PROGNOSTIC OF MAXIMUM FLOW RATE BY SASISS MODEL:
SENSIBILITY TO RUGOSITY AND SLOPE

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ABSTRACT: This research aimed to analyse the sensibility of maximum non-erosive flow rate, proposed by Walker & Skogerboe (1987), in response to the variation of field parameters: slope (varying from 0.007 to 0.019 m m⁻¹) and soil superficial rugosity (varying from 0.01 to 0.0477 m¹/³ s) under the conditions of open furrow irrigation with continuous flux in silte clay loam soil. The sensibility analysis was carried out by simulation through the SASIS software (software specifically developed for superficial irrigation simulation), developed by Pordeus & Azevedo (2005). Input data was collected from four experimental areas under distinct field conditions. As a result, impracticable maximum non-erosive flow rates could be identified in response to certain combinations of soil superficial rugosity and slope. It was observed that the increase of both rugosity and slope caused the maximum non-erosive flow rate variation to decrease.

KEYWORDS: Irrigation, open furrow, software of irrigation.

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RESUMO: Esta pesquisa visou analisar a sensibilidade da vazão máxima não erosiva, proposta por Walker & Skogerboe (1987), em relação à variação dos parâmetros de campo: declividade do sulco (variando de 0,007 a 0,019 m m\(^{-1}\)) e rugosidade da superfície do solo (variando de 0,01 a 0,0477 m\(^{1/3}\) s) sob as condições de irrigação por sulco aberto com fluxo contínuo e solo franco silte argiloso. A análise da sensibilidade foi realizada através de simulações pelo Software SASIS (Software Aplicado à Simulação da Irrigação por Superfície), desenvolvido por Pordeus & Azevedo (2005). Os dados de entrada foram coletados de quatro áreas experimentais sob diferentes condições de campo. Como resultado, vazões máximas não erosivas consideradas impraticáveis puderam ser identificadas em resposta a certas faixas de combinações entre a rugosidade da superfície do solo e declividade. Pôde-se verificar o que tanto o crescimento da rugosidade quanto da declividade reduziu a variação da vazão máxima não erosiva.

PALAVRAS-CHAVE: Irrigação, sulco aberto, software de irrigação.

INTRODUCTION

Currently, a major concern of man is the management of water resources in a sustainable manner, to meet the growing demand for food by the world's population in order to avoid compromising future generations, farmers have sought to optimize the use of water through planned irrigation systems.

Irrigated agriculture is responsible for over 80% of global water consumption with respect to agricultural production system. When the irrigation process is carried out inadequately, causes serious damage to the environment because of entrainment for the surface and underground water bodies of synthetic fertilizers and pesticides, also causing the removal of fertile soil layers.

In order to improve efficiency of application and distribution of the furrow irrigation water, the water management of the techniques is the use of non-erosive maximum flow rate during the advance phase. Another method is to use intermittent flow of water in the distribution furrows, the two methods, is the positive improvement
in the performance of surface irrigation systems. However, both have the disadvantage of requiring the farmer, more labor-intensive and more investment in equipment.

The objective of this research was to analyze the sensitivity of the maximum flow non-erosive proposed by Walker & Skogerboe (1987), the furrow slope field parameters ranging from 0.007 to 0.019 m m\(^{-1}\) and roughness of the soil surface of 00.1 to 0.0477 m\(^{-1/3}\) s, open furrow irrigation system with continuous flow to soil type loam silt clay.

**MATERIAL AND METHODS**

For spatial numerical solution of the equations of the kinematic waves model, it was used, in this research, the Eulerian integration procedure with first order approximation by Walker & Humpherys (1983) and Wallender (1986), which results in two algebraic equations more stable and easier to be dissolved in microcomputers. Conceptually, the approximation considers the surface and subsurface profile of water throughout the wetted area during sequential stages of calculation. The Figure I illustrates the surface and subsurface profiles of flow in the times \(t_{i-1}\) and \(t_i\), identifying the cells which compse them. During each stage of calculation the water flow advances an incremental distance, \(\delta x\); e.g., during the first interval (first stage of calculation), extends to a distance \(\delta x_1\); in the second interval, to a distance \(\delta x_2\), and so. It can be generalized to the distance of the advancing front, \(x_i\), in the time \(t_i\), as it follows:

\[
x_i = \sum_{k=1}^{i} \delta x_k
\]

Where \(\delta x_k\) is the \(k^{th}\) increment of space, defined by the advance during the interval, when \(i = k\), where \(k\) is the number of time increment.

**Source** : Walker & Skogerboe (1987)

Figure I. Schema of progression of superficial flow and infiltration for the constant interval.
Equation of water infiltration was obtained on equation:

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

(2.0)

Where \( Z \) = accumulated infiltration (m\(^3\) m\(^{-1}\) min\(^{-1}\)), \( \tau \) = infiltration opportunity time (min), \( k \) = empirical coefficients of Kostiakov- Lewis infiltration equation (m\(^3\) min\(^{-a}\) m\(^{-1}\)), \( a \) = empirical coefficients exponent of Kostiakov-Lewis infiltration equation; \( f_o \) = basic infiltration rate in (m\(^3\) m\(^{-1}\) min\(^{-1}\)).

The maximum non-erosive flow was obtained through the following equation:

\[
Q_{\text{max}} = \left( \frac{V_{\text{max}}^2}{3600} \right)^{1/2}
\]  

(3.0)

Where \( Q_{\text{max}} \) = maximum non-erosive flow (m\(^3\) min\(^{-1}\)), \( V_{\text{max}} \) = maximum non-erosive speed (m min\(^{-1}\)), estimated by Walker and Skogerboe (1987) 8-10 m min\(^{-1}\) in erosive soils and 13-15 in less erosive soils, \( n \) = Manning roughness coefficient (m\(^{1/3}\) s), \( \rho_1 \) e \( \rho_2 \) = coefficients which express the geometry of the furrow, dimensionless; \( S_o \) = steepness of the furrow (m m\(^{-1}\)).

The infiltrated volume was determined by using the trapezoidal rule by the equation:

\[
V_{\text{infiltrated}} = \frac{L}{2} \sum_{i=1}^{n} (Z_i + Z_{i+1})
\]  

(4.0)

where: \( L \) - length of the area, \( Z_i \) – accumulated infiltration to point \( i \), m\(^3\) m\(^{-1}\); \( n \) - number of segments in which the furrow is subdivided

The accumulated infiltration in each segment of the furrow is given by:

\[
Z_i = k t_i^a + f_o \tau_i
\]  

(5.0)

where: \( k \) - Kostiakov-Lewis equation constants, m\(^3\) min\(^{-a}\) m\(^{-1}\), \( a \) - Kostiakov-Lewis equation empirical constants, \( f_o \) – basic infiltration rate, m\(^3\) m\(^{-1}\) min\(^{-1}\), \( t_r \) - time of recession, min, \( t_{ai} \) - time of advance for \( ai^{th} \) station, min.

The recession phase is marked by disappearance of water from surface soil. According to some authors, the recession occurs as soon as the water application ends. In this work, the depletion and recession phases were neglected, considering that the cutting time, \( t_{com} \), replaces \( t_r \) in the Equation 5.0.
The analysis of the effect of slope and roughness of the soil surface on the maximum flow nonerosive in furrow irrigation was obtained with three batches of the Perimeter field data São Gonçalo Irrigation (PISG) in the city of Sousa-PB, Brazil and data experiments carried out by e GUFCQ, farm of Utah State University in Logan, USA, published by Azevedo (1992), used in the statement of SIRTOM model. These data are used by the accuracy with which they were obtained and for representing extreme conditions in relation to various parameters. Table 1 shows data of flow \( Q \), slope \( S_o \), water application time \( t_{co} \), furrow length \( L \), furrow spacing \( E \), Manning hydraulic roughness \( n \) and infiltration parameters \( k \) and \( a \) and the empirical constants of the furrow geometry equation \( C \) and \( M \) in the examples studied.

**RESULTS AND DISCUSSION**

The results of the sensitivity analysis, the maximum flow non-erosive, are shown in Table 1. It is observed that there were marked variations in flow rate \( Q_{max} \) in relation to the roughness \( n \) and slope \( S_o \). For PISG1 field data, it was found that for \( S_o \) equals 0.007 m m\(^{-1}\) where \( n \) varied from 0.0477 to 0.01 m\(^{1/3}\) s, \( Q_{max} \) increased from 0.17 to 4.19 L s\(^{-1}\) (increase of 4.02 L s\(^{-1}\)), while for data PISG2, PISG4 and GUFCQ, the minimum and maximum values of flow were 0.17 to 6.67; 0.10 to 4.62 and 0.14 to 8.34 L s\(^{-1}\) (increases of 6.50, 4.52 and 8.20 L s\(^{-1}\)) respectively. However, when PISG1 analyzed for the amount of \( S_o \) m 0.019 m\(^{-1}\) in the same range of variation of roughness, \( Q_{max} \) increased from 0.06 to 1.51 L s\(^{-1}\) (just adding 1.45 L s\(^{-1}\)), however, for data PISG2, PISG4 and GUFCQ, the minimum and maximum values of flow were 0.05 to 2.05; 0.03 to 1.34 and 0.04 to 2.26 L s\(^{-1}\) (increments of 2.00; 1.31 and 2.22 L s\(^{-1}\)) respectively.

Regarding the roughness of 0.01 m\(^{1/3}\) s when the slope ranged from 0.007 to 0.019 m\(^{-1}\), the maximum non-erosive flow decreases from 0.17 to 0.06 L s\(^{-1}\) (down 0.11 L s\(^{-1}\)), however, for the roughness of 0.0477 m\(^{1/3}\) s, this range of variation slope of the maximum non-erosive flow decreases from 4.19 to 1.51 L s\(^{-1}\) (decline 2.68 L s\(^{-1}\)). While for PISG2, PISG4 GULFCQ and when analyzed the variation of the maximum flow non-erosive roughness 0.01 m\(^{1/3}\)s for slope ranging from 0.007 to 0.019 m m\(^{-1}\) values were obtained 0.17-0.05; 0.10 to 0.03; and 0.14 to 0.04 respectively. When it considered that the surface roughness of 0.0477 m\(^{1/3}\) s, values is from 6.67 to 2.05; 4.62 to 1.34; and 8.34 to 2.26 respectively for PISG2, and PISG4 GULFCQ.

By analyzing the four field data it was found, then there is a conjugate of \( n \) and \( S_o \) effect on \( Q_{max} \) value, or a parameter of the effect depends on the effect the other. The
largest value $Q_{\text{max}}$ (8.34 L s$^{-1}$) was greater for the smaller roughness and slope, the reverse happening to the lowest value $Q_{\text{max}}$ (0.04 L s$^{-1}$), then it appears that the surface roughness exerts much greater effect on the maximum flow that the non-erosive slope and for any value of $S_o$, as $n$ increases $Q_{\text{max}}$ also increases, since for any value of $n$, $Q_{\text{max}}$ decreases with an increase in $S_o$, a fact that once explained in equation of maximum flow non-erosive proposed by Walker & Skogerboe (1987), $S_o$ as a divisor is the maximum speed non-erosive water ($V_{\text{max}}$), while $n$, besides being a multiplicative factor $V_{\text{max}}$ is squared, therefore, $Q_{\text{max}}$ increases as $n$ increases and decreases when $S_o$ increases. For the slope and roughness tracks used in this sensitivity analysis, which express real field conditions, were detected combinations of these parameters that generate maximum flows non-erosive impractical because they are both very small and too large. In practical terms, $Q_{\text{max}}$ must exceed the minimum flow, so one that guarantees that water will advance to the final of the irrigated area, and less than or equal to flow normally available to irrigators for water managers in irrigated area; including in many cases at a reduced flow strategy is impractical due to the availability of a certain volume of water for sufficient time to allow the use of a maximum non-erosive flow.

These results demonstrate the need for special attention to estimate the roughness of the ground surface, which must be as accurate as possible, since it may even become use limitation of a maximum flow non-erosive because of lead to impractical values of $Q_{\text{max}}$, outside the acceptable range in the literature, which is 1.2 to 4.0 L s$^{-1}$. Walker & Skogerboe (1987) recommend, for smooth advance and irrigated areas, for prepared freshly areas for field conditions in which the density of the culture obstructs water courses movement, respectively, to values equal to 0.02, 0, 04 and 0.15. Table 2 shows, in bold, the combinations between $n$ and $S_o$ that result in acceptable $Q_{\text{max}}$. This sensitivity analysis was also of great value to establish an interface in SASIS software, able to guide the user of this tool in the imput of appropriate values for $n$ and $S_o$, the process of simulation of furrow irrigation with continuous flow and optimizing your performance.

Criddle (1956) cited by Bernard (1995) proposed an empirical equation, dependent on the slope of the furrow, to calculate the maximum non-erosive flow, the values obtained from this equation are adequate for medium texture soils and slope close to 0.5%. In clay soils can increase the flow and sandy soils, which will decrease it. This equation, the flow is overrated for smaller slope than 0.5% and underestimated for
more slopes than 0.5%. The equation Walker & Skogerboe (1987), used in this research takes advantage of the equation Criddle (1956), because its degree of empiricism is smaller, since, besides the slope, it also considers the roughness and the ability of water courses storage furrow through empirical parameters of the geometry of the cross-flow section. To implement the reduced flow strategy, Daker (1988) has a maximum initial flow table that a furrow can receive without being subject to erosion, due to its slope, for the minimum slope (0.5 per thousand) the maximum flow rate is 4.0 L s\(^{-1}\), as to the maximum slope (5.0 per thousand) is 1.3 L s\(^{-1}\). According to this author, the reduced flow will depend on the infiltration rate of the soil parameter that can be determined for the various processes.

**CONCLUSIONS**

The study identified combinations of ranges between the roughness of the surface of the soil and the slope of the furrow, resulting in impractical maximum flows, small or large values. It was also found, the combined effect of these parameters, and that the greatest effects correspond to roughness.

**REFERENCE**


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**Table 1.** Field data used in the furrow irrigation analysis

<table>
<thead>
<tr>
<th>Parameters</th>
<th>PISG1</th>
<th>PISG2</th>
<th>PISG4</th>
<th>GUFCQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (L s⁻¹)</td>
<td>1.33[¹]</td>
<td>1.47[¹]</td>
<td>1.13[²]</td>
<td>1.30[²]</td>
</tr>
<tr>
<td>Furrow length (m)</td>
<td>67</td>
<td>100</td>
<td>115</td>
<td>217</td>
</tr>
<tr>
<td>Slope (m m⁻¹)</td>
<td>0.0030</td>
<td>0.0016</td>
<td>0.0024</td>
<td>0.0173</td>
</tr>
<tr>
<td>Cutoff time (min)</td>
<td>90</td>
<td>115</td>
<td>86</td>
<td>300</td>
</tr>
<tr>
<td>Manning Coefficient, n (m⁻²s)</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.013</td>
</tr>
<tr>
<td>Parameter of section, 𝜌₁</td>
<td>0.291</td>
<td>0.185</td>
<td>0.339</td>
<td>0.730</td>
</tr>
<tr>
<td>Parameter of section, 𝜌₂</td>
<td>2.847</td>
<td>2.766</td>
<td>2.806</td>
<td>2.980</td>
</tr>
<tr>
<td>k (m³ m⁻³ s⁻¹)</td>
<td>0.03781</td>
<td>0.02931</td>
<td>0.0054</td>
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<tr>
<td>α</td>
<td>0.165</td>
<td>0.302</td>
<td>0.412</td>
<td>0.0</td>
</tr>
<tr>
<td>fₑ (m³ min⁻¹ m⁻¹)</td>
<td>0.00186</td>
<td>0.00186</td>
<td>0.000186</td>
<td>0.000022</td>
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<td>Zₑq (m)</td>
<td>0.090</td>
<td>0.060</td>
<td>0.020</td>
<td>0.050</td>
</tr>
</tbody>
</table>

[¹] Flow rate adopted by the farmer in the field; [²] Flow determined in the design, used by the authors in the demonstration of the SIRMOD and SIRTM models.

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**Tabela 2.** Análise de sensibilidade para a vazão máxima não erosiva

<table>
<thead>
<tr>
<th>Rugosidade</th>
<th>PISG1</th>
<th>PISG2</th>
<th>PISG3</th>
<th>GUFCQ</th>
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<tbody>
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<td></td>
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<td>0.011</td>
<td>0.015</td>
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<td>0.01</td>
<td>0.17</td>
<td>0.11</td>
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<td>0.85</td>
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<td>2.64</td>
<td>1.92</td>
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