continuing to hold the valve open as represented in Figure 3.2. The valve will stay open throughout the irrigation of that set of furrows. The valve continues to fill, filling Section B as well. When the weight of the water in Section B is greater than the
weight of water in Section A, the valve pivots, forcing the water in Section A to rush into Section B resulting in the flexible tubing being snapped shut (Austin, 2003b).

Figure 3.2 Colin Austin’s tilt valve (Jumman and Mills, 2005).

However, Jumman and Mills (2005) conducted experiments on a number of variations of the tilt valve. The findings of these experiments were that the tilt valve failed to shut-off the flow completely down the tertiary line. This was due to insufficient force applied by the valve on the flexible tubing as well as the valves not being able to provide the parallel, smooth surfaces required to stop the flow completely. Achieving the correct cut-off time was extremely difficult. This was due to the increasing resistance to flow in the bleed tube as the valve filled up which resulted in the flow rate in the bleed tube not being constant. Due to the delicate balance of the system as well as the sensitivity of the system to uncontrolled variables such as twists in the pipe, the system was deemed impractical (Jumman and Mills, 2005).

3.3 Alternative Valve Options

Hoffman et al. (1990) showed a number of pipeline delivery systems. These included the gated pipe system and a buried multi-set irrigation system. These will be introduced, however the focus will be placed on the valves as the objective of this section is to find alternative valves to Colin Austin’s tilt valve and riser system.
A flow-through gated pipe system consists of a single gated pipeline installed in a series of level segments at the top end of the field (Humpherys, 1986). Each segment is one irrigation set with a stair-step drop at its lower end. A semiautomatic butterfly valve is located downstream of the drop. The water only occupies 60 to 75 percent of the pipe cross sectional area, with the gates near the top end of the pipe, above the water surface for all upstream sets. The valve, located just below the drop, is used to release water to the next downstream set (Hoffman et al., 1990). Humphreys et al., 1983) developed a torsion spring operated valve which is commonly used. A three way valve can also be used to split the field up into sections. (Fischbach and Goodding, 1971).

A multi-set system divides the normal furrow length of 300 to 400 m into several shorter sections of 60 to 90 m. This results in an application efficiency of about 80 percent if operated on a normal irrigation cycle of 7 to 14 days. This can be improved to above 90 percent if lighter, more frequent irrigations are applied. Small stream are sequenced to the top of each section, with runoff from each section continuing down the furrows into the next section. The buried lateral automatic multi-set system, delivers water to the furrows from a pipe buried approximately 40 cm below the soil surface so that farm operations can continue unhindered (Worstell, 1979). This system uses a valve developed by Humpherys and Stacey (1975) so as to automate the system (Hoffman et al., 1990).

The three way valves developed by Fischbach and Goodding (1971) and Humpherys and Stacey (1975), used in the above systems show potential as alternatives. Fischbach and Goodding (1971) used an inflatable rubber diaphragm to stop the flow of water through the valve. A three way pilot valve controls the air in and out of the diaphragm of the automatic valves (Fischbach and Goodding, 1971). Humherys and Stacey (1975) use a similar bladder valve with a three way pilot valve that controls the filling and emptying of the bladder.

Jumman and Mills (2005) suggested a number of alternatives. These were the surge valve and the piston valve. A surge valve is a valve which has been specifically designed for surge flow irrigation, a system whereby a field is irrigated in short surges. There are two main surge flow valves types: the bladder valve and the
The bladder valve uses an inflatable bladder in each of the branches in the tee shaped valve. The bladder inflates to block flow in that branch and deflates to let water past. These bladders can either be inflated by water pressure in the pipeline or by air pressure. The mechanical surge valve is usually a butterfly disk valve which operates across the tee junction, single butterfly, or in each of the tee branches, double butterfly. This valve can be powered by electricity, air pumps or water pressure (Henggeler et al., 1986). Jumman and Mills (2005) suggested that by making slight alterations to these valves, such as setting the time period that each side is open, could result in a system which is suited to short furrow irrigation. However, the cost of 8 and 10 inch valves cost US$755 to US$895 with the controller costing between $545 and $1015 depending on the controller’s features (Nishihara and Shock, 2001).

The piston valve is connected to the lateral of the ASFI system. A bleed tube is used to fill water into a bucket. The weight of the water in the bucket opposes the tension in the spring, pushing the piston down to the critical level, as indicated in Figure 3.3. Once the piston moves past the critical level, the pressure in the system pushes the piston down onto the O-Ring, snapping the valve shut. The flow in the lateral is therefore shut off and the riser is overcome. The bucket drains when the valve closes. The valve is kept in the closed position by the pressure of the water in the mainline. Hence, when flow in the mainline seizes, the tension spring is able to pull the piston up and reset the system (Jumman and Mills, 2005).
The assessment of this valve was that the piston valve was impressive with regards to completely shutting off flow down the lateral. The ball valve on the bleed tube ensured the correct cut-off time. The piston valve does not require any electrical components which greatly reduce both the initial and running costs. This is also advantageous as many of the users of this system would be in rural areas, without power supply. The piston valve is also more compact and robust than the tilt valve. The piston valve was also easier to connect to the pipe network. The piston valve bucket was more effective at draining than the tilt valve. A disadvantage of the piston valve was that it was unable to reset without assistance, however a proposed solution to this would be to engineer a hole in the system. Eliminating the need for the riser would reduce the number of components and therefore the cost of the system (Jumman and Mills, 2005).
4. COMPARISON OF ASFI WITH OTHER IRRIGATION SYSTEMS

The use of short furrows has some substantial advantages and can outperform all other types of irrigation systems which results in substantial improvements to irrigation efficiency, effectiveness and economic margins (Lecler, 2006). With regards to the water application and suitability to a wide range of crops and soils, automated short furrow irrigation has the potential advantage that water application can be reduced to only 15 mm per irrigation event, without the distribution uniformity and application efficiency being compromised. The use of relatively small, frequent, uniform and low loss irrigation water applications allows a range of crops and soils to be irrigated with automated short furrow irrigation relatively efficiently and effectively. Other irrigation systems, whilst competing with automated short furrow irrigation in some aspects, fall short in others. In addition, with automated short furrow irrigation, operation is largely automated and there are no pipes that need to be moved or siphons that need to be primed, labour requirements are low (Lecler, 2005a).

4.1 ASFI Compared to Sprinkler Irrigation

Automated short furrow irrigation may provide the desired combination of low cost and high efficiency required for small scale farmers and will allow the farmers to operate relatively independently of each other. Lack of independence has resulted in considerable problems, for example, when an upstream grower of a shared sprinkler system fails to maintain nozzles, repair leaks or set correct pressures, this leaves downstream growers who are distant from the pumps with much frustration, high energy bills and low yields (Lecler, 2006). Automated short furrow irrigation can be much more effective than sprinklers as sprinklers wet the entire surface area so there are significant evaporation losses, some during application and the rest by evaporation from the upper soil layers. Short furrows, by contrast, result in most of the water going straight to the useful zone by subsurface flow (Austin, 2003a). Sprinklers are often run for long time periods so to minimise evaporation losses, whereas automated short furrow irrigation has shorter and more frequent irrigations. Automated short
furrow irrigation and sprinklers both distribute water horizontally, however, automated short furrow irrigation is gravity rather than pressure fed (Austin, 2003b). Wind has a negative influence on the distribution uniformity of sprinkler irrigation (ARC, 2003). Crosby et al. (2000) conducted experiments in South Africa on pressurised systems for small-scale farmer irrigation. The findings were that correct pressures in the system were required for efficient operation of sprinklers. However, pumps rarely operate at specified design pressures. Other problems encountered were incorrect management and maintenance of stand times, non-matching sprinklers and therefore inconsistent application rates, defective or missing sprinklers and variations in pressure throughout the system. A major difficulty of small-scale farmers is in obtaining skilled advice on equipment selection and design (Crosby et al., 2000). Crosby et al. (2000) also found that farmers forgot to move sprinklers which resulted in over-watering in certain areas. Moving sprinklers in high crops such as sugarcane is difficult, especially in obtaining to correct sprinkler position. Wear and tear is not immediately visible with a sprinkler continuing to operate until it completely fails. However, the sprinklers efficiency may have deteriorated sufficiently, long before that stage, to negatively influence costs and production. Worn nozzles can double application rates which, like leaking pipes, can cause water logging. The suitability of soils to sprinkler irrigation is also a major concern. Soil surface crusting is a problem throughout South Africa, with surface sealing resulting in infiltration rates as low 2mm/h. This is disadvantageous for sprinkler irrigation with poor water infiltration leading to ponding or run-off (Crosby et al., 2000).

4.2 ASFI Compared to Drip Irrigation

Automated short furrow irrigation has very high flow rates compared to drip irrigation for a short time period which results in a much wider water spread with horizontal rather than vertical flow. This benefits plant growth (Austin, 2003b). Automated short furrow irrigation needs significantly less capital and operating costs than drip. In addition, automated short furrow also professes to promote better gas exchange in the root zone which promotes better crop growth (Lecler, 2005a). Drip irrigation is considered an efficient system, however there is proof that drip irrigation can be inefficient, as a result of mismanagement and maintenance problems (Koegelenberg
and Reinders, 2001). Koegelenberg and Reinders (2001) conducted studies in six regions of South Africa on the performance of drip irrigation systems under field conditions. The drip lines were recovered from the field and tested along with new dripper lines in the laboratory with results shown in Table 4.1. Dripper lines with regular type emitters generally had a reduced average discharge due to emitters being clogged. The increase in discharge of certain regular type emitters was as a result of a sharp object being used to open blocked emitters. The increase in discharge of 58% of pressure compensated emitters were possibly due to objects being stuck between the compensating membrane and the labyrinth, or the compensating membrane loosing some of its elasticity over time (Koegelenberg and Reinders, 2001).

Table 4.1 Percentage of drip lines with emitter discharges deviating from the average discharge of new emitters (Koegelenberg and Reinders, 2001).

<table>
<thead>
<tr>
<th>Emitter type</th>
<th>Reduced discharge (%)</th>
<th>Average discharge (%)</th>
<th>Increased discharge (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>50</td>
<td>34</td>
<td>16</td>
</tr>
<tr>
<td>Pressure compensating</td>
<td>8</td>
<td>34</td>
<td>58</td>
</tr>
</tbody>
</table>

Other disadvantages of drip irrigation are that root diseases are more prevalent due to root zone being almost permanently wet, the pipes and drip laterals in the field impede cultivation and highly pervious soils cannot be irrigated by drip irrigation due to insufficient lateral movement of soil moisture. Drip irrigation also has the disadvantage that rainfall is not effectively utilized as a result of the continuously high soil moisture content (ARC, 2003). Reasons for the use of automated short furrow irrigation over bucket-drip kits and other small scale innovations are firstly that traditional flood and short furrow irrigation is used by many small scale farmers. Secondly, water application is visible where some drip and especially subsurface drip systems have failed to reach a high level of efficiency due to users over-irrigating as a result of the water application not being visible. Thirdly, automated short furrow irrigation does not require relatively sophisticated water filtration as is required in bucket drip systems (Lecler, 2005a).
5. DESIGN CONSIDERATIONS AND COMPUTER MODELS FOR ASFI

The hydraulic performance of furrow irrigation, including SFI, is dependant on the infiltration characteristics of the soil and the resistance to flow in the furrows, furrow shape, slope, length and spacing and the flow rate (Jurriens and Lenselink, 2001). These need to be optimised to obtain an efficient system. The Computer models, discussed in Chapter 5.7, are an integral part of this optimisation.

5.1 Soil

The soil characteristics that need to be obtained before deciding on the system layout are the soil type and texture, soil depth, possibility of crust forming, result of interaction with irrigation water and the infiltration characteristics. The infiltration characteristics are the most important of all the soil characteristics (ARC, 2003). Practically any soil can be irrigated using short furrow irrigation, however, the design and layout will be totally different (Austin, 2003a).

5.2 Furrow Spacing

The furrow spacing depends on the water movement in the soil, the crop type and the cultivation practice (Kay, 1986). Ideally, adjacent wetting patterns overlap each other and there is an upward water movement known as capillary rise that wets the entire ridge, providing the entire root zone with water (Brouwer et al., 1988). On sandy soils, there is only a small lateral movement of water and furrows therefore need to be close together then on clay soils (Kay, 1986). Double ridged furrows are sometimes used on clay soils. This allows for additional plant rows on each ridge, facilitating manual weeding (Brouwer et al., 1988). The furrow spacing has to comply with the tractor wheel spacing (ARC, 2003). Alternate furrow or wide-spaced furrow irrigation is an irrigation method whereby water is applied to every second furrow instead of every furrow. Alternate furrow irrigation (AFI) has shown successful results in a variety of cropping systems and in different climatic conditions as a method of
conserving water without a production loss. (Bakker et al., 1997). For further information on AFI, refer to Rogers (1995) and Bakker et al. (1997).

5.3 Furrow Shape

The furrow shape depends on the stream size, soil types and crops (Kay, 1986). Each furrow needs to be large enough to carry the water without furrows being damaged (Kay, 1986). Clay soils use a wide, shallow furrow to achieve a large wetted area so as to promote infiltration as seen in Figure 5.1b (Kay, 1986). Narrow, deep V-shaped furrows are used on sandy soils to reduce the soil area through which water percolates as illustrated in Figure 5.1a. Sandy soils are however less stable and tend to collapse (Brouwer et al., 1988).

![Figure 5.1 Furrow shape on a) Sandy soils and b) Clay soils (Brouwer et al., 1988).]

5.4 Furrow Slope

SFI involves the use of small earth canals, constructed at a constant gradient (Koegelenberg, 2004). SFI can be used on flat land and on mildly sloping land with a maximum gradient of 0.5%. An uneven gradient will result in uneven wetting along the furrow (Brouwer et al., 1988). When it is practical, furrows should be straight and parallel to the field edge and aligned down the main land slope. If the main slope of the land is too steep, furrows can be aligned across the main slope, thus reducing the furrow slope (Crosby et al., 2000). Soils with higher clay contents require flatter gradients as the water advances quicker on these soils. For SFI, the distribution was most uniform at a flat slope, irrespective of the flow rate and soil type (Crosby et al., 2000).
5.5 Flow Rate

Irrigation times for flood irrigation are long with significant water of up to 50 mm being applied and approximately 7 to 10 days between irrigation events. SFI applies approximately 5 mm of water, but irrigation events are more frequent, daily or every few days resulting in the soil moisture level being more uniform. The irrigation depth is controlled by the short irrigation times with the high flows, relative to the area, spreading the water. The short, intense bursts of irrigation are followed by a period in which no irrigation takes place, allowing the water to soak into the soil. Small areas are irrigated at a time to achieve the desired intensity (Austin, 2003b). It must be balanced against soil type and slope to minimise erosion, and against field slope and length to ensure a reasonable cut-off time. Operating at a flow rate either above or below the design flow rate can result in ineffective and non-uniform water applications (Ley, 2003).

5.6 Furrow Length

Increasing the furrow length on all soil types reduces irrigation efficiency due to deep percolation losses (Raine and Bakker, 1996). Applying larger irrigation depths can result in furrows being longer as there is a greater time period for water to flow down the furrows and infiltrate. Practically, the furrow length may need to be made equal to the field length, instead of the ideal length (Brouwer et al., 1988). Furrows that are on steeper sloping land of up to 0.3% can usually be longer as water moves more rapidly down the steeper slope of the furrow. However, the sloping land increases the risk of soil erosion (Kay, 1986). The maximum slope should therefore be 0.5% (Brouwer et al., 1986). On mechanised farms, short furrows require a lot of work as the flow is frequently changed between furrows. However, short furrows are usually a more efficient irrigation practice as it is easier to keep percolation losses low (Brouwer et al., 1988).

Hanson (2001) showed that shortening the field length by one-half results in the water reaching the end of the field faster. This substantially reduces the deep percolation losses and considerably improves the distribution uniformity for fields longer than 300 metres. However, the normal furrow inflow rate must still be used. Using the same irrigation time will result in an increased surface runoff. The irrigation time
must therefore be decreased as halving the furrow will reduce the required irrigation time by approximately 30%. The shorter advance time results in a better uniformity along the field. Halving the furrow length usually improves the distribution uniformity by between 10 and 15% (Hanson, 2001).

5.7 Computer Models for ASFI Design

A potential improvement to furrow irrigation efficiency and performance is the use of simulation models to predict furrow irrigation performance and assess changes in management variables. A number of models have been developed to simulate surface irrigation systems. Some of these models have been developed into user friendly computer programs with the aim of being used by irrigation practitioners as decision support tools (Hornbuckle et al., 2006). Of these, the most widely used computer programs, that incorporate all the phases of an irrigation are the one dimensional SIRMOD and SRFR. One dimensional models are those in which the relevant variables, such as distance downstream and time, are a function of the primary direction (Strelkoff et al., 2002). Associate Professor Maheshwari from the University of Western Sydney evaluated a range of surface irrigation models, including SIRMOD and SRFR, to predict advance and recession times, run-off and volume balance error using field data of over 100 irrigation events for a range of field conditions. SIRMOD was found to be the most suitable for these field conditions with errors generally being less than 15 percent (Meyer and Bowmer, 2005).

SIRMOD III provides simulation, evaluation and design capabilities for border, basin and furrow irrigation under either continuous or surge flow operations. The simulation of surface irrigation hydraulics at the field level uses either hydrodynamic, zero-inertia or kinematic wave algorithms which are used to obtain an optimal combination of sizing and operational parameters to maximise application efficiency. The evaluation algorithm uses the “two point solution” of the “inverse” problem allowing the infiltration parameters to be computed from the input of advance data. The design algorithms use a standard volume balance procedure (Utah State University, 2006). The simulation routine used in SIRMOD is based on the numerical solution of the Saint-Venant equation, as described by Walker and Skogerboe (1987), for the
conservation of mass and momentum (Hornbuckle et al., 2006). Inputs required for SIRMOD to simulate an irrigation event include infiltration characteristics, hydraulic resistance (Manning’s n), furrow geometry, furrow slope, furrow length, inflow rate and advance cut-off time. The most difficult inputs to determine adequately are the infiltration characteristics and the furrow inflows, which are also the most sensitive inputs in the SIRMOD model (McClymont et al., 1996). Furrow infiltration characteristics are represented in SIRMOD with the Kostiakov-Lewis infiltration equation:

\[ Z = k t^a + f_o t \]

Where \( z \) is the cumulative infiltration (m³/m furrow), \( t \) is the time (min) that water is available for infiltration, \( a \) and \( k \) are fitted parameters and \( f_o \) (m³/min⁻¹/m furrow) is the steady or final infiltration rate (Walker and Skogerboe, 1987).

According to Kruger (1998), the infiltration rates in South Africa (RSA) are generally higher than those found in the United States of America (USA) as a result of the RSA climate being generally dryer and warmer than that of the USA, resulting in different geological and ground forming processes. This causes the range of soil intake families used in SA to become extended compared to the range used in the USA, as illustrated in Figure 5.3, and needs to be considered when determining the soil infiltration characteristics (Kruger, 1998).

![Figure 5.3 Comparison between USA and RSA soil ranges (Kruger, 1998)](image_url)
SIRMOD has a user-friendly interface with graphical outputs providing for easy interpretation of irrigation performance which makes it a useful decision support tool for irrigation designers and managers. Outputs include a detailed advance-recession trajectory, distribution of infiltrated water, volume balance, run-off hydrograph, depth of water flow at the field end, application and requirement efficiencies and distribution uniformities (Raine and Walker, 1998).

Hornbuckle et al. (2006) conducted experiments in the Murrumbidgee Irrigation Area (MIA) in New South Wales and found that the greatest potential for SIRMOD to improve furrow irrigation is by direct usage by irrigators. This involves measuring the furrow inflow and advance characteristics to obtain the infiltration characteristics and then running SIRMOD to determine the optimal management regimes. This requires simple and cost effective methods of determining the inflow and advance characteristics (Hornbuckle et al., 2006). Hornbuckle et al. (2006) found that SIRMOD adequately predicted furrow irrigation for the soil conditions in the MIA, with infiltration volumes predicted by SIRMOD and measured infiltration volumes being highly correlated ($r^2 = 0.9474$) (Hornbuckle et al., 2006). McClymont et al. (1996) conducted an experiment for furrow irrigation of sugarcane in Australia. It was found that SIRMOD under predicted the advance times by an average of 22 percent and the measured infiltration volumes by an average of 16.9 percent. This was attributed to a systematic error within the model which might be able to be removed by applying an appropriate calibration procedure (McClymont et al., 1996). Raine et al. (1997) conducted experiments on surface irrigation in the Burdekin Delta in Australia and found that only small adjustments to the Manning hydraulic resistance were required to improve the accuracy of the SIRMOD predictions, indicating that the advance rates predicted by SIRMOD were similar to the field measured rates for this site. However, as a result of large variations in soil infiltration properties both across the field and throughout the season, model predictions are only as accurate as the input data quality. Therefore, unless the input data is obtained from actual irrigations and includes a measure of field variation, the model should only be used to show trends (Raine et al., 1997).
6. DISCUSSION AND CONCLUSIONS

The literature confirms that higher efficiencies are possible for shorter furrows. Eldeiry et al. (2004) showed, on clay soils in Egypt, that higher application efficiencies are possible for SFI, which is more sensitive to deviations of the flow rate from the optimum flow rate on clay soils. This can, however, be overcome using ASFI as the flow rate can be more accurately controlled, therefore obtaining the high efficiencies that are possible with SFI. It is also possible that this sensitivity is due to the furrow slopes used. Crosby et al. (2000) showed that high distribution uniformities were possible for flow rates of 5 m³h⁻¹ and 10 m³h⁻¹ on loam and sand, which represent a relatively large range of flow rates. Thus, on these soils, flow rate deviations would not have as significant an impact as suggested by Eldeiry et al. (2004) on clay soil. The disadvantages of SFI include difficult mechanical cultivation, water losses in the supply furrow and the system is labour intensive. These problems can be largely eliminated using ASFI. The difficulties associated with mechanised cultivation can be reduced by using long furrows, divided into small sections. The losses in the supply furrow are eliminated with the use of a pipe network. The system also uses minimal labour as it is automatic and does not require labour to divert the flow down each lateral.

The concepts of Austin’s system are promising. However, independent studies showed that the tilt valve and riser system was impractical and was not able to shut off flow completely in the tertiary line. Hence, there was a need to investigate alternate valve options. The three way valves proposed by Fischbach and Goodding (1971) and Humphery and Stacey (1975) are very similar to, and possibly predecessors of, the bladder surge valve. The mechanical surge valve and the bladder surge valve are deemed too expensive for widespread use and it can therefore be assumed that the Fichbach and Goodding (1971) and the Humphery and Stacey (1975) valves would also be too expensive.

The piston valve has been proposed as an alternative to Colin Austin’s tilt valve and riser system. The piston valve shows promise, however, it is still in the embryonic phase of development. The system therefore needs to be refined, with further
development and testing. These developments include possibly eliminating the need for the riser and enabling the system to reset automatically. Part of the project, as discussed in the Project Plan in Chapter 7, will therefore be to implement these valve developments. The piston valve is inexpensive which gives it an economic advantage over the other alternatives discussed.

A potential negative aspect of ASFI is that it is not suited to land with steep gradients. This can sometimes be solved by constructing the furrows perpendicular to the main slope. There will be cases when this will not be possible, however, the majority of land could be irrigated by this method. There are numerous advantages to ASFI as listed in the document. ASFI is relatively inexpensive when compared to a drip or sprinkler system, while at the same time high efficiencies are possible if implemented correctly. It therefore meets the needs of many subsistence farmers who could not previously afford a highly efficient system. The high efficiency and uniformity of the system is due to only small amounts of water applied at a time, which results in little water passing through the root zone and being lost to deep percolation. Not all the surface is wetted, which results in relatively low evaporation losses and improved efficiencies. It is therefore verified that there is a need for short furrow irrigation, which was the main objective of the literature review. The advantages of ASFI over other systems need to be validated. The system will therefore be compared to a drip system, as shown in the Project Plan.

The optimal design of SFI is necessary to obtain an ASFI system which is able to compete with systems such as drip and sprinkler irrigation. It is evident that the system efficiency, as well as the practicality of the system, plays a crucial role in the SFI layout. The optimum efficiency of the system is therefore balanced against factors such as tractor tyre spacing so as to obtain the best system. Computer models are crucial in obtaining the optimum balance of the design considerations for given conditions and will therefore be critical for the development of ASFI as discussed in the project plan. It was concluded that SIRMOD III would be the most suitable simulation model for ASFI. This is due to the extensive usage of the program proving its suitability to a wide range of conditions. Research also shows that this is the most accurate simulation model.
7. PROJECT PROPOSAL

7.1 Introduction

A number of reasons were given in Section 1 for the development of a new irrigation system, known as Short Furrow Irrigation (SFI). To summarise: South Africa is classified as a water scarce and semi-arid country (Perret, 2002; Badenhorst et al., 2002). 10 of the 19 water management areas in South Africa were already stressed in 2000 (DWAF, 2004a). The agriculture sector accounts for approximately 62% of the total water use in South Africa (DWAF, 2004b). Surface irrigation accounts for 90% of irrigation worldwide (ARC, 2003). Typical application efficiencies for regular surface irrigation systems range from 45% to 60% (Ley, 2003). These efficiencies can be improved by using shorter furrow lengths as in short furrow irrigation. Short furrow irrigation is an efficient and low cost means of delivering water to plants (Austin, 2003b). It is, however, labour intensive (ARC, 2003). Therefore, the development of automated short furrow irrigation system could prove valuable. However, the system would require a cheap and simple valve system to automate the distribution of water (Austin, 2003a).

7.2 Problem Statement

The objective of this project is to develop and evaluate a novel, automated system for short furrow irrigation. The system will be assessed by recording the application efficiency, distribution uniformity and coefficient of uniformity as well as the crop yield and the results will be compared to a drip irrigation system as a result of the high efficiencies that are possible with drip irrigation. The suitability of operational characteristics and components will be assessed in a sugarcane production environment. In order to meet the main objectives of the project, the following main tasks will be performed:

- Conduct a theoretical analysis of short furrow irrigation.
- Further development and refinement of the piston valve.
• Design and implement a prototype irrigation system for sugarcane, including furrows, pipe network and a novel, automatic control valve.

• To obtain suitable emitters for the system

• Assess performance of Automated Short Furrow Irrigation including the application efficiency, distribution uniformity, co-efficient of uniformity and crop yield relative to a reference drip irrigation system.

• To compile a report on the above assessment. This report will include developing specific recommendations for application and/or further research and development.

The analysis, design, implementation and assessment of the system can be broken down into three considerations. These are the agronomic, economic and engineering considerations. The agronomic considerations include the practicality of the system, the yields obtained and soil moisture monitoring. The economic considerations take account of how the cost of the system compares to other irrigation systems and the suitability of the system to a range of farmers, from subsistence to commercial farmers. The engineering considerations include the application uniformity as well as the flexibility of the system to various conditions. These three considerations will be examined throughout the progress of the project.

7.3 Project Plan and Methodology

The objectives listed in Section 7.2 are the main tasks that need to be completed. A timescale for the project has been included in the form of a Gantt chart in the APPENDIX. The project has been broken down into a number of phases. The complete processes of the major phases are shown on the Gantt chart, with the other phases being minimised. This allows for easy reading as the Gantt chart fits on one page.

The first phase is the theoretical phase. The first objective in the theoretical phase is to write a project proposal and literature review. This will allow clear objectives for the project to be set and will give a theoretical background to the project as well as showing the need for Automated Short Furrow Irrigation. During this time, the crop
suitability at the test site, Ukulinga Research Farm, will be investigated. This involves obtaining climate data for the area from an ARC weather station on the farm as well as observing the crop grown on neighbouring farms. The piping and emitter materials as well as surge valves will also be researched to assess their suitability to Automated Short Furrow Irrigation. A report on the piping and emitter materials will then be compiled. The proposed farming system will then be determined and reported on. This includes the land preparation processes such as land levelling.

The next phase is the field setup. Firstly the field will be irrigated using sprinklers to obtain the correct soil moisture content for ploughing. The field will then be ploughed and then disked to break up the clods. A GPS survey of the field will then be conducted and a topographical map of the field will be made. This will then be used to assess the levelling options, amount of levelling required, approximate final furrow slope, field size and therefore field setup. The water source will then be tested to determine the maximum flow rate possible for the system which could affect the system design.

The next phase is the prototype valve construction and testing. This will prove if the valve will work or not and what adjustments are needed. The valve tested will be a modification on the Piston valve proposed by Jumman and Mills (2005).

The next phase is the computer simulation phase. This firstly involves practicing on SIRMOD. The soil and infiltration characteristics from an experiment conducted at Mt. Edgecombe will then be used to conduct SIRMOD simulations. A report on tolerances of factors such as flow rate, slope and irrigation time for a required irrigation depth will be compiled to assess. These factors can be altered and the effect of the change can be determined by assessing the application efficiency, requirement efficiency and distribution uniformity. The furrow testing will then be planned according to the guidelines set in the tolerance report.

The next phase is the machinery phase. This involves visiting Cedara Agricultural College to see if there is machinery that could be used for the project. Experts in the field of irrigation will then be contacted to determine the options for levelling, trenching and furrow shapers. The options will include the different types of
machinery available as well as the possibility of using contractors for levelling and trenching. The options will be discussed with the project supervisors to finalise the machinery decisions. A prototype furrow shaper will then be designed and constructed at Ukulinga Research Farm. The shaper will probably have three tines with a ducks foot attachment to make the furrows. The central tine will make the irrigation furrow and the two outer furrows will be used for planting the cane. A press wheel will probably be attached at the back of the implement and used to obtain the desired irrigation furrow shape and to help prevent erosion.

The next phase is the test furrow construction and testing phase. The test furrows will be constructed using the furrow shaper. A furrow slope survey will then take place using markers at set intervals along the furrow. The furrows will then be tested by recording the flow rate, the advance front and the recession front. The field’s infiltration and soils characteristics can then be determined. The field test data will then be analysed and the optimum combination of furrow slope, furrow length and flow rate will be obtained. The furrow design framework will then be finalised.

The next phase is the design phase, which involves designing the furrow and drip layout, the pipe layout and the piston valve. The first step in the design phase is to determine the field set up. As a result of the ASFI system being compared to a comparative drip system, the field needs to be laid out so as to obtain statistically sound results. Biometrists from either UKZN or SASRI will be spoken to in this regard. Both systems need to be optimally set up and must not impede the other system. The furrow layout design will integrate the design considerations discussed in the literature review. The field levelling guidelines will then be set. Using this information, the furrow layout will then be designed using SIRMOD. The drip irrigation layout also needs to be designed. Once the furrow layout is known, the pipe and emitter layout can be designed. The required pipe size can be determined which will result in the required valve size being obtained. The valve can then be designed taking into consideration the adjustments needed to the prototype valve.

The next phase is the soil correction phase. The soil characteristics of the field need to be obtained. A soil survey was done on the field by Moodley (2001), however, another soil survey will be done on the field so as to obtain information on the soil
such as salinity and sodicity. Soil samples will be taken in various portions in the field. The soil and water samples will then be analysed at SASRI and the fertilizers and lime that are required for the soil correction will be obtained and will be disked into the soil at the appropriate time as shown on the Gantt chart in the APPENDIX.

The next phase is the valve construction and testing phase. However, before this phase can begin the piping and emitter materials and the valve components must be purchased, as well as the comparative drip system components. The valves will then be constructed and tested at the Ukulinga Research Farm workshop, which is equipped with lathes, milling machines as well as all the other equipment required.

The next phase is the implementation phase. Firstly, the field layout will be setup, with pegs marking the plots. The land will then be levelled, ensuring each plot is levelled according to the levelling guidelines as determined previously. The Trimble GPS will then be used to survey the field and a topographical map will made to ensure that the land levelling is according to the design. The seed cane will then be obtained and the field will be ridged with the furrow shaper. The furrow shaper will make the ridges the length of the field, for both the plots of ASFI and drip irrigation. In the drip irrigation plots, the dripper tape will be installed in the central furrow and then covered over, probably by hand. The central furrows will probably be spaced 1.8m apart and will comply with the tractor wheel spacing. The appropriate trenches will then be dug to install the mainline and laterals for both the ASFI and drip irrigation. Once the pipes and the dripper tape have been laid and the emitters attached to the ASFI system, the valve will be setup and attached to the system. Both the ASFI and drip irrigation system will then be tested and adjustments will possibly be made. The crop will then be planted with the help of personal from SASRI. The monitoring devices such as tensiometers will then be installed. The furrows may need to be maintained after the crop has been planted.

The next phase is the irrigation and testing phase. These tests will likely include obtaining the distribution uniformity, application efficiency, plant measurements and light interception. The crop will be irrigated and testing will take place for 12 months. Pesticides and herbicides will need to be applied. Real time climate data will be required throughout the 12 months. This will either be done by obtaining data from
the ARC weather station or by setting up a weather station on site. Ideally, in this region, an 18 month ratoon is used, however, due to the time restrictions on the MSc project, 12 months will be used. This will not be problematic as the yield will be compared to the drip system. The irrigation scheduling still needs to be decided upon, but will probably aim at operating both systems optimally while trying to keep the water application relatively equal for each system.

The next phase is the harvest and reestablishment phase. The crop will either be harvested as trash or burnt cane. If the cane is burnt, this will need to be done just before the crop is harvested. The cane will then be weighed and the sucrose content measured, probably at SASRI, with the yield of the Short Furrow system being compared to the drip system.

The next phase is the report or assessment phase. A number of interim performance reports will be completed throughout the construction and testing phase and the implementation phase. On the completion the implementation phase, a harvesting and re-establishment report will be compiled. The re-establishment report will show the extent to which the harvesting process has negatively impacted the field layout. This is important as it will determine the labour requirements and the impact of re-establishment on a yearly basis. This will be followed by the final report being written and submitted, with recommendations given.

7.4 Equipment and Resources

- Land (Ukulinga Research Farm).
- Soil moisture sensors and monitoring devices, possibly tensiometers from UKZN to obtain flow depths to calculate distribution uniformity and application efficiency. Other monitoring devices that could be used are wetting front detectors and growth stations.
- Computer and GPS. The Trimble Roving GPS, available from UKZN, will be used to survey the field.
- Tractor, plough, levelling implement, disk, a herbicide sprayer, a trencher, and furrow shaper. The tractor, plough, disk and herbicide sprayer are available at
the Ukulinga Research Farm. The furrow shaper will be made at Ukulinga Research Farm. The leveller will either be a land plain or grader. The trencher will probably be a Bobcat with a ditch-witch attached.

- Valve components and manufacturing machinery. The valve will mainly be made out of PVC piping and fittings. The manufacturing machinery will be a lathe, milling machine as well as other, smaller machinery such as a drill. Springs for the piston valve will be made by local spring manufacturers.
- Piping and pipe accessories. A number of piping materials, including T-tape PE lay-flat, Colin Austin’s pipe and LDPE, have been suggested. These may need to be imported to South Africa if the local suppliers do not stock the item.
- A comparative drip system will be used.
- A contact head tank or pressure reducer and regulator. This will be required for both systems due to the high pressure in the system.
- A weighing device will be used to weigh the cut cane so as to compare the Short Furrow and Bucket Drip crop yields.

### 7.5 Health, Safety and Ethical Considerations

The first health and safety consideration is fire. Ukulinga research farm is equipped with the necessary fire fighting equipment. With regard to an intentional fire, it may be necessary to alert Oribi airport as the field is situated in close proximity to the airport. The smoke from the fire could also prove to be a health risk. The next health and safety consideration is with regards to harvesting and other labour requirements. For this, the correct protective clothing, shoes and eyewear must be worn. Care must be taken, especially with regard to harvesting, as sharp objects are used. The next consideration is related to the tractor and implements. Earplugs must be worn by the driver. The driver must also make certain not to place anyone in danger and must follow the correct safety procedures. Fertilizers, pesticides and herbicides can also pose a risk. It is important to make sure that these will not have any negative impact on the surrounding environment. It is important to note that this field is not near a river or stream which the pesticides and herbicides could impact negatively.
7.6 Budget

The budget for the project is as represented in Table 7.1.

Table 7.1 Project budget.

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8. REFERENCES


Lecler, N. 2005a. Personal communication. SASRI, Durban, RSA, 4 May 2005


Lecler, N. 2006. Personal communication. SASRI, Durban, RSA, 6 April 2006


Utah State University. 2006. SIRMOD III. [Internet]. Biological and Irrigation Engineering Department, Utah State University, Utah, USA.


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**APPENDIX**