Agricultural Water Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

# Predicting soil moisture distribution, dry matter, water productivity and potato yield under a modified gated pipe irrigation system: SALTMED model application using field experimental data

A.F. El-Shafie[a,*], M.A. Osama[b], M.M. Hussein[a], A.M. El-Gindy[b], R. Ragab[c]

[a] *Water Relations and Field Irrigation Department, National Research Centre, Egypt*
[b] *Agricultural Engineering Department, Faculty of Agricultural, Ain-Shams University, Egypt*
[c] *Center for Ecology and Hydrology, Wallingford, United Kingdom*

ARTICLE INFO

*Article history:*
Received 6 September 2015
Received in revised form 29 January 2016
Accepted 1 February 2016
Available online xxx

*Keywords:*
Gated pipe
Self-compensating
Potato
Soil moisture
SALTMED model

ABSTRACT

The use of gated pipes in surface irrigation helps to reduce water losses commonly associated with the use of the traditional furrows. This study focused on predicting soil moisture content, total dry matter, crop yield and water productivity of potato crop using traditional and modified, self-compensating gate outlet (SCGO) gated pipe using the SALTMED model to explore the model suitability to identify the optimum and economic gate spacings. The traditional gated pipes are known to exhibit a range of pressure head variations along the pipeline causing a non-uniform discharge from orifices while the modified gate pipe system, known as compensating gated pipes (SCGO) stabilizes the pressure heads and produce more uniform water discharge along the pipe line. The effect of three gate spacings (0.7, 1.0 and 1.5 m) was studied in a field experiment that has been conducted for two successive seasons, 2011–2012 and 2012–2013. The SALTMED model has been applied and showed excellent agreement between the simulated and observed soil moisture, dry matter, yield and water productivity. Similar to the field results, the simulated values indicated that the modified (SCGO), with the 1.5 m gate spacing, gave the highest yield and water productivity. The modified gated pipe received less water than the traditional gated pipe, due to its high application efficiency. In addition to water saving, there is an economic benefit for using 1.5 m gate spacings as its cost is low (14 gates per 21 m pipe length) in comparison with 1.0 m and 0.7 m spacings. The results confirmed SALTMED ability to simulate with high precision, soil moisture, dry matter, water productivity and yield for potato under gated pipe irrigation. Therefore, the model can be used for design purposes to identify the optimum and economic gate spacings without the need to conduct expensive, costly and labor intensive field trials.



## 1. Introduction

Surface irrigation is one of the oldest methods of irrigation in the world. However surface irrigation (basin, border, surge, and furrow) results in field water losses ranging between 30 and 40% (Keller and Keller, 1995). Waterlogging and low application efficiency are the main problems usually associated with the use of surface irrigation in the Nile Delta (Ali and Mohammed, 2015). The use of a gated pipe system is recognized as a more efficient system of surface irrigation. Goyal, (2014) reported that the irrigation application efficiency of improved gated pipes can reach up to 81%. Gated pipe irrigation utilizes portable rigid pipes or flexible tubing with uniformly-spaced and manually adjustable outlets for diverting water into the furrows. The traditional gated pipe system has uniformly spaced orifices, and is usually made of aluminium or PVC. It has a sliding gate on each outlet to control the area of each orifice to supply the required amount of water to the plant in the field. It is operated under the pressure-head. The gated pipe system has many advantages, such as little wastage of water, easy handling, the possibility to irrigate a large number of furrows simultaneously and the fact that it does not interfere with agricultural operations (Muzmuder, 1983). The modified gated pipe system, or self-compensating gated pipe (SCGO), usually has an internal piece of flexible diaphragm inside the gate changes shape to maintain constant pressure along the pipe (El-Hagarey, 2015). Uniform water flow from each outlet is regulated by sliding gates adjusting the size of the outlet opening to get the desired flow along

* Corresponding author.
*E-mail addresses:* ahmedfaris30@yahoo.com, mammohand2005@gmail.com (A.F. El-Shafie).

http://dx.doi.org/10.1016/j.agwat.2016.02.002
0378-3774/

the pipe (Smith and Gillies, 2010; El-Awady et al., 2005). El-Shafie et al. (2009) tested the Self- Compensating Gated Outlet (SCGO) and reported that the performance analysis showed that the average discharge of 29 l $min^{-1}$ was obtained at pressure range of 5–9 kPa with coefficients of variation of less than 0.9%. El-Hagarey et al. (2010) developed and evaluated auto-compensating nozzle (poppet nozzle) and found that poppet nozzle compensates the pressure head difference along irrigation pipes and produces stable and harmonized flow along the pipes.

Irrigation management models can be useful tools to investigate the soil moisture distribution uniformity and irrigation efficiency of systems such as gated pipe. In the latter, different gates might have different discharge rates leading to non-uniform soil moisture. In such case, models could help in improving the water distribution by identifying the best set of parameters to be used. One of these irrigation water management model is SALTMED.

The early version of the SALTMED model has been successfully tested against field data of tomato grown in Syria and Egypt for five seasons 2000–2002 in both countries (Ragab et al., 2005a,b). The latest model developments have been published by Ragab (2010, 2015). The model has been successfully applied in a sugar cane field experiment in Iran (Golabi et al., 2009), on several field crops in north-east Brazil (Montenegro et al., 2010), on tomato and potato in Italy, Crete and Serbia (Ragab et al., 2015), on sweetcorn, chickpea and quinoa in Morocco (Hirich et al., 2012, 2014; Fghire et al., 2015), on quinoa in Denmark (Razzaghi et al., 2011), on chick pea in Portugal (Silva et al., 2013) and on quinoa and amaranth in Italy (Pulvento et al., 2013, 2015). In all those tests, the model was successfully able to simulate dry matter and final yield, soil moisture and nitrogen profiles.

Therefore, the SALTMED model was selected for this study. The main objectives of this study are to predict yield, water productivity and soil moisture for traditional and modified (SCGO) gated pipe irrigation systems under three spacings between gates, 0.7, 1.0 and 1.5 m, using SALTMED model and to assess the model's ability as a design tool to obtain the optimum gate spacings.

## 2. Materials and methods

### 2.1. The experimental site

The field experiment was carried out at the Faculty of Agriculture farm, Ain-Shams University Shalakan, Kalubia Governorate, Egypt. The field is located at latitude 31°4′ E, longitude 30°13′ N, 14 m above sea level. The site is representative of the old alluvial soil of the Nile Delta. The field experiment on potato crop included two irrigation systems during two successive seasons of 2011–2012 and 2012–2013. The experimental site is characterized by a semi-arid climate. The averages of the two seasons' meteorological data at the experimental station of Shalakan are shown in Table 1. The soil of the site has a clay–loam texture along the entire profile. The main physical properties were determined in situ and in the laboratory at the beginning of the trial and are reported in Table 2.

### 2.2. Irrigation system description

Two systems were studied, the first system is a modified gated pipe being self-compensating gate outlet (SCGO), while the second is traditional gated pipe. Three spacings between gates along the pipeline 0.7, 1.0 and 1.5 m, were considered. These spacings are standard manufacturer design. In the gated pipe system, the pipeline is made of PVC of 110 mm diameter, with gated outlet diameter 50 mm.

Traditional gated pipe usually exhibits a range of pressure head variations along the pipeline as well as non-uniform discharge from orifices while the modified gated pipe system, or self-compensating gated pipe (SCGO), usually has an internal piece of flexible diaphragm inside the gate that changes shape to maintain constant pressure along the pipe (El-Shafie et al., 2009; El-Hagarey et al., 2010; El-Hagarey, 2015).

Before the start of the growing seasons, the water discharge was measured in the field for traditional and modified gated pipe of 0.7, 1.0 and 1.5 m spacing between gates. In general there was a slight variation in discharge between the first and the last gate of the modified gated pipe under 0.7, 1.0 and 1.5 m spacing. The data indicated good uniformity of discharge from each outlet being regulated along the pipeline under modified gated pipe for all spacings as the SCGO automatically adjusts its discharge, pressure head and uniformity of water distribution along the pipeline. The data of the traditional gated pipe system showed a slight variation in discharge between gates under the 1.5 m spacing between gates, while there was more variation in discharge between gates under 0.7 and 1.0 m spacing between gates.

### 2.3. Experimental design

The experimental design was split plot with three replications. The total area of the experiment was 3168 $m^2$ and was divided into six main plots of 528 $m^2$ each; every plot was divided into three sub-plots. Each sub plot had the same number of furrows and were 70 cm apart. Layout of the experimental design and spacings between gates of irrigation systems are shown in (Fig. 1). Discharges from gates were measured under operating pressure of 0.28 bar.

Potato crop was chosen for this study. All the plots received full irrigation requirements and the same fertilizer amounts. Potato seeds were transplanted to each furrow at 25 cm distance between plants. The plant density is the same for each treatment. Three samples were taken at different times during growth period stages (40, 70 and 110 days after transplant) to measure the dry matter. The yield was harvested after 115 days of crop transplanting in the two growing seasons to measure tuber fresh yield, and water productivity.

### 2.4. SALTMED model

A detailed description of the SALTMED model and the equations of the key processes of evapotranspiration, water and solute transport, the nitrogen cycle, drainage and crop growth have been provided by Ragab (2002, 2015) and Ragab et al. (2005a, 2005b). The model is suitable for all irrigation systems. The model calculates the reference evapotranspiration (ETo) by several methods among them is the FAO modified Penman–Monteith equation according to Allen et al. (1998), which was selected for this study. SALTMED provides a detailed plant growth process for biomass calculation. SALTMED also produces information on crop growth stage length and the relative yield for future climatic scenarios, so this approach could be a useful decision support system for sustainable agronomic management (Pulvento et al., 2015).

The model input consists of meteorological data, irrigation data, water quality, crop parameters, nitrogen fertilizers and soil parameters. Meteorological data were obtained from the field weather station (temperature, relative humidity, radiation, wind speed and rainfall). Crop-specific input data were the Leaf Area Index, LAI, plant height, maximum and minimum root depth, and each growth stage length. The irrigation input values were those applied in the field for the two irrigation systems (traditional and self-compensating gated pipe) and for the three spacings between gates along pipeline (0.7, 1.0 and 1.50 m), during 2011–2012 and 2012–2013 growth seasons. The soil profile, which has clay–loam properties, was divided into four layers of 0.00–0.20, 0.20–0.30,