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DESIGN AND EVALUATION OF AN AUTOMATED SHORT FURROW IRRIGATION SYSTEM

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ABSTRACT Automated short furrow irrigation (ASFI) is a prototype irrigation system that has the potential to be robust and relatively low cost, with highly effective and efficient water use. ASFI also has low energy requirements compared to other irrigation systems. The aim of this project was to develop, implement and evaluate a suitable ASFI system and to compare the system to a reference sub-surface drip irrigation (SSDI) system with sugarcane as the test crop. This process resulted in the development of a "boot and piston valve", which was used to automatically control the flow between specific plots. The valve was then used in a trial of the ASFI system at the University of KwaZulu-Natal's Ukulinga research farm. The testing and evaluation included irrigation uniformity tests and the crop yields. The results indicate that the ASFI performance in terms of distribution uniformity and yield data for the Ukulinga trial could be described as "similar to" SSDI and that the ASFI was considerably more cost effective than the SSDI system in terms of operating and fixed costs per hectare. It is therefore believed that the ASFI system meets the required objectives of the project in that it is robust, low cost (both operating and fixed) and able to supply water efficiently and effectively.

Keywords: short furrow irrigation irrigation, sugarcane, economics, energy conservation, water conservation, South Africa.

INTRODUCTION Farmers, worldwide, are facing increasing pressure to use water and energy more effectively in order to sustain profits and increase yields. In South Africa the demand for water in the year 2000 was estimated to exceed supply in 10 of the 19 water management areas with irrigation estimated to use 62% of the total water use (DWAF, 2004). In addition, the capacity to generate electricity in South Africa is currently battling to meet the demands for energy and the cost of electricity has recently been approved by regulators to increase by approximately 25% per year for the next 3 years. There is thus considerable pressure to utilise both water and energy more efficiently in South Africa.

This papers contains an overview of the development and evaluation of a novel Automated Short Furrow Irrigation system (ASFI). The ASFI system is aimed at providing farmers with a robust, relatively low cost but highly effective option to facilitate precision irrigation.

DESCRIPTION OF THE ASFI SYSTEM The novelty of the ASFI system begins at the field edge. From the field edge water is conveyed in a sub-main pipe consisting of low class polyethylene or PVC piping. Polyethylene laterals join into the sub-main via an automated "boot and piston" valve. The laterals (running downhill) convey water to emitters typically made of 10 mm diameter lengths of polypipe, spaced at a distance to suit the row spacing of the crop and to permit controlled trafficking where necessary. The emitters convey water into short furrows. Figure 1 contains a schematic diagram of the ASFI system. The furrows are approximately 30 m in length and are typically "U‟ shaped, with a top width of approximately 0.15 m and a depth of 0.15 m. The ends of the furrows are blocked and coincide/intersect with the position of the next downstream lateral. The furrows should be land-planed so that they are relatively smooth. In the Ukulinga trial, sugarcane was planted on either side of the short furrows in a tramline arrangement, so that controlled-trafficking could take place, i.e. 0.6 m between cane plants and 1.8 m between furrows.

When an irrigation application is initiated the most upstream boot and piston valve allows water into the most upstream lateral and, via the emitters, into the first set of 24 short furrows. The boot and piston valve also prevents flow to the remaining downstream laterals. After a predetermined time, the valve automatically stops the flow to the first set of furrows and allows water to flow to the next downstream lateral and set of furrows. This sequence continues automatically until a whole field has been irrigated. Typically all the lateral and sub-main piping would be buried, so that only the emitters are visible and trafficking can take place in the field without disturbing the irrigation system and *vice versa*.

METHODOLOGY The ASFI system was developed and installed in a trial at the University of KwaZulu-Natal Ukulinga research farm near Pietermaritzburg in South Africa. Full details of the study are contained in Mills (2009). The engineering, economic, agronomic and practical performance characteristics of the ASFI system, were compared by Mills (2009) to Sub-Surface Drip Irrigation (SSDI) by taking measurements and keeping records of sugarcane yields, water use, soil water levels, system overhead and operating costs and assessments of the uniformity of irrigation water applications. The two treatments used in the trial, namely ASFI and SSDI, were arranged in a randomised block design with four replications on a total trial area of 0.5 hectares. SSDI was included as a treatment because it is often considered to be the benchmark in terms of irrigation system performance. In the plant crop, both treatments received nearly identical amounts of water. The irrigation scheduling tool, SAsched (Lecler, 2004) was used to schedule the irrigation water applications using weather data from a nearby automatic weather station.

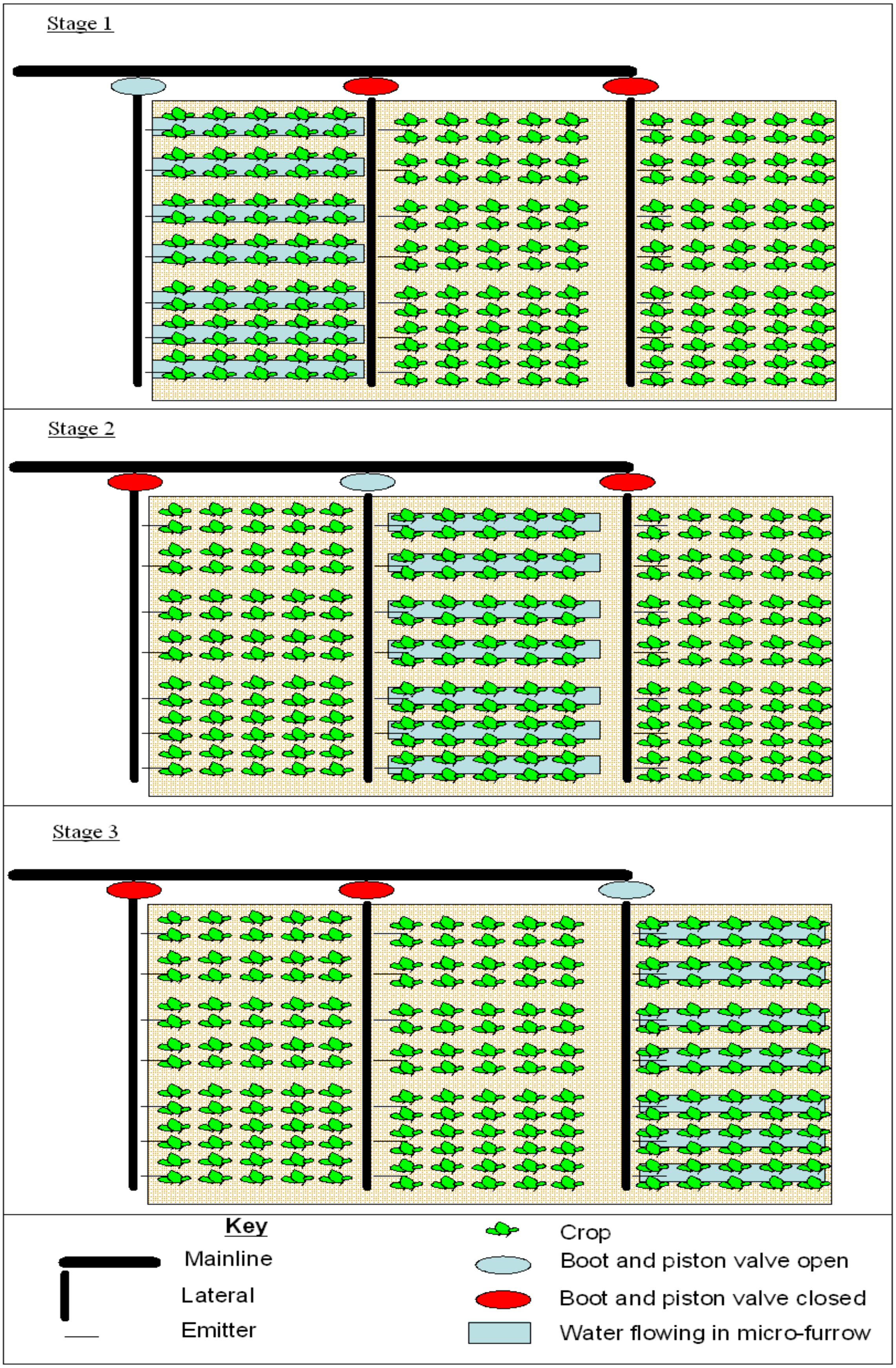

Figure 1. Stages of irrigating using the ASFI system (after Lecler, 2006)

EVALUATION OF THE ASFI SYSTEM The main focus of the engineering evaluations was to evaluate the distribution uniformity of applied water for a specified depth of application, and investigate the factors affecting the uniformity of water applications. In addition, system flexibility and ease of management were assessed. The ability to control the depth and timing of irrigation water applications is important because, when the amount of water applied per irrigation application is not well matched to soil water holding characteristics, performance will be poor because of either:

- excessive crop stress if the soil is depleted to a level coinciding with larger irrigation applications, or
- inefficient irrigation with excessive runoff and deep percolation losses and associated drainage problems, if large irrigation applications are applied at relatively low soil water depletion levels to avoid excessive drying of the soil and crop water stress.

Both of these are typical problems with conventional furrow irrigation, especially on soils with low water holding capacities.

Infield measurements of various surface irrigation performance parameters were undertaken based on procedures described in Koegelenberg and Breedt (2003). The data from the field measurements were then used together with a surface irrigation simulation programme, SIRMOD III, to assess the performance of the furrows in terms of low quarter distribution uniformities, DU_{lq} (Walker, 2004). The DU_{lq} for the six furrows evaluated in the trial ranged from 71% to 81% for water application depths of only 10 mm. These DU_{lq} values are considered to be very good even though the slopes at the trial site (1:40) were steeper than optimum, and many of the system parameters were not optimised because of constraints related to the prototype system. Many of these initial constraints have since been overcome as the developers have grown in knowledge of the system.

Theoretical simulations undertaken using SIRMOD III have since shown that DU_{lq} values above 85% can be obtained for a range of slopes and soil types, and that the DU_{lq} values are relatively insensitive to variations in slope, soil characteristics, and flow rates compared with typical (long) furrow irrigation. For most soils optimum furrow lengths are between 20 m and 40 m; however, for heavy clay soils, the furrow lengths can be considerably extended to > 200 m, with a concurrent reduction in system cost. The application depth of 10 mm per irrigation water application means that even poor soils with low water holding capacities can be effectively irrigated without excessive losses or crop stress. Because only a small portion of the total field surface area is wetted, losses due to evaporation from the soil surface are relatively low, especially when compared with overhead sprinkler/centre pivot irrigation systems.

The ASFI system was considered to be easy to manage, highly flexible from an operational perspective and had minimal maintenance requirements. A fertigation system was developed to apply nutrients. Apart from refinements to the boot and piston valve, no system problems or deterioration in components, for example clogging of emitters, has been observed. Although the furrows used in ASFI are short, the configuration of the piping and emitters is such that the furrows and piping do not interfere with mechanised field operations and controlled trafficking is encouraged. High machine operating efficiencies, associated with long in-field travel paths, are attainable.

Substantially less energy is used for ASFI compared to other irrigation systems. For example, ASFI requires a pressure of only 70 kPa at the field edge compared to approximately 150 kPa for traditional drip irrigation (considered to be a relatively low pressure system) and 250 kPa for centre pivot systems. Reduced pressure and water losses are directly related to reduced energy requirements and operating costs. Preliminary analyses using the Irriecon V2 economic analysis tool (Armitage *et al*., 2008) and data from, *inter alia*, the Ukulinga trial, indicate that there will be at least a 40% cost saving for ASFI relative to SSDI, for similar or better crop yields and equivalent water usage.

In the Ukulinga trial plots, the average cane yield attained using ASFI was 129t/ha for a 12 month plant crop. In the same trial, the average yield for cane irrigated using SSDI was 123 t/ha. Nearly identical amounts of water were applied to both the SSDI and ASFI plots. The soils at the trial site are shallow Westleigh and Mispah types, only about 0.6m deep. Typical cane yields for a 12 month irrigated crop in the same region are less than 90 t/ha, on much better soils.

Sugarcane agriculturalists and irrigation practitioners have commented favourably on the potential for ASFI during field days held at the Ukulinga trial site. Agriculturalists were particularly impressed with the simplicity of ASF, compared to SSDI and the impressive cane yields.

CONCLUSIONS ASFI may offer the desired combination of low cost, high efficiency and easy management, needed for precision irrigation. Similarly to SSDI, small amounts of water can be applied frequently with ASFI, with a high degree of flexibility and with relatively high distribution uniformities. This facilitates effective irrigation under a wide range of soil, crop and climate conditions. However, dissimilarly to SSDI, ASFI is a relatively low cost and simple form of irrigation. The wider community would benefit from ASFI facilitating efficient production utilising less water, especially where SSDI is not viable for financial or other reasons. This is vitally important given limited water resources in most countries and the increasing competition for them, particularly in South Africa.

A key aspect of the system is the boot and piston valve which allows the use of buried piping and provides good flow control and renders the system relatively robust without requiring electronics, electric power and associated communication systems. Although the furrows are short, machinery run lengths can be long, resulting in high machinery field operating efficiencies. The layout of the system also encourages controlled trafficking and associated system benefits.

While ASFI has many potential advantages, the system still needs to be evaluated under commercial farming conditions. The knowledge and systems required to implement a commercial scale system trial have been developed during this project.

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