Automated Short Furrow: A System for Precision Irrigation

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ABSTRACT

Farmers, worldwide, are facing increasing pressure to utilise resources, particularly water, more effectively. This paper is about a prototype irrigation system aimed at providing farmers with a relatively simple and low cost method to facilitate precision irrigation. The irrigation system, named 'automated short furrow' (ASF) uses substantially less energy than conventional systems requiring a pressure of only 70 kPa at the field edge. Water is applied sequentially to sets of relatively small and short furrows, typically approximately 30 m in length. By automating the sequencing of the short furrow sets, and controlling the flow of water into the furrows, operational and labour overheads are minimal and system performance is enhanced. With the relatively short furrows, the distribution uniformity of applied water is very high under a wide range of conditions, even when small amounts of water (<15 mm) are applied per application. Since only a very small proportion of the soil surface is wetted, there are relatively low evaporation losses from the wet soil surface. The configuration of the system piping and emitters is such that, although the irrigation furrows are short, relatively high machine operating efficiencies are possible and controlled trafficking is encouraged. In a field trial, the average cane yield obtained using the prototype irrigation system was 129 t/ha for a 12 month plant crop. In the same trial the average cane yield for cane irrigated using sub-surface drip irrigation was 123 t/ha for a nearly identical amount of water.

Keywords: irrigation, sugarcane, economics, energy conservation, water conservation, efficiency

INTRODUCTION

Farmers, worldwide, are facing increasing pressure to use water and energy more effectively whilst boosting and sustaining profits. Unfortunately, however, irrigation efficiencies are often misunderstood and quoted somewhat casually without losses being measured or defined accurately. All this contributes to a situation where there is much confusion and misconception regarding irrigation systems performance and options to become more precise (Clemmens, 2000). Many issues surrounding irrigation efficiency and performance could be addressed if greater emphasis was placed on the fates of applied water at the field, farm and watershed scales, especially in the development of improved irrigation systems and associated management strategies.

Thus, before describing the development and trial of a novel irrigation system, named 'automated short furrow' (ASF), a perspective of irrigation systems performance is provided in this paper. This includes an explanation of the water balance and how irrigation uniformity and other characteristics of irrigation systems can impact water management options and performance. The ASF system is aimed at providing farmers with a robust, relatively low cost but highly effective option to facilitate precision irrigation.

IRRIGATION PERFORMANCE FUNDAMENTALS

Any consideration of irrigation systems performance should consider the water balance, the uniformity of irrigation water applications and the management of the water applications.

The water balance

In Figure 1 the various fractions of water applied which are involved in defining irrigation performance at the field level are illustrated.

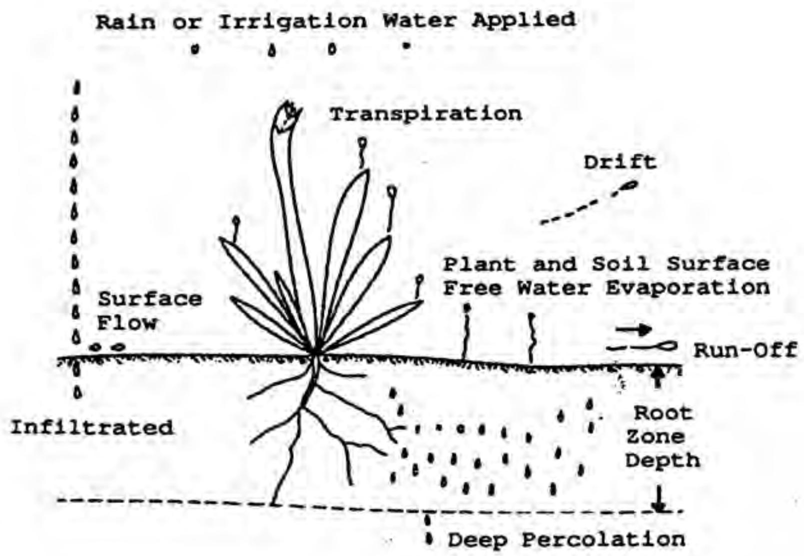

Figure 1 Various fates of water in the soil-plant-atmosphere system (ASCE, 1978)

The components of the water balance can be deemed, amongst other things, to be, 'beneficial', 'non-beneficial' and 'consumed' or 'non-consumed' (Burt *et al.*, 1997). The aim of improved and more precise irrigation is to reduce as far as possible, the non-beneficial components, especially the consumed, non-beneficial components such as evaporation from the soil surface. Runoff and excessive deep percolation losses (i.e. in excess of leaching requirements) from a field are non-beneficial but not consumed. They return to the system and are potentially available for other users downstream. However, this "return flow" water is often of much poorer quality than the original irrigation water and valuable nutrients and top-soil may be lost in runoff and deep percolation. Energy and finances used to apply irrigation water which is not used beneficially are also wasted.

Uniformity of irrigation water applications

Irrigation uniformity refers to the evenness of irrigation water applications. It can have significant effects on irrigation performance because even if the timing and average magnitude of water applications is well matched to crop water demand and soil water storage capacity, non-uniformity results in some areas receiving relatively higher water applications and other areas receiving relatively lower water applications. Excessive runoff and deep percolation losses are likely on the areas receiving the relatively higher water applications and reductions in crop yield can be expected on the areas receiving the relatively lower water applications. The traditional approach to dealing with low uniformities is to increase water applications. However, reductions in crop yields can also occur on the areas receiving excess water and thus the benefits of such an approach, especially on poorly drained fields are doubtful. Irrigation practitioners should rather aim at improving the uniformity of water applications.

Water management

Managers of irrigation systems, by the appropriateness of their actions and/or instructions often contribute the most to poor or good irrigation systems performance. Important performance characteristics of an irrigation system which impact on how easily or well a system is managed are the inherent flexibility of the irrigation system in terms of the amount of water which can be applied at each irrigation application, how frequently/flexibly the water can be applied, the associated labour requirements and the rate at which water is applied.

Thus, in addition to cost effectiveness and robustness, characteristics of an irrigation system capable of precision irrigation include:

- a great degree of operational flexibility,
- a water application method which results in reduced non-beneficial components of the water balance, such as evaporation from the soil surface, excessive runoff and/or deep percolation, and
- a high degree of uniformity in the spatial extent of water applications as non-uniformity can seldom be effectively corrected by simply adjusting water application amounts, as is often presumed.

Whilst many irrigation systems fulfil many of these ‘precision irrigation’ requirements, there are also numerous issues. For example, the cost and maintenance requirements of drip irrigation are often prohibitive; runoff losses and high evaporation losses from the soil surface under centre pivots can be problematic; uniformity and energy demands of ‘big guns’ often renders them ineffective; traditional ‘long’ furrow irrigation systems often have poor uniformity and matching the frequency and amount of water applied to crop water requirements can be problematic, especially on shallow soils. Thus, there is still great potential to improve irrigation systems and motivation to develop and assess novel systems such as automated short furrow irrigation.

AUTOMATED SHORT FURROW IRRIGATION

A novel system to implement precision irrigation was developed and installed in a trial at the University of KwaZulu-Natal Ukulinga research farm near Pietermaritzburg in South Africa. The engineering, economic, agronomic and practical performance characteristics of the irrigation system, named “automated short furrow” (ASF) were compared to sub-surface drip (SSD) irrigation by taking measurements and keeping records of sugarcane yields, water use, soil water energy levels, system overhead and operating costs and assessments of the uniformity of irrigation water applications. The two treatments used in the trial, namely ASF irrigation and SSD irrigation, were arranged in a randomised block design with four replications on a total trial area of 0.5 hectares. SSD 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.

Description of the ASF irrigation system

The novelty of the ASF 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 a ‘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. The emitters convey water into short furrows. 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 approximately 40 minutes, the 'boot 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*.

Evaluation of the ASF 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 stressing 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 ASF 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 ASF 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 ASF compared to other irrigation systems. For example, ASF 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 ASF relative to SSD, for similar or better crop yields and equivalent water usage.

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

In the Ukulinga trial plots, the average cane yield attained using ASF was 129t/ha for a 12 month plant crop. In the same trial, the average yield for cane irrigated using sub-surface drip irrigation (SSD) was 123 t/ha. Nearly identical amounts of water were applied to both the SSD and ASF 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.

CONCLUSIONS

ASF may offer the desired combination of low cost, high efficiency and easy management, needed for precision irrigation. Similarly to SSD, small amounts of water can be applied frequently with ASF, 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 SSD, ASF is a relatively low cost and simple form of irrigation. The wider community would benefit from ASF facilitating efficient production utilising less water, especially where SSD 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 Australia and in South Africa.

A key aspect of the system is the boot and piston valve which allows the use of buried piping 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 ASF 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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