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THE EFFECT OF SLOPE, FURROW LENGTH AND FLOW RATE ON CANE AND SUGAR YIELD USING FURROW IRRIGATION.

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ABSTRACT

Furrow irrigation is the most common method of applying water to sugarcane at Macdom Sugarcane Estate in Chisumbanje, Zimbabwe. The plantation is facing problems in irrigation water management. The study was conducted in Macdom Sugar Estate to evaluate the effect of slope, furrow length and flow rate on cane and sugar yield. A split-split plot design, with three treatments and three levels; 0.06, 0.08 and 0.1% slope, 100, 200 and 300 m furrow length and 0.8, 1.2 and 3 l/s flow rate was conducted. Cane and sugar yields in the study were 9.07 to 12.86 t/ha/month and 0.83 to 1.49 t/ha/month, respectively. Cane and sugar yields were not significantly affected by slope and furrow length whereas, flow rate had a significant effect on both cane and sugar yield. The variation of means due to the interaction effects of slope, furrow length and flow rate were found to be significant ($p<0.05$) on cane yield. It can be concluded that 300 m furrow length and 3 l/s flow, which gave 12.860t/ha/month cane yield with the slope 0.08% is better for sugar production at Macdom Sugarcane Estate in Chipinge District, Manicaland Province Zimbabwe. A combination of 300m furrow length at 0.08% slope and 3 l/s flow rate can be recommended. This combination had high irrigation performances as well as saving water compared to other combinations.

Keywords: Furrow irrigation, performance indices, cane and sugar yield.

INTRODUCTION

Background of the study

The main factors that impact on the performance of furrow irrigation can be categorised as design, soil and water management variables. Design variables include the longitudinal slope of the field which affects both the rate of advance and recession and the length of the furrow which determines the flow rate required. The infiltration characteristics of a soil determine the rate of infiltration of water into the soil and hence control both the rate of advance and recession of water down the furrow. The depth of application, furrow flow rate and time to cutoff the irrigation are management variables. For most irrigators, time to cutoff is the only quantity that can be varied to achieve a desired level of irrigation performance (Raine & Smith, 2007), whereas the inflow rate can be a limiting factor to reach the desired level.

Increasing the volume of stream flow is another way of attaining more uniform irrigation on long furrows, (Walker, 2003). A second approach is to increase intake opportunity time at the lower quarter of the furrow by encouraging ponding by blocking the furrow end. Eldeiry et al., (2005), found that furrow length and inflow rates are the main management and design parameters affecting application efficiency in clayey soil.

The infiltrated volume at any point within a furrow is a function of the opportunity time and is therefore sensitive to the infiltration rates at all locations upstream of that point (Gillies et al., 2011). In principle, furrow irrigation is said to have attained high application efficiencies when the infiltrated depth from the inlet to the furrow end is almost uniform. For this condition to be realised, the stream flow and opportunity time during irrigation should be about the same along the furrow length. Practically this is not possible given that irrigation water begins to infiltrate at the inlet and if the stream size is small and the slope is almost flat deep percolation results at the top end of the furrow.

To achieve the desired depth of application and uniformity, irrigators tend to increase the application times often leading to deep percolation at the upstream and runoff at the downstream end. Deep percolation losses are also prevalent in highly permeable soils under surface irrigation systems, (Koech, 2013). Shorter application times may reduce the risk of deep percolation and excessive runoff but may also lead to insufficient water at the downstream end. Infiltration variability in surface systems thus presents probably the biggest challenge to both designers and irrigators and significantly reduces irrigation water use efficiency, (Gillies 2010).

For long term sustainability of an irrigation system, improvements in the performance of current water application and on farm water management practices seem to be more necessary than any other practice. To increase the sustainability of irrigated agriculture, an important aspect that has been considered in several studies is to design efficient irrigation systems at the farm level (Hsiao et al., 2007). Irrigation systems improvement requires the consideration of the factors influencing the hydraulic processes, water infiltration and the uniformity of water application to the entire field. The consideration of all these aspects makes irrigation management a complex decision making and field practice process. Playan and Mateos (2006), reported that in general all irrigation systems can attain approximately the same level of efficiency, when they are well designed and appropriately selected for the specific condition, due to that irrigation is site

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specific. However, differences among irrigation systems appear in many areas as a consequence of design, management and maintenance.

Worldwide, sugarcane is irrigated using furrow, overhead and drip irrigation methods. Furrow irrigation is the most common method of irrigating sugarcane in Zimbabwe. Macdom Sugarcane Plantation in Chisumbanje has been using furrow irrigation method since its establishment in 2008, but there is little quantitative information about the field performance of irrigation systems except the work by Mark (2015). The field layout consists of 350 m long furrows length on one side of feeder canals at 0.05% slope. This length affects the tillage and harvesting efficiency. The use of flexible gated pipes was introduced at the estate in 2014 and irrigators are finding it hard to establish the optimum design and management parameters such as; furrow length, slope and geometry, inflow rate and cutoff time.

OBJECTIVES

Broad Objective

The main aim of the study was to determine the effect of design and management parameters (slope, furrow length and flow rate) on cane and sugar yield using layflat flexible gated pipes furrow irrigation.

Specific Objectives

i. To determine the effect of slope, furrow length and flow rate on cane and sugar yield.

ii. To come up with the optimum combination of design and management parameters,

MATERIALS AND METHODS

Description of the Study Area

The study was conducted at Macdom Investments Estate in Chisumbanje, Manicaland, Zimbabwe (20051`09.04``S, 032014`55.58``). The study was carried out from August 2015 to September 2016. The estate is 5390 hectares and the study was carried out in Section C, which is 400 hectares. The area receives unimodal rainfall stretching from December to March and the dry season is from April to early December. Chisumbanje receives an average of 600 mm annually. The average maximum and minimum temperatures are 37^0C and 23^0C respectively. The soil (Chisumbanje 3B soil) is a dark grey to black vertic soil (clay content 60-75%) overlying weathered basalt, with soil depth varying from moderately shallow to moderately deep (50-100cm), (Bechtel, 1984). The high clay content of the basalt results in a high water retention of 210mm/m. Infiltration rates into dry cracked soil surface are extremely high (400mm/hour),

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but rates drop rapidly (1mm/hour) as the surface soils swell and seal the cracks (Bechtel, 1984). The soil has a wide range of phosphate levels combined with a high phosphate fixation capacity. The site has been selected as a representative of the dry land areas in the low veld part of the country, as it has vertisols which have very low infiltration rates that needs good irrigation management.

Field Layout and Experimental Setting

Site selection

The slopes in, cane fields of Chisumbanje Sugar Estate are categorised as flat (0 to 0.05%), mild (0.05 to 0.1%) and steep (>0.10%) slopes. Three fields representing slope variations of each category in the estate were selected.

Land levelling and tillage operation

The average longitudinal and lateral slopes were 0.5 and 0.6%, respectively. Land leveling was carried out using a GPS assisted receiver scraper in order to modify the lateral slope to the desired slopes.

After harrowing, a 30 m x 30 m grid survey was carried out and the results were transferred into computer software (Opti-surface) that optimises the cut and fill soil volumes and minimises not only costs, but also the risk of 'scalping' into the subsoil. Land leveling was carried out using a 510 HP, 4WD articulated tractors towing a single 15.3 m^3 laser controlled ejector scrapers.

Land preparation consisted of sub soiling, harrowing, disc ploughing and bed forming were carried out and furrows were prepared using bed former ploughs spaced 1.8 metres. The furrow was trapezoidal in shape at the beginning of the season and gradually changed to a parabolic shape with use. After bed formation the slope of furrows was checked using line level at 10 m interval. Cane setts were planted end-to-end in the furrow bottom using a sugarcane planter at two lines per bed at 0.8m spacing.

Experimental set up

In order to examine water distribution uniformity along the outlets of gated pipes, each of the selected fields were divided into three; upstream, middle and downstream reaches based on their proximity from the inlet box of the pipe. From each compartment, one irrigation set was selected to conduct the measurement. An irrigation set comprised of 30 outlets on one side of the pipe and 20 were opened at a time while the remaining 10 were used for maintaining uniform flow and pressure throughout the measurement. The outlets were numbered from one to twenty starting

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from the guider (guider is a clamp used as a check dam at each irrigation set located at downstream of the pipe) to the upstream.

Field C6, which is 600 m by 300 m with an average longitudinal and lateral slope of 0.035 and 0.05%, respectively was selected for the study. The field was divided into six equal sized plots of 100 m by 300 m. These plots were randomly assigned for the design slopes. Each plot was separately levelled as per the required laterals slopes for each replication. Each plot was divided into three sets consisting of fifteen furrows spaced at 1.8 m apart. Furrow length was randomly assigned to each furrow set. Each furrow set was also divided into three sub sets consisting of five furrows each. Flow rate treatments were assigned to the sub sets randomly. The middle three furrows were used for monitoring irrigation events, with outer ones acting as buffers.

Experimental design and treatments

The experimental treatments were slope, furrow length and flow rate. Each treatment had three levels with two replications for the main plot factor (slope). The treatment levels were 0.06, 0.08, 0.1% furrow slope, 100, 200, 300 m furrow length and 0.8, 1.2, 3 l/s flow rate. The experiment was designed as split-split plot arrangement, where slopes constituted the main plot factor, furrow length constituted the sub-plot factor and flow rates constituted the sub-sub-plot factors.

Data Collection

This study was conducted from August 2015 to September 2016 at Macdom Sugarcane Estate. Cane variety, ZN10, planted on 30th September, 2015, was used during the determination of the effect of slope, furrow length and flow rate on cane and sugar yield. Soil moisture, stalk diameter and height, juice brix and % pol data were collected.

Soil moisture determination

Soil moisture determination was done by taking soil samples before an irrigation event, at 25 m interval along the furrow length from each plot at two depths, 0-30 cm and 30-60 cm, using soil auger. Soil moisture content was determined using the gravimetric method.

The volumetric moisture content (θv) was computed by multiplying the dry weight soil moisture fraction (W) by bulk density of the soil in gm/cm^3 (ρb) and divided by specific weight of water (ρw).

The allowable depletion of the soil moisture was 0.5 of the total available moisture in the soil. The irrigation scheduling model, Irrigweb was used to estimate the next date of an irrigation event.

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Assessment of Cane and Sugar yield

Destructive cane sampling was carried out, 11 months after planting and the following cane and sugar yield parameters were determined:

Stalk height and diameter were determined from twenty randomly selected millable stalks from the middle row by measuring the length from the soil surface to the top most visible dewlap (TVD) following the procedure described by Clements (1980). Diameter of stalk was measured using a vernier caliper at three cane positions (top, middle and bottom) from 20 millable stalks on each sampling spots. The millable stalks were recorded at harvest time from the sampling spots by counting the number of millable stalks per plot. Cane yield was determined by weighing 20 millable stalks from sampling spots of 18.0 m^2. Cane yield was calculated using the equation by Abdel-Wahab (2005).

$$\textbf{Cane yield (ton/ha)} = (N \times W \times A{-}1 \times 10\,000)/1\,000$$

where;

N = Number of millable stalks per plot

W = Average weight of millable stalks in kg

A = Plot area (A=1.8*10) in m^2

The juice brix, i.e. the total solids present in the juice expressed as a percentage was measured using a refractometer reading from crushed juice in twenty millable stalks. The per cent pol is an apparent sucrose content of a sugar product determined by direct or single polarisation. The per cent pol was determined by a means of a polarimeter. Purity (%), which refers to the percentage of sucrose present in the total solid content of the juice was calculated using equation (ICUMSA, 1994).

$$\textbf{Purity (\%)} = (\text{Pol \%} - \text{Brix \%}) \times 100$$

Estimated recoverable sucrose refers to the total recoverable sugar percentage in the cane. This was calculated as described by Berg (1972) and (ICUMSA, 1994) using the equation:

$$\textbf{ERS (\%)} = [\text{Pol \%} - (\text{Brix\%} - \text{Pol \%})\ 0.61]\ 0.75$$

where;

ERS = Estimated Recoverable Sucrose

0.61 = non-sugar factor, representing the amount of sucrose lost in final process

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0.75 = cane factor, representing the correlation factor between theoretical yields of molasses mixed juice and primary juice for the same variety and the same cut of cane determined by milling test

Sugar yield is a function of both sucrose accumulation and vegetative growth (cane yield) (Sundara, 2000). It was estimated as the product of cane yield per hectare and average estimated recoverable sucrose content (%) of 20 millable canes taken from the sampling spots using the equation below (Yusof, et al., 2000).

Sugar yield (t/ha) = [Cane Yield (t/ha) x ERS (%)] /100

Method of Data Analysis

The data were analysed using Genstat version 12 and the mean separation was done using ANOVA at 5% significance level.

RESULTS

Effect of Treatment on Cane and Sugar Yield

Cane yield

The mean cane yields obtained were 10.491, 10.667 and 10.989 t/ha/month for 0.06, 0.08 and 0.1% slopes, 10.47, 11.21 and 11.88 t/ha/month for 100, 200 and 300 m furrow length and 10.003, 10.737 and 11.407 t/ha/month for 0.8, 1.2 and 3l/s flow rates, respectively. The analysis of variance showed that the difference between the means due to the effect of slope and furrow length on cane yield was not significant ($p>0.05$), whereas that of flow rate was highly significant ($P<0.01$).

The higher flow rates had better cane yield and it was observed it increased as the flow rate increased from 0.8 to 3 l/s (Table 1).

Table 1: The effect of slope, furrow length and flow rate on cane yield (t/ha/month)

Slope (%)	Furrow length (m)	Mean cane yield (t/ha/month)*		
		Flow rate (l/s)		
		0.8	1.2	3
	100	9.445[cb]	10.4[cb]	10.565[cb]
0.06	200	10.1[cb]	10.235[ab]	10.74[cb]
	300	10.785[cb]	10.915[b]	11.235[ab]
	100	9.070[c]	9.675[cb]	9.845[cb]
0.08	200	10.065[cb]	10.555[cb]	10.965[b]
	300	11.235[ab]	11.730[ab]	12.860[a]
	100	10.185[cb]	10.265[cb]	11.575[cb]
0.1	200	10.755[bc]	11.225[ab]	11.995[ab]
	300	10.885[b]	11.230[ab]	11.785[ab]
		S	F	Q
	SEM±	0.0685	0.353	0.054
	LSD (0.05)	0.417	1.221	0.159
	CV%	1.4	7.7	2.0

*Means followed by the same superscripts in the same column or row are not statistically different

The effect of interaction between slope, furrow length and flow rate on cane yield was found to be significant ($p<0.05$) as indicated in analysis of variance on Table 1. The minimum cane yield achieved was 9.07 t/ha /month for interaction of the 0.08 % slope, 100 m furrow length and 0.8 l/s flow rates and the maximum achieved cane yield was 12.86 t/ha /month for the interaction of the 0.08% slope, 3 l/s flow rate and 300 m furrow length (Table 1).

Sugar yield

The mean sugar yields obtained were 1.001, 1.019 and 1.092 t/ha/month for 0.05, 0.08, and 0.1 % slopes; 0.973, 1.052 and 1.087 t/ha/month for 100, 200, and 300 m furrow lengths and 0.991, 1.028 and 1.093 t/ha/month for 0.8, 1.2, and 3 l/s flow rates, respectively (Table 2).

The analysis of variance for sugar yield showed non–significant ($P>0.05$) difference in slope, furrow length and their interaction. However, the effect of flow rate showed significant difference ($P<0.05$) as indicated in Table 2.

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Table 2: The effect of flow rate on sugar yield

Level	Mean sugar Yield(t /ha/month)*		
	S	F	Q
1	1.001	0.973	0.991^{b}
2	1.019	1.052	1.028^{b}
3	1.092	1.087	1.093^{a}
SEm $\pm$			0.0331
LSD (0.05)			0.07
CV%			8.4

*Means followed by the same superscripts are not statistically different

There was a yield increase as all slopes, furrow length and flow rate increased. But the increment of sugar yield at each level of treatments had no statistically significant differences except for flow rate. The maximum yield was observed at the flow rate of 3 l/s. Since there is no significance sugar yield difference between levels of slope and furrow length, the higher levels of the two treatments with 3 l/s flow rate have good yield potential.

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

Interaction effects of slope, furrow length and flow rate on cane yield was found to be significant ($p<0.05$). The highest cane yield was obtained from treatment combination of 0.08 % slope, 200 m furrow length and 3 l/s flow rate while the least was obtained from treatment combination of 0.08 % slope, 200 m furrow length and 0.8 l/s flow rate. Similarly, the effects of flow rate on cane yield were also significant. On the other hand, sugar yield was significantly affected ($P<0.05$) by flow rate with mean values of 0.991,1.028 and 1.093 t/ha/month for 0.8, 1.2 and 3 l/s flow rates respectively). This was due to the fact that better irrigation uniformity was attained in higher flow rates.

Ascough and Kiker (2002), reported that distribution uniformity of a system has an effect on the crop yield. The result showed that the different levels of the main plot (slope) and sub plot (furrow length) have no effect on yield of sugarcane. This may be due to laser levelling which improves the uniformity water distribution.

Conclusions

Furrow irrigation is the most widely used method of irrigation water application to sugarcane in Zimbabwe. If the furrow irrigation is to remain a sustainable and positive social and economic force in the 21st century, it needs to evolve into an efficient, cost effective, and environmentally benign technology. For the long term sustainability of an irrigation system, improvements in the performance of current water application and on-farm water management practices are mandatory.

Flow rate substantially affected sugar cane yield while the slope and furrow length did not have that much effect.

The best irrigation uniformity and cane yield was given by the interaction of 0.08% slope, 300m furrow length and 3l/s flow rate. Therefore this combination is better for sugar production at Macdom Estate.

Recommendations

Based on field experiences and findings reported, the following recommendations were forwarded.

The variability of discharge along the length of the layflat has two main components. These are variation resulting from pressure head and the variation that would result from variations in gate area. Therefore further studies should be carried out to establish the relationship between gate pressure and opening areas.

The need for placing check structures for steeper fields across their longitudinal slope should be evaluated in terms of improving distribution uniformity.

Based on the result of the study, newly developed sugar cane plantations and expansions of existing cane areas having similar soil characteristics with that of the study site should consider their design for furrow slope up to 0.1%, longer furrow length with optimum flow rate combination.

The experiment was undertaken by constant inflow rates with different application time to manage water application level. Hence further research work should also be done by incorporating cut off time and irrigation interval.

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