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Performance Evaluation of Gated Pipes Technique for Improving Surface Irrigation Efficiency in Maize Hybrids

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Abstract

Waterlogging and low application efficiency are the main problems inherent with surface irrigation in the Nile Delta. Develop surface irrigation using gated pipes (GP) is a new method to be used to distribute water into furrow irrigated fields as strategy based on water saving. Laboratory calibration was conducted out to evaluate the hydraulic characteristics of pipe gates. Field experiments were conducted at the Experimental Farm of the Agriculture Faculty, Minufiya University during 2013 and 2014 seasons to evaluate the performance of utilize gated pipes technique for irrigating five maize varieties (S.C 10, S.C 130, S.C 131, S.C 2031 and T.W.C 321). The results revealed that the highest amount of water applied was with traditional surface irrigation (6423.81 $m^3 \cdot ha^{-1}$). Use of gated pipes system GP1 as compared to traditional irrigation reduced water application by 923.81 $m^3 \cdot ha^{-1}$ with grain and stover yields increases of 5.7% and 3.4%, respectively. Traditional irrigation system achieved lowest irrigation performance parameters compared to gated pipes systems. Maize physiological attributes, yield, water use efficiency (WUE) and nitrogen accumulation were significantly decreased by either deficit or surplus irrigation than of GP1 rate. S.C 2031 variety significantly surpassed other varieties in abovementioned traits. Significant interaction effects were detected in both seasons. Maize varieties respond differently to irrigation systems. The highest values of grain yield (11062.6 and 10911.8 $kg \cdot ha^{-1}$) and stover yield (13639.0 and 13902.2 $kg \cdot ha^{-1}$) were obtained by S.C 2031 irrigated with GP1 system in both seasons. From the above mentioned results, it is concluded that the gated pipes technique is better than traditional irrigation for improving WUE and maize productivity under Nile Delta conditions.

Keywords

Maize, Hybrids, Gated Pipes, Irrigation Efficiency

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1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops grown principally during the summer season in Egypt. Great attention has been paid to increase maize total production. This could be achieved by using of high yielding varieties and avoid water flooding and deficit stress. [1] [2] reported that maize genotypes are significantly differed for grain and stover yields and associated traits. Many investigators found high variation among maize varieties in their yield in favor of single cross varieties as mentioned by [3] [4]. Meanwhile [5] found that three way cross 310 (T.W.C) significantly surpassed other single crosses (S.C 10 and S.C 122) in clay soil. The responses of plants to flooding or deficit water depend on the genotype, growth stage, level and duration of stress, and physical parameters of the soil. [6] [7] stated that plants are developed different morphological, physiological and biochemical mechanisms which inhibit the harmful effects of stresses.

Water scarcity is a growing global problem challenging sustainable development and placing a constraint on producing enough food to meet increasing food requirements. Egypt is mainly an agricultural country depending on the Nile water and consumes about 80% - 85% for agriculture annually [8]. The cultivated area of old land is about 2.7 million hectare irrigated by traditional surface irrigation (flooding method) according to data issued by Ministry of Agriculture, Egypt. Surface irrigation is the most widely used method as a conventional practice at the Egyptian farmers. Despite this progressive water shortage farmers continue to use flooding irrigation. Poor management, uniformity and distribution of water have been cited as the most frequent problems of flooding irrigation, resulting in waterlogging, salinization and less water use efficiency [9]. Water application efficiency gives a general sense of how well an irrigation system performs its primary task of getting water to the plant roots. Water infiltration into soil is a key to crop production and salinity control [10]. Researchers show that over 45% of water applied is lost to deep soil drainage and surface runoff [11].

The efficient use of water through modern irrigation systems is becoming increasingly important in arid and semi-arid regions with limited water resources [12]. Saving water and improving water use efficiency need to be developed. Water saved will be use for increase the cultivated area and overall crop production. Developing surface irrigation using gated pipes is a new method used to distribute water to furrow as strategy based on water saving. The gated pipe has many advantages: 1) requires small area of land to install the system; 2) reduces the seepage and evaporation losses and better water distribution; 3) low cost and maintenance requirements and 4) can improve human public health by avoiding contact with infected water. [13] reported that the differences between 0.80 ET_c and 1.00 ET_c treatments were not significant, while the lowest maize growth and yield were obtained from 0.60 ET_c treatment. The same authors added that the 0.80 ET_c irrigation treatment had the same or even greater WUE than 1.00 and 0.60 ET_c. Nitrogen absorption by cereal crops plays a main role in plant growth. As a result of this, N is considered a strong tool for high crop yield. The excessive water application significantly reduced N, P and K absorption of maize plants.

The main objectives of this study were to find out some practical effective ways regarding saving water particularly under the present status of water shortage facing Egypt. So, this study was planned to 1) improve the distribution uniformity of water discharge along the gated pipe and control of the water direction and reduce erosion in front of the gate, by designing a new outside gate locally to take the place of the side gate; and 2) evaluate the performance of some maize hybrids in light of use gated pipes technique for improving surface irrigation under the old lands of the Nile Delta.

2. Materials and Methods

2.1. Experimental Site Specification

2.1.1. Laboratory Experiment

Laboratory experiment was conducted at National Laboratory for Testing Irrigation Equipment, Agricultural Engineering Research Institute, Egypt to evaluate the hydraulic characteristics of a modified gate. The gate was designed from a gate valve (3.45 cm D.) installed on the pipe orifice using rubber and external flexible hose mounted in front of the valve to control the direction of water. The laboratory testing equipments contained an electric centrifugal pump, flow meter, pressure gauges, manometer and control valve. The gate discharge along line was experimentally measured by direct method using bucket with capacity of 30 liter and stopwatch. Gated pipes line used for laboratory test was 12 m length with 150 mm inner diameter and 156 mm outer diameter. The velocity of water flow in the pipe was calculated according to the continuity equation, where discharge was measured by a flow meter. The distance between gates was fixed along the pipe line (0.70 m). Average discharge of water flowing in the gates was calculated by the following steps:

Calculation of the Reynold's number (R_e) according to Equation (1) as given by [14].

$$R_e = \frac{V \cdot D}{\upsilon} \tag{1}$$

where:

$V =$ Average velocity in the pipe ($\text{m}\cdot\text{sec}^{-1}$)

$D =$ Inside pipe diameter (m)

$\upsilon =$ Kinematics viscosity ($\text{m}^2\cdot\text{sec}^{-1}$)

The used value of kinematic viscosity (υ) was taken 1×10^{-6} considering that the water was at 20˚C.

Calculation of head losses due to friction from Equation (2)

$$h_f = f\frac{LV^2}{D2g} \tag{2}$$

where:

$h_f =$ Friction head loss (m)

$f =$ Darcy-Weisbach resistance coefficient

$L =$ Length of pipe (m)

$V =$ Average velocity of water flowing in the pipe line ($\text{m}\cdot\text{sec}^{-1}$)

$g =$ Gravitational acceleration (9.81 $\text{m}\cdot\text{sec}^{-2}$)

$D =$ Inner diameter of pipe (m)

The value of Darcy coefficient (f) was calculated by using the Equation (3) consider that R_e is up to 3.2×10^6.

$$f = 0.0032 + \frac{0.221}{R_e^{0.237}} \tag{3}$$

Calculation of head (h_{si}) which occurred due to the decrease in flow velocity inside the pipe was determined from Equation (4) as follows:

$$h_{si} = \frac{v_{\max}^2 - v_i^2}{2g} \tag{4}$$

where:

$h_{si} =$ Super imposed head (m)

$v_{\max} =$ Maximum average velocity of water flowing in the pipe line ($\text{m}\cdot\text{sec}^{-1}$)

$v_i =$ Average velocity of water flowing in the pipe line ($\text{m}\cdot\text{sec}^{-1}$)

Determination of the total head inside the pipe (h_m) at any discharging outlet this was determined from Equation (5).

$$h_m = h_p + h_{si} - h_f \tag{5}$$

where:

$h_p =$ Water head produced by the pump (m)

Considering the value of h_{si} is zero, the total head at the first gate (orifice) can be determined from Equation (6).

$$h_{m1} = h_p - h_f \tag{6}$$

Determination of the average velocity (v), the Equation (7) was used to calculate the average velocity at any gate (i)

$$v_i = \sqrt{2gh_i} \tag{7}$$

Discharge of water at any gate was determined from Equation (8).

$$q_i = c_d \times \frac{\pi}{4} d^2 \times v \tag{8}$$

where:

$q_i =$ Average discharge of water flowing in the gate ($m^3 \cdot sec^{-1}$)
$c_d =$ Average coefficient of discharge $(c_d = 0.65)$
$d =$ Average diameter of the gate (m)
$v =$ Average velocity in the gate ($m \cdot sec^{-1}$)

2.1.2. Field Experiments

Two field experiments were conducted at the Experimental Farm of the Faculty of Agriculture, Minufiya University in Shebin El-Kom, Egypt (latitude 30˚31'39"N, longitude 31˚04'03"E) during the two summer growing seasons of 2013 and 2014. Properties of the experimental soil are given in **Table 1**. Soil samples were randomly collected before sowing from depths of 0 - 20, 20 - 40 and 40 - 60 cm using an auger for estimating some mechanical and chemical properties as described by [15] [16]. Soil bulk density was determined using of cylinders according to [17]. Soil field capacity and wilting point were determined in the laboratory as described by [18].

2.2. Experimental Design and Treatments

The feasibility of producing maize under gated pipes technique was investigated comparing with traditional surface irrigation. The field experiment included twenty treatments which were all possible combinations between four irrigation treatments (traditional surface "flooding" and gated pipes with three discharge rates, *i.e.* 3.6 $m^3 \cdot h^{-1}$ "GP1", 4.8 $m^3 \cdot h^{-1}$ "GP2" and 6 $m^3 \cdot h^{-1}$ "GP3") and five maize hybrids (S.C 10, S.C 130, S.C 131, S.C 2031 and T.W.C 321). The outside diameter of gated pipe is 6" and 6 m length. Pipe is made of UPVC with gates spacing 0.70 m. The flow rate out of each gate system is controlled by the percent of opening the main valve according to the discharge rates. Maize hybrids used for study were white color varieties produced by Agricultural Research Center, Egypt except S.C 2031 which produced by Hi-Tech Co.

A layout of the experimental plots is shown in **Figure 1**. Each of surface irrigation system (traditional or gated pipes) was divided into five sectors to evaluate the five hybrids which randomly assigned. Sub-plot area was 60 m length × 3.5 m width, occupying an area of 210 m^2. Each plot was included 5 furrows, 0.7 m width for each (furrow area = 42 m^2). A distance of 2.1 m was left between each irrigation treatments as a border. In the gated pipes technique, the pipes were located at the head of the irrigated field across the furrows and connected directly with main valve and water pump (60 $m^3 \cdot h^{-1}$). Each furrow had one gate to water control and measure the irrigation efficiency. The irrigation treatments were distributed in the main plots, whereas maize hybrids were assigned at random in the sub-plots.

Table 1. (a) Mechanical and physical properties of the experimental field soil. (b) Chemical properties of the experimental field soil.

(a)

Soil depth (cm)	Particle size distribution (%)			Texture class	Bulk density $g \cdot cm^{-3}$	Field capacity %	Permanent wilting point %	Available soil water %
	Sand	Silt	Clay					
0 - 20	20.27	41.17	38.56	Clay loam	1.29	42.45	21.90	20.55
20 - 40	20.80	40.51	38.69	Clay loam	1.31	40.95	20.45	20.50
40 - 60	17.32	36.75	45.93	Clay	1.33	38.89	19.14	19.75

(b)

Soil depth (cm)	Soluble cations $meq \cdot l^{-1}$				Soluble anions $meq \cdot l^{-1}$			Soil nutrients ppm		
	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^{2-}	SO_4^{2-}	N	P	K
0 - 20	6.60	0.84	2.40	1.46	7.65	0.60	3.05	34.8	9.3	302.5
20 - 40	4.85	0.70	1.53	1.42	5.75	0.45	2.30	32.4	8.4	287.1
40 - 60	4.55	0.65	1.45	1.35	5.63	0.40	1.97	30.2	8.1	274.6

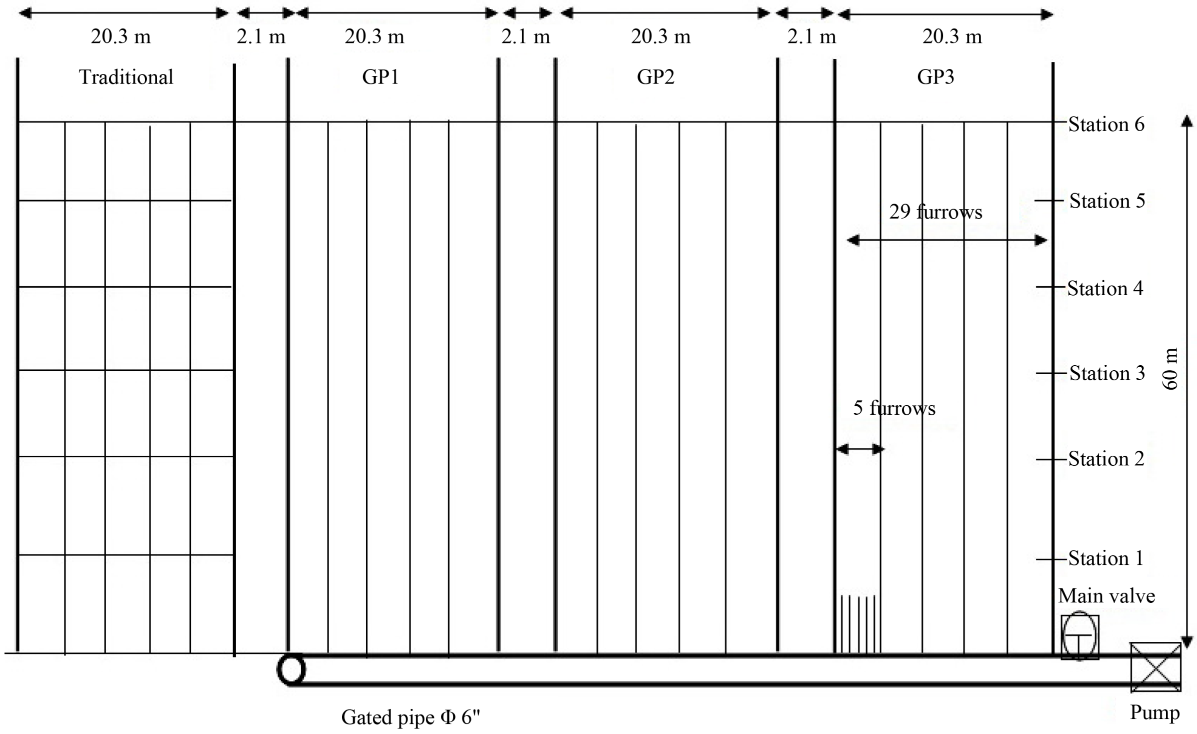


Figure 1. Layout of experimental replicate.

2.3. Irrigation Performance Parameters

Using field stalks and surveying tape, the furrows were divided into number of six stations having equal distances between them (10 m). Irrigation water advanced into the furrow (arrival times) were recorded at the end of each station. When water uncovers the field surface completely as a wave moving at the same direction of flow, recession times were observed and recorded at each station. This mark is the initiation of the water drying or recession front.

The water infiltration opportunity time along furrow length is the difference between the last time when water disappeared and the first time when water started at the same point along furrow. It can be determined according to [19] as formulated in Equation (9).

$$t_o = t_r - t_l \tag{9}$$

where:

t_o = infiltration opportunity time (min)

t_l = advance time (min)

t_r = recession time (min)

Cutoff time of water flow (min·furrow^{-1}) is cumulative time since the initiation of irrigation until the inflow is terminated. It was recorded when the water has been totally arrived in the end of each furrow. Irrigation water applied (m^3·ha^{-1}) was calculated according to the cutoff time and discharge rate depends on the maize growth stage and environmental conditions.

Water infiltration in soil depth (Z) was measured in the upper 30 cm of soil surface using double ring infiltrometer in beginning of experiment at site location. The two rings were driven into the soil to 15 cm depth. The two rings were set to measure infiltration rate in the next 15 cm soil layer. Filling water rate into inner cylinder was also recorded. The disappeared irrigation depth was recorded with interval time. Water infiltration was determined according to Equation (10).

$$Z = 9.32 t_o^{0.47} \tag{10}$$

System coefficient of variation (CV%) was estimated from Equation (11).

$$CV = \frac{S}{\overline{Z}}(100) \tag{11}$$

where:

S = Standard deviation

$\overline{Z}$ = Depth average of water distribution along furrow stations

The schedule parameter (α) specifies the deviation of any schedule irrigation depth (d) to average of water distribution depth $\left(\overline{Z}\right)$ in terms of CV and can be calculated according to [10] as formulated in Equation (12).

$$\alpha = \frac{1}{CV}\left(\frac{d}{\overline{Z}} - 1\right) \tag{12}$$

where:

d = Water depth expressing the plant water requirement calculated from ET.

The uniformity coefficient (UC) can be expressed in power distribution for water infiltrated depth which determined from Equation (13) as stated by [20].

$$UC = 1 - 0.8CV \tag{13}$$

The distribution uniformity (DU) is a measure of how uniformly water is applied to the area being watered, expressed as a percentage. It determined from Equation (14).

$$DU = 1 - 1.3CV \tag{14}$$

Application and storage efficiencies were used to evaluate the design of the irrigation system synchronizing with the irrigation scheduling.

Storage efficiency (E_s) defined as the ratio of amount of water stored to the water needed into root zone. It was calculated as from Equation (15).

$$E_s = 100\left(1 - P_D\right) \tag{15}$$

The deficit percentage (P_D) is defined as the ratio of water deficit to the required water into the root zone, can be formulated using linear distribution for water applied by the irrigation system (**Figure 2**) according to [21] in Equation (16).

$$P_D = \frac{\left(1.725 + \alpha\right)^2 CV}{6.9\left(1 + \alpha CV\right)} \tag{16}$$

When the linear distribution is used to express the water profile of irrigation system, α will range from −1.725 to 1.725 under optimum irrigation, $\alpha \geq 1.725$ in deficit irrigation, and $\alpha \geq -1.725$ in excess irrigation according to [21]. In deficit irrigation condition, when $\alpha \geq 1.725$ and $d \geq Z_{max}$, no deep seepage has occurred. The deficit percentage can be determined using of Equation (17).

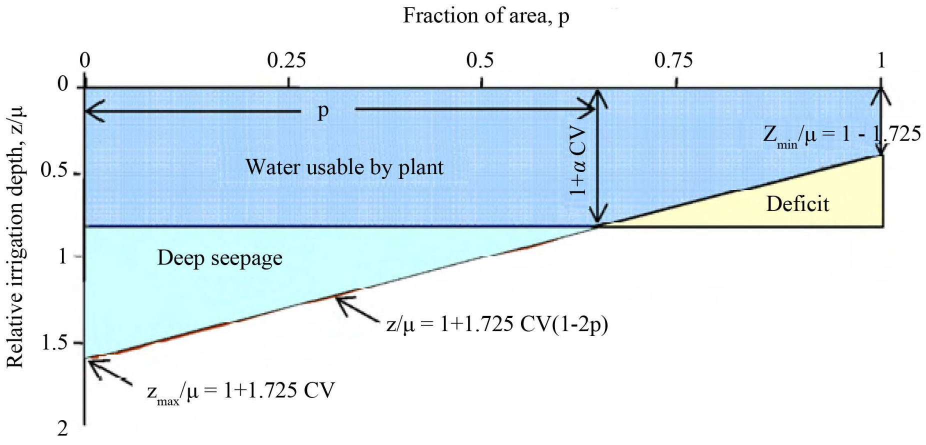


Figure 2. Linear cumulative frequency curve with relative required depth (1 + α CV) according to [21].

$$P_D = \frac{\alpha CV}{1+\alpha CV} \tag{17}$$

Application efficiency (E_a) is defined as the ratio of water stored in the root zone to the total water applied. E_a was calculated from Equation (18).

$$E_a = 100\left(1 - P_s\right) \tag{18}$$

where:

P_s = deep seepage percent.

The deep seepage percent can be described using a linear distribution as derivative from the basic analyses by [21]. In under irrigation when α ranged from −1.725 to 1.725, deep seepage percentage P_s could be determined from Equation (19).

$$P_s = \frac{\left(1.725 - \alpha\right)^2 CV}{6.9} \tag{19}$$

When $\alpha \le -1.725$, deep seepage percentage could be calculated from Equation (20).

$$P_s = -\alpha CV \tag{20}$$

Water saving is referring to the consumption differences among surface irrigation systems.

2.4. Agronomic Measurements

During the growth phase, total chlorophyll (Chl) was measured at 50 days after sowing (DAS) with a hand-held chlorophyll meter (SPAD-502, Konica Minolta Company, Tokyo, Japan). At the period of 60 - 75 DAS crop growth rate (CGR) g plant^{-1} day^{-1} was determined as the following formula:

$$CGR = \frac{W_2 - W_1}{T_2 - T_1}$$

where: W_1 and W_2 = plant dry weight (g.) at T_1 and T_2 (date of sampling), respectively. After 75 DAS, ear leaf area (ELA) was determined as formula, ELA = ear blade length × maximum blade width × 0.75 (cm^2).

At maturity, grain and stover yields (based on 15.5% moisture content) were determined by hand harvesting the area of two inner furrows and converted to kg·ha^{-1}. Yield samples of eighteen plants were collected along the furrow from each plot to determine yield components.

Irrigation water use efficiency (WUE) in kg·m^{-3} was calculated according to formula, WUE = Grain yield kg·ha^{-1}/amount of irrigation water applied m^3·ha^{-1}.

Plant chemical composition was determined by plant partitioned into stover (stalk and leaves) and grains. Samples were dried in air-oven at 70˚C to constant weight before grinding with a mill to pass through a 0.5 mm sieve. The samples were chemically analyzed to determine their contents of nitrogen. The total nitrogen percentage was determined by the Kjeldahl method as described by [22]. Nitrogen accumulation (kg·ha^{-1}) = sample N concentration × dry matter yield.

2.5. Agronomic Practices

The experimental field was ploughed twice, harrowed and leveled with slope 0.1% after wheat harvesting. Maize planting was done on 8th and 10th May 2013 and 2014, respectively using two grains per hill at a spacing of 25 cm and thinned to one plant at 21 DAS, to give a population of 57,140 plants ha^{-1}. The experiment was irrigated seven times, where the first irrigation was applied at 21 DAS and the following irrigations were applied every 13 days until physiological maturity. All experimental plots were fertilized with NPK. Calcium superphosphate (15.5% P_2O_5) was added during soil preparation at the rate of 74 kg P_2O_5 ha^{-1}. Nitrogen fertilizer at a rate of 286 kg N ha^{-1} in the form of urea (46.5% N) was added in two equal doses, the first dose was added after thinning (before the first irrigation), while the second dose was applied before the second irrigation. Potassium fertilizer was added in the form of potassium sulfate (48% K_2O) at the rate of 57 kg K_2O ha^{-1} before the first irrigation. Weed control was done chemically before seedling emergence and mechanically after emergence in a timely manner.

2.6. Statistical Analysis

Data were analyzed using an analysis of variance split plot design with three replicates described by [23]. Statistical analysis was done using CoStat Version 6.311 (CoHort software, USA). Treatments means were compared using Duncan's multiple test [24]. Means followed by the same letter are not significantly different from one another at $P < 0.05$. Capital letters in rows and columns indicate significant differences among irrigation systems and maize hybrids, respectively. Small letters indicate significant differences of the interaction between irrigation and hybrids treatments.

3. Results and Discussion

3.1. Laboratory Calibration

Laboratory calibration of modified gate along pipe line was illustrated in **Figure 3**. Results of hydraulic parameters (**Table 2**) showed that the average of determined discharges for GP1, GP2 and GP3 were 3.6, 4.8 and 6

Table 2. Hydraulic parameters of gates under different discharge rates.

Gate number	Q ($m^3 \cdot h^{-1}$)	V ($m \cdot sec^{-1}$)	R_e	f	H_f (m)	H_{si} (m)	H_m (m)	V_i ($m \cdot sec^{-1}$)	q ($m^3 \cdot h^{-1}$)
GP1 system (3.6 $m^3 \cdot h^{-1}$)									
1	36.0	0.5657	84848.48	0.0182	0.0020	0.0000	0.1280	1.5849	3.4682
2	32.4	0.5091	76363.64	0.0186	0.0028	0.0031	0.1303	1.5990	3.4992
3	28.8	0.4525	67878.79	0.0190	0.0032	0.0059	0.1327	1.6136	3.5311
4	25.2	0.3960	59393.94	0.0195	0.0032	0.0083	0.1351	1.6281	3.5628
5	21.6	0.3394	50909.09	0.0201	0.0030	0.0104	0.1375	1.6422	3.5937
6	18.0	0.2828	42424.24	0.0209	0.0026	0.0122	0.1397	1.6555	3.6228
7	14.4	0.2263	33939.39	0.0218	0.0020	0.0137	0.1417	1.6676	3.6493
8	10.8	0.1697	25454.55	0.0232	0.0013	0.0149	0.1435	1.6780	3.6722
9	7.2	0.1131	16969.70	0.0252	0.0007	0.0157	0.1449	1.6864	3.6904
10	3.6	0.0566	8484.85	0.0291	0.0002	0.0162	0.1459	1.6921	3.7029
GP2 system (4.8 $m^3 \cdot h^{-1}$)									
1	48.0	0.7542	113131.3	0.0172	0.0033	0.0000	0.2267	2.1089	4.6150
2	43.2	0.6788	101818.2	0.0176	0.0047	0.0055	0.2308	2.1282	4.6572
3	38.4	0.6034	90505.05	0.0180	0.0053	0.0104	0.2351	2.1478	4.7001
4	33.6	0.5279	79191.92	0.0185	0.0054	0.0148	0.2394	2.1672	4.7426
5	28.8	0.4525	67878.79	0.0190	0.0050	0.0186	0.2435	2.1859	4.7836
6	24.0	0.3771	56565.66	0.0197	0.0043	0.0218	0.2475	2.2035	4.8221
7	19.2	0.3017	45252.53	0.0206	0.0033	0.0244	0.2511	2.2194	4.8569
8	14.4	0.2263	33939.39	0.0218	0.0022	0.0264	0.2542	2.2331	4.8868
9	9.6	0.1508	22626.26	0.0237	0.0012	0.0279	0.2567	2.2440	4.9107
10	4.8	0.0754	11313.13	0.0274	0.0004	0.0287	0.2583	2.2514	4.9268
GP3 system (6 $m^3 \cdot h^{-1}$)									
1	60.0	0.9428	141414.1	0.0165	0.0050	0.0000	0.3600	2.6577	5.8161
2	54.0	0.8485	127272.7	0.0168	0.0041	0.0067	0.3647	2.6748	5.8534
3	48.0	0.7542	113131.3	0.0172	0.0033	0.0126	0.3696	2.6930	5.8932
4	42.0	0.6599	98989.90	0.0177	0.0026	0.0179	0.3748	2.7116	5.9340
5	36.0	0.5657	84848.48	0.0182	0.0020	0.0224	0.3799	2.7301	5.9745
6	30.0	0.4714	70707.07	0.0189	0.0014	0.0263	0.3849	2.7479	6.0134
7	24.0	0.3771	56565.66	0.0197	0.0010	0.0294	0.3895	2.7643	6.0493
8	18.0	0.2828	42424.24	0.0209	0.0006	0.0319	0.3935	2.7787	6.0807
9	12.0	0.1886	28282.83	0.0227	0.0003	0.0336	0.3968	2.7903	6.1061
10	6.0	0.0943	14141.41	0.0261	0.0001	0.0347	0.3991	2.7983	6.1237

Figure 3. Laboratory calibration for gated pipe line.

$m^3 \cdot h^{-1}$ respectively. The actual discharges (q) from the gates along line were nearly equal to theoretical discharges values. The coefficient of variation (CV%) of discharges gates along the pipes line was 2.28%, 2.27% and 1.80% for GP1, GP2 and GP3 systems, respectively. The values of head pressure pump were 13, 23 and 36.5 cm for GP1, GP2 and GP3, respectively. This means that gates discharges were approximately constant. Accordingly, uniformity of water flow from the first gate to last gate along gated pipe lines according to different GP systems.

3.2. Irrigation Performance Parameters

3.2.1. Water Saving

Results in **Table 3** show that the values of irrigation water applied varied from 4404.76 to 6423.81 $m^3 \cdot ha^{-1}$ per season. Utilization of GP1, GP2 or GP3 as compared to traditional method reduced substantial amounts of water by 923.81, 1566.67 and 2019.05 $m^3 \cdot ha^{-1}$, respectively. Water saving may be resulting from minimize advance time, which results in lowering water losses. Maize is a water-stress sensitive crop. If water saving is a major issue, then, some yield reduction must be accepted as shown by the trade-off in this study between water saving and yield loss under GP2 and GP3. Using a higher efficiency gated pipes irrigation system is recommended for irrigating maize especially under deficit irrigation in case of water scarcity from a water-saving viewpoint.

3.2.2. Advance and Recession Phases

Results of the advance and recession times and infiltration volume of the irrigation systems were illustrated in **Figure 4** for fourth irrigation at 60 DAS. Under gated pipe irrigation technique, the highest advance and recession phase exhibited by GP3 (6 $m^3 \cdot h^{-1}$) meanwhile the slow advance rate resulted from low water outflow (3.6 $m^3 \cdot h^{-1}$). The advance phase should be completed as quickly as possible so that the intake opportunity time over the field will be uniform and then cutoff water inflow when enough water has been added to refill the root zone. This can be accomplished with a high water discharge into the field but without soil erosion. These results agree with those reported by [25] [26].

3.2.3. Water Infiltration

Infiltration rate as a function of opportunity time t_o is illustrated in **Figure 4** for fourth irrigation at 60 DAS. Infiltration is perhaps the most crucial factor affecting surface irrigation. The amount of water entering the soil and the duration of that irrigation varies greatly with irrigation systems. Because of this extreme variability, the infiltration rate is often varied along furrow. Water infiltration in traditional methods was greater than in gated pipes systems and it was basically due to the lower speed of water in the furrows. Furrows had satisfied their requirements of irrigation and some stations had over irrigation volumes in traditional method, resulting in more water deep seepage than other irrigation systems. Generally, GP1 (**Figure 4(b)**) achieved the best water infiltration with less water deficit. Meanwhile, GP3 (**Figure 4(d)**) produced more water deficit than other irrigation

Table 3. Cutoff time and amount of water applied per each irrigation (average of the two seasons).

Irrigation number	Traditional irrigation	Gated pipes discharge rates					
		GP1 (3.6 $m^3 \cdot h^{-1}$)		GP2 (4.8 $m^3 \cdot h^{-1}$)		GP3 (6 $m^3 \cdot ha^{-1}$)	
	Water applied ($m^3 \cdot ha^{-1}$)	Cutoff time (min.)	Water applied ($m^3 \cdot ha^{-1}$)	Cutoff time (min.)	Water applied ($m^3 \cdot ha^{-1}$)	Cutoff time (min.)	Water applied ($m^3 \cdot ha^{-1}$)
1	880.95	55	785.71	36	685.71	26	619.05
2	861.90	52	742.86	35	666.67	25	595.24
3	907.14	53	757.14	32	609.52	26	619.05
4	1023.81	61	871.43	45	857.14	32	761.90
5	1050.00	63	900.00	44	838.10	28	666.67
6	857.14	53	757.14	32	609.52	24	571.43
7	842.86	48	685.71	31	590.48	24	571.43
Sum	6423.81	385	5500.00	255	4857.14	185	4404.76

systems due to little quantity of water applied. These results are consistent with the findings of [21] [25].

3.2.4. Application and Storage Efficiencies

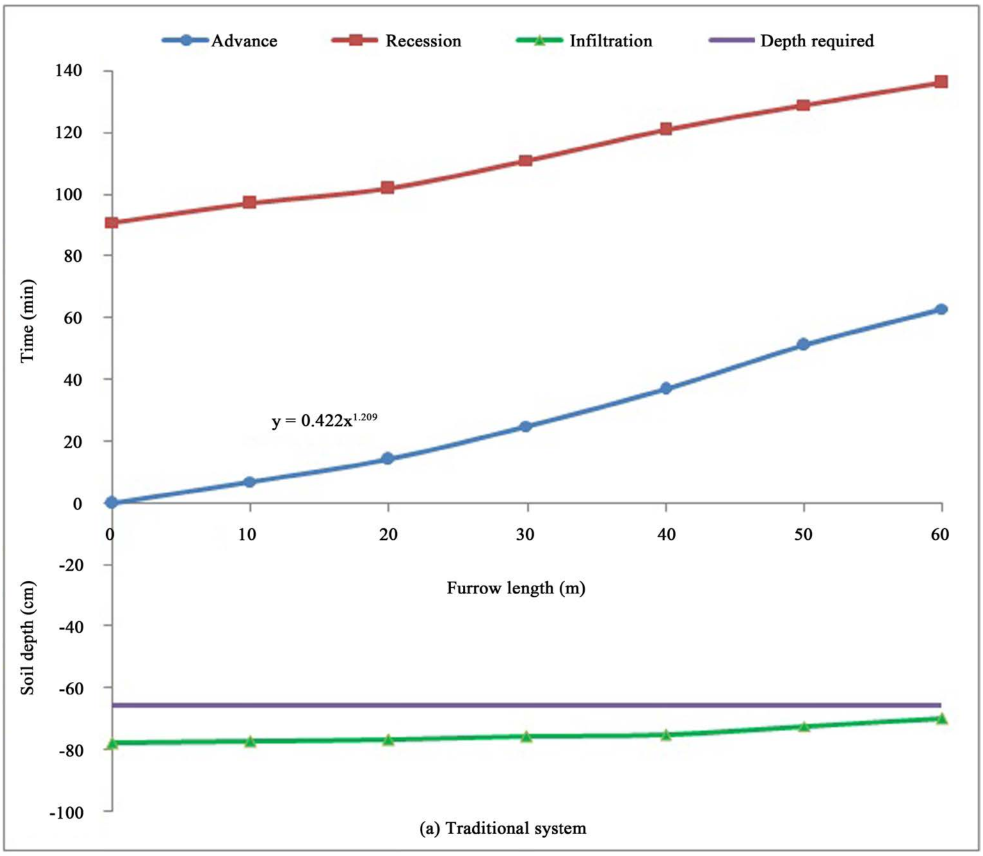
Data in **Table 4** show that application efficiency was improved by delivering water inside the furrow in gated pipes systems to minimize advance time, which results in decreasing water losses and ensuring that the depths and discharge variations over the field are relatively uniform and, as a result, available soil water in the root zone is also uniform. Traditional and GP1 irrigation systems achieved the highest storage efficiency without significant difference. Storage efficiency achieved values equal or nearly 100% in complete excess irrigation condition because the root zone is fully irrigated ($P_D = 0$), while application efficiency (E_a) have values less than 100% depending on uniformity CV [10]. Water application efficiency gives a general sense of how well an irrigation system performs its primary task of getting water to the plant roots. According to previous results, there is strong evidence that GP2 followed by GP1systems are more efficient than traditional irrigation method. In this respect, [26] indicated that the gated-pipe system has a high value of application efficiency (79% - 88%) compared with the open field head ditch (69% - 71%).

3.2.5. Uniformity

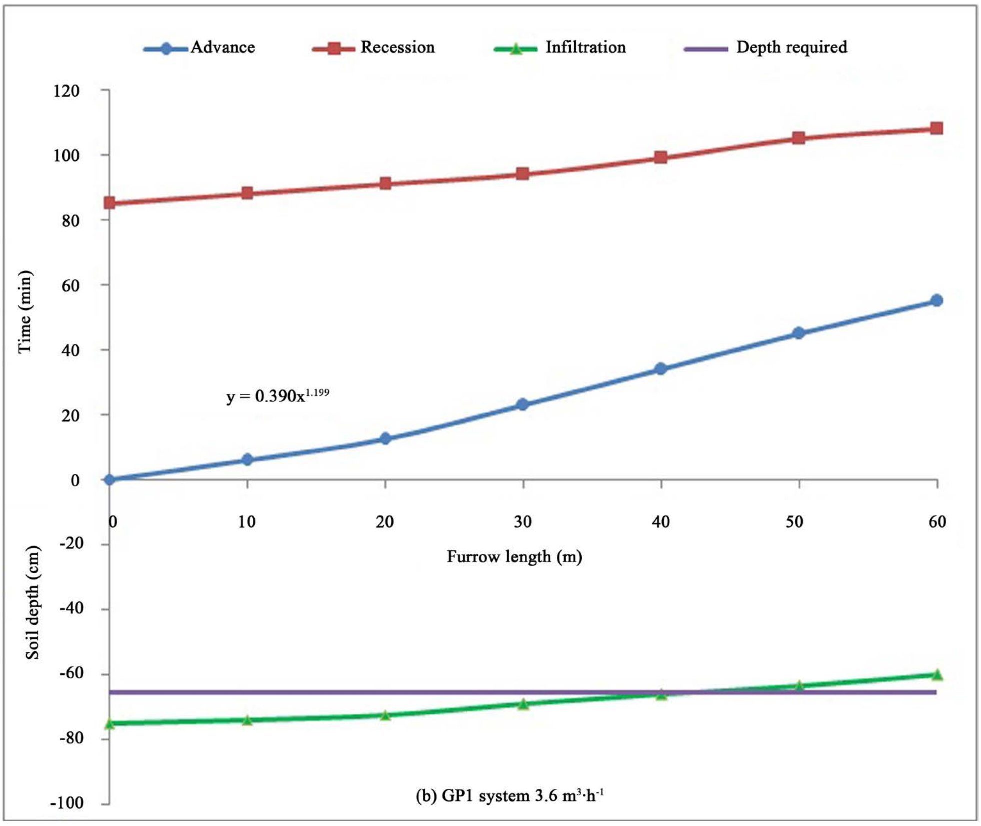
From the data in **Table 4**, it is evident that the values of distribution uniformity and uniformity coefficient were significantly influenced by irrigation systems. Gated pipes systems exhibited the highest values of DU and UC more than traditional method. Uniformity of water distribution in GP3 system was better than the other irrigation systems. The low value of uniformity was mainly due to the longer contact time which leads to temporal variations of the soil moisture distribution which is more evident along the field irrigated with traditional method. Non-uniformity of water application under irrigation system creates both deficit and excessive irrigation amounts into plant root zone [21]. To achieve high efficiency and uniformity of surface irrigation systems, all parts of an irrigated field should receive water for near equal period of time with a minimum of water lost to runoff or to deep percolation below the root zone.

3.3. Physiological Attributes

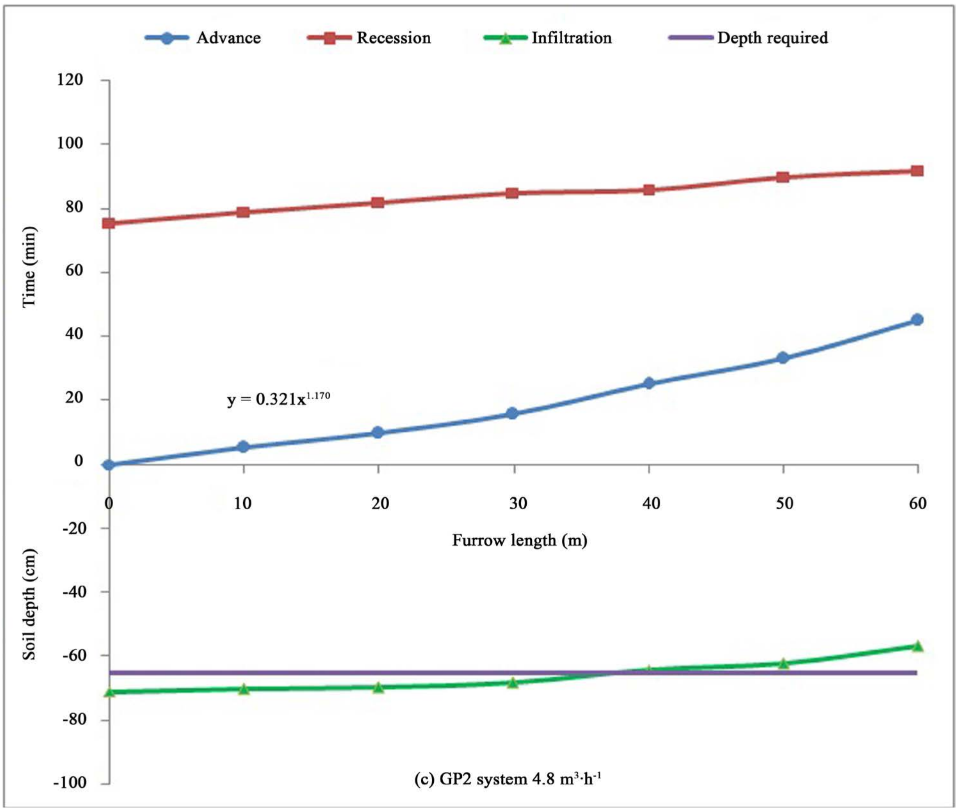
Physiological traits were significantly affected by irrigation systems and maize hybrids (**Table 5**). In both seasons, GP1 (3.6 $m^3 \cdot h^{-1}$) exhibited the highest values of Chl, CGR and ELA. The increases in Chl, CGR and ELA resulting from GP1 amounted to 14.34%, 13.44% and 5.46%, respectively more than the traditional irrigation. Flooding irrigation treatment was over-irrigated and resulted in considerable water losses by runoff and deep percolation below the root zone (**Figure 4**). Relative greenness of maize leaves was also affected due to flooding treatment as there was fading of leaf color as reflected by their corresponding SPAD values [27]. In this concern, [28] [29] mentioned that increasing or decreasing soil moisture may be resulted in unbalanced soil water-air re-



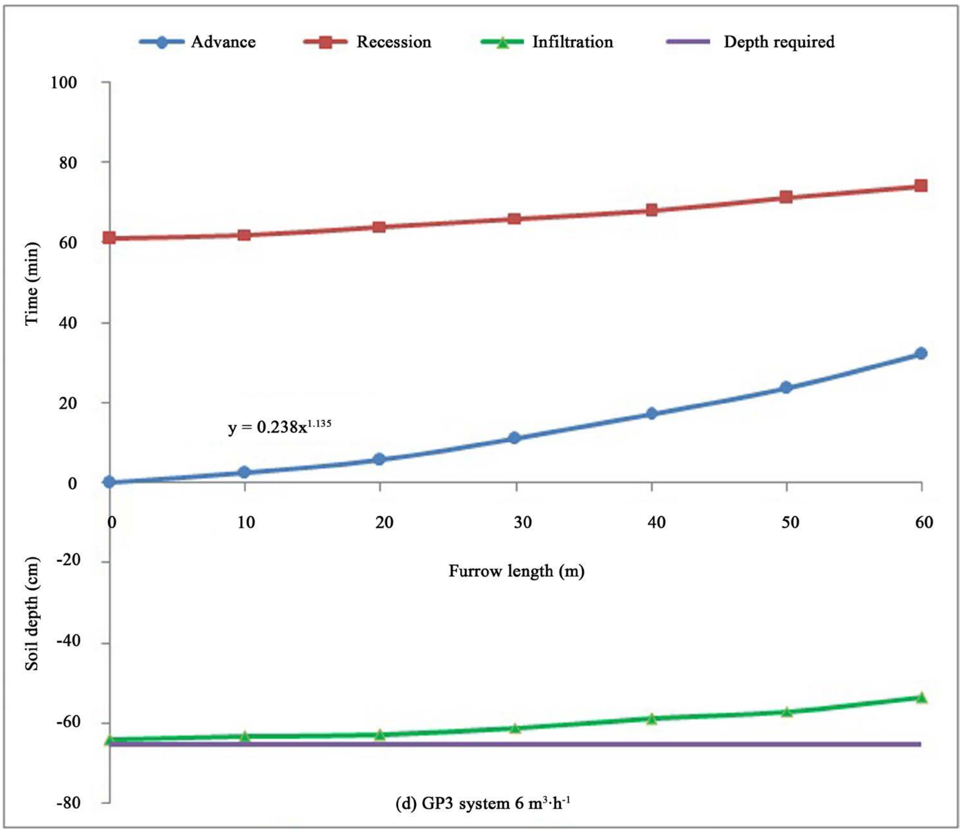
(a) Traditional system



(b) GP1 system 3.6 $m^3 \cdot h^{-1}$



(c) GP2 system 4.8 m³·h⁻¹



(d) GP3 system 6 m³·h⁻¹

Figure 4. Advance, recession and infiltrated water distributions curves of irrigation systems.

Table 4. Irrigation performance parameters per each irrigation (average of the two seasons).

Irrigation number	Ź (cm)	CV%	*α*	UC%	DU%	E_a%	E_s%
Traditional system							
1	72.738	10.901	−0.976	91.279	85.829	88.475	99.008
2	72.374	10.871	−2.996	91.304	85.868	67.428	100.00
3	73.051	10.785	−1.276	91.372	85.979	89.089	99.634
4	73.984	10.395	−1.090	91.684	86.487	91.679	99.315
5	76.945	12.070	−0.532	90.344	84.310	94.357	97.341
6	72.374	10.871	0.715	91.304	85.868	99.068	91.296
7	71.829	10.746	0.255	91.404	86.031	98.201	94.055
Mean	**73.328 a**	**10.948 a**	**−0.843 c**	**91.241 d**	**85.767 d**	**89.757 c**	**97.236 a**
GP1 system (3.6 $m^3 \cdot h^{-1}$)							
1	67.616	10.145	−0.381	91.884	86.811	96.131	97.238
2	66.681	9.602	−2.793	92.318	87.518	73.184	100.00
3	66.815	10.155	−0.562	91.876	86.798	92.301	97.889
4	69.446	11.035	−0.502	91.172	85.655	92.070	97.467
5	70.296	11.170	0.217	91.064	85.479	96.319	94.039
6	66.815	10.155	1.649	91.876	86.798	99.991	85.652
7	65.820	8.628	1.405	93.098	88.784	99.872	89.073
Mean	**67.641 b**	**10.127 b**	**−0.138 bc**	**91.898 c**	**86.835 c**	**92.838 ab**	**94.480 a**
GP2 system (4.8 $m^3 \cdot h^{-1}$)							
1	63.563	6.448	0.351	94.842	91.618	98.235	96.063
2	61.711	7.312	−2.861	94.150	90.494	79.078	100.00
3	60.340	6.439	0.685	94.849	91.629	98.990	95.777
4	66.477	7.786	−0.169	93.771	89.878	95.950	97.233
5	66.524	7.517	1.095	93.986	90.228	99.568	92.395
6	60.340	6.439	4.546	94.849	91.629	92.576	71.616
7	59.870	6.035	3.855	95.172	92.155	96.031	77.905
Mean	**62.689 c**	**6.854 c**	**1.071 b**	**94.517 b**	**91.090 b**	**94.347 a**	**90.141 b**
GP3 system (6 $m^3 \cdot h^{-1}$)							
1	59.323	4.696	2.038	96.243	93.895	99.933	91.266
2	59.294	4.288	−4.127	96.570	94.425	82.301	100.00
3	59.323	4.696	1.320	96.243	93.895	99.888	94.163
4	60.340	6.439	1.354	94.849	91.629	99.872	91.981
5	59.082	4.979	4.392	96.017	93.528	94.869	82.058
6	59.349	3.570	8.804	97.144	95.360	74.077	76.089
7	59.350	3.570	6.821	97.144	95.360	86.564	80.419
Mean	**59.437 d**	**4.605 d**	**2.943 a**	**96.316 a**	**94.013 a**	**91.072 bc**	**87.997 b**

Table 5. Physiological traits as affected by surface irrigation systems and maize hybrids during 2013 and 2014 seasons.

Hybrids irrigation systems	2013						2014					
	SC 10	SC 130	SC 131	SC 2031	TWC 321	Mean	SC 10	SC 130	SC 131	SC 2031	TWC 321	Mean
						Total chlorophyll (SPAD value)						
Traditional	38.41 j	39.64 ij	40.87 hi	43.41 fg	46.61 d	**41.79 C**	39.17 hij	41.04 fgh	38.05 ijk	41.67 fg	41.23 fgh	**40.23 C**
GP1	42.50 g	44.29 ef	45.31 de	54.48 a	48.44 c	**47.01 A**	43.37 ef	45.47 cde	47.38 bc	51.83 a	45.79 cd	**46.77 A**
GP2	38.27 j	42.10 gh	40.24 i	52.32 b	43.32 fg	**43.25 B**	40.22 ghi	40.81 gh	42.04 fg	48.46 b	44.73 de	**43.25 B**
GP3	33.46 k	40.15 i	38.22 j	45.30 de	39.55 ij	**39.34 D**	36.42 k	37.94 jk	41.19 fgh	42.00 fg	40.78 gh	**39.67 C**
Mean	**38.16 D**	**41.55 C**	**41.16 C**	**48.88 A**	**44.48 B**		**39.80 D**	**41.32 C**	**42.17 BC**	**45.99 A**	**43.13 B**	
						Crop growth rate (g plant^{-1} day^{-1})						
Traditional	7.69 ijk	8.51 fg	9.25 de	11.02 b	8.80 ef	**9.05 B**	8.12 H	10.02 e	9.36 f	12.14 b	9.28 f	**9.78 B**
GP1	8.24 f-i	10.21 c	11.82 a	12.27 a	9.73 cd	**10.46 A**	8.84 g	11.20 c	10.62 d	12.74 a	11.10 c	**10.90 A**
GP2	7.34 k	7.50 jk	8.55 fg	9.24 de	8.28 fgh	**8.18 C**	6.66 i	8.73 g	9.53 f	10.13 e	8.66 g	**8.74 C**
GP3	6.44 l	7.54 jk	7.96 g-j	8.66 f	7.80 h-k	**7.68 D**	6.04 j	8.08 h	8.57 g	9.49 f	8.07 h	**8.05 D**
Mean	**7.43 D**	**8.44 C**	**9.40 B**	**10.30 A**	**8.65 C**		**7.41 D**	**9.51 B**	**9.52 B**	**11.12 A**	**9.28 C**	
						Ear leaf area (cm^2)						
Traditional	571.5 g	587.3 f	631.5 c	681.3 b	588.5 f	**612.0 B**	594.6 g	575.0h	623.4 de	659.2 b	602.4 fg	**610.9 B**
GP1	618.5 d	603.3 e	686.9 b	710.9 a	622.4 cd	**648.4 A**	630.3 d	618.4 e	624.2 de	687.5 a	646.2 c	**641.3 A**
GP2	531.2 i	511.3 j	597.4 ef	604.5 e	563.4 g	**561.6 C**	552.4 i	556.1 i	603.9 f	620.9 e	554.3 i	**577.5 C**
GP3	440.3 l	476.2 k	567.1 g	548.2 h	511.4 j	**508.6 D**	461.5 m	496.9 l	513.4 k	531.2 j	536.3 j	**507.9 D**
Mean	**540.4 D**	**544.5 D**	**620.7 B**	**636.2 A**	**571.4 C**		**559.7 D**	**561.6 D**	**591.2 B**	**624.7 A**	**584.8 C**	

lations that lead to reducing the photosynthesis activity and unbalanced relations between plant hormones and biological processes in the whole plant organs. These adverse conditions in the treated soils are undoubtedly of great importance throughout the vegetative growth and dry matter accumulation. The findings obtained in this study were in good agreement to those reported by [30]-[33].

There were significant differences among maize hybrids in their physiological characters (**Table 5**). S.C 2031 variety significantly surpassed the other hybrids. S.C 2031 had Chl, CGR and ELA values that were 21.69%, 44.34% and 14.62% greater than those of S.C 10, respectively. Such results could be attributed to the differences in the genetic constitution of the tested varieties. Increase in Chl and consequently increase in rate of dry matter accumulation leads to an increase in ear leaf area because proportion of dry matter allocated to leaves are increased constantly. Genetic variability of maize genotypes was also reported by [2] [4] [27].

The interaction between irrigation systems and varieties had a significant effect on physiological traits in both seasons. S.C 2031 plants irrigated with GP1 (3.6 $m^3 \cdot h^{-1}$) surpassed other combinations and gave the highest values of Chl (54.48 and 51.83), CGR (12.27 and 12.74) and ELA (710.88 and 687.45) in both seasons. Meanwhile, S.C 10 irrigated with GP3 (6 $m^3 \cdot h^{-1}$) achieved the lowest values. Some of the differences among genotypes in growth and photosynthesis can be traced to different capacities for water acquisition and transport at a given water status [6]. This superiority might be due to well utilization of soil nutrients in meristematic tissues and metabolism activity which improved these traits. These results are consistent with the findings of [27] and [32].

3.4. Yield and Its Components

The data in **Table 6** and **Table 7** show that the differences among the surface irrigation treatments were significant for yield and its components. The irrigation systems significantly affected plant height. Using of GP1 system (3.6 $m^3 \cdot h^{-1}$) achieved the longest stems, while the shortest one was recorded with GP3 system (6 $m^3 \cdot h^{-1}$). With regard to maize ear traits, GP1 system surpassed other systems in number of rows per ear, number of grains per row and 100-grain weight followed by traditional irrigation in both seasons. From these results, it can be concluded that the superiority of GP1 in yield than traditional irrigation may be generally due to the tendency of this technique to produce more leaf chlorophyll, ear leaf area and CGR as shown in **Table 5**. The maize productivity was highly significantly affected by irrigation systems. Gated pipes system (GP1) produced the highest significant grain and stover yields, followed by traditional system. In contrast, GP3 system produced the lowest yields in both seasons. These results showed a positive relation between the yield and water quantity applied (**Table 3**). However, applying several inches of excess water (flooding) will lower the net return for the irrigated field potentially due to depressed grain yield resulting from more infiltration in traditional irrigation than GP (**Figure 4**) lead to leaching nutrients below the active root zone and inhibiting soil aeration. On the contrary, water deficit reduce carbon availability and dry matter partitioning to the ear during the critical period that determines grain number [34] and size of the sinks [1]. Corn yield is closely related to crop evapotranspiration (ET_c) and usually yield would be lowered if ET is lowered [12]. Drought and flooding are abiotic stresses which caused crop yield decrease [21] [35]. In this concern, other investigators indicated that the furrow irrigation by gated pipes achieved the highest yields of maize [9] [36] and sugarcane [26].

Results in **Table 6** and **Table 7** indicated that maize varieties exhibited significant differences in their yield and its components. Results revealed that, S.C 2031 variety significantly surpassed other varieties in plant height followed by T.W.C 321 variety, while S.C 130 had the shortest plants. S.C 2031 variety recorded the highest values of number of rows per ear, number of grains per row and plant grain yield without significant different with S.C 130 and S.C 131 for number of rows in the first season. However, the highest grain index was recorded by T.W.C 321 followed by S.C 2031 variety without significant. On the contrary, the lowest values were obtained by S.C 10 (for number of rows per ear), S.C 130 (for 100-grain weight) and S.C 131 (for number of grains per row) in both seasons. These results can be attributable to changes in light interception and utilization due to increases in chlorophyll content and ear leaf area (**Table 5**). An increase in CGR during the vegetative growth is indicative of response of the photosynthetic apparatus to an increase in demand for assimilates to afford growth of the grain fraction. Varieties significantly affected dry matter production and partitioning into the different plant components (grain and stover). S.C 2031 exhibited the highest grain and stover yields ha^{-1} in both seasons. It is clear from the obtained results that, S.C 2031 variety sowing led to an increase amounted to 32.06%, 21.71%, 12.29% and 18.99% for grain yield ha^{-1} and 39.44%, 21.75%, 11.09% and 20.71% for stover yield ha^{-1} than other S.C 10, S.C 130, S.C 131 and T.W.C 321, respectively. Genotypic superiority for grain and stover yields is particularly related to differences in any of yield components and dependent on the inherent genetic potential of the varieties themselves. In our study, varieties with higher values of physiological traits were higher yielding than those with lower values. These results are in harmony with those obtained by [4] [37] and [38] who indicated that single crosses of maize significantly surpassed the other crosses in growth and yield attributes.

The interaction effect between irrigation systems and varieties had a significant effect on the most yield and its components traits. No interaction effects were detected on number of rows per ear and 100-grain weight in both seasons. The highest values of yield attributes being obtained for S.C 2031 variety irrigated with GP1. By contrast, the shortest plants were recorded by S.C 130 and S.C 10 varieties irrigated with GP3. The lowest grains number was detected by irrigated S.C 10 and S.C 130 in the first season and S.C 10, S.C 130 and S.C 131 in the second one with GP3 system. Concerning maize yields, S.C 2031 variety irrigated with GP1 exhibited the first significant rank in plant grain yield and grain and stover yields ha^{-1}. Therefore this combination is recommended as the treatment that maximizes grain and stover yields. This combination may be exhibited better water and light utilization due to maintenance of green leaf area and leaf photosynthesis rather than other treatments. There is evidence that the variations in the grain yield response were due to variations in physiological traits that co-

Table 6. Yield components of maize as affected by surface irrigation systems and maize hybrids during 2013 and 2014 seasons.

Hybrids irrigation systems	2013						2014					
	SC 10	SC 130	SC 131	SC 2031	TWC 321	Mean	SC 10	SC 130	SC 131	SC 2031	TWC 321	Mean
Plant height (cm)												
Traditional	270.5 ef	250.6 hi	279.4 cde	289.8 abc	283.5 bcd	**274.8 B**	276.2 c	246.2 de	289.3 b	294.3 ab	290.9 b	**279.4 B**
GP1	278.4 de	256.2 gh	287.3 bcd	300.1 a	292.6 ab	**282.9 A**	275.7 c	251.5 d	301.5 ab	305.8 a	292.0 b	**285.3 A**
GP2	234.2 ij	236.4 jk	263.8 fg	262.6 fg	255.0 ghi	**250.4 C**	239.0 ef	229.7 fgh	268.1 c	272.4 c	269.0 c	**255.7 C**
GP3	222.4 l	227.1 kl	244.6 ij	253.1 fgh	248.9 hi	**239.2 D**	224.9 gh	218.6 h	237.1 efg	254.3 d	251.9 d	**237.4 D**
Mean	**251.4 C**	**242.6 D**	**268.8 B**	**276.4 A**	**270.0 B**		**253.9 C**	**236.5 D**	**274.0 B**	**281.7 A**	**276.0 AB**	
Number of rows per ear												
Traditional	13.33	14.00	14.67	14.67	14.00	**14.13 A**	13.33	13.33	14.00	16.00	13.33	**14.00 Ab**
GP1	13.33	14.67	15.33	15.33	14.00	**14.53 A**	14.00	14.00	15.33	16.00	14.00	**14.67 A**
GP2	12.00	12.67	12.67	14.00	13.33	**12.93 B**	12.67	13.33	12.67	13.33	13.33	**13.07 BC**
GP3	11.33	12.67	12.00	12.67	12.00	**12.13 B**	12.00	12.00	12.67	12.67	12.00	**12.27 C**
Mean	**12.50 C**	**13.50 AB**	**13.67 AB**	**14.17 A**	**13.33 B**		**13.00 B**	**13.17 B**	**13.67 B**	**14.50 A**	**13.17 B**	
Number of grains per row												
Traditional	42.67 def	43.67 b-e	44.00 b-e	46.33 abc	43.33 cde	**44.00 B**	43.33 cde	45.33 bcd	43.67 cde	47.33 ab	43.00 de	**44.53 B**
GP1	42.67 def	47.00 ab	46.00 a-d	48.00 a	45.00 a-d	**45.73 A**	43.67 cde	48.67 a	46.33 abc	49.00 a	44.67 bcd	**46.47 A**
GP2	36.67 hi	39.67 fgh	32.67 jk	39.00 gh	40.67 efg	**37.73 C**	38.67 fg	37.00 ghi	35.33 ij	38.33 fgh	41.00 ef	**38.07 C**
GP3	30.67 k	34.00 ij	29.67 k	31.67 jk	34.67 ij	**32.13 D**	33.33 jkl	30.67 l	32.00 kl	35.67 hij	34.00 jk	**33.13 D**
Mean	**38.17 B**	**41.08 A**	**38.08 B**	**41.25 A**	**40.92 A**		**39.75 B**	**40.42 B**	**39.33 B**	**42.58 A**	**40.67 B**	
100-grain weight (g.)												
Traditional	32.71	30.47	31.68	33.82	34.21	**32.58 A**	33.47	31.01	32.22	34.37	34.40	**33.10 A**
GP1	33.06	30.77	31.81	34.40	34.66	**32.94 A**	33.66	31.57	31.97	34.56	35.06	**33.37 A**
GP2	31.53	29.56	30.67	32.78	32.23	**31.35 B**	32.06	29.15	30.64	32.89	32.80	**31.51 B**
GP3	28.94	28.25	29.60	30.32	30.54	**29.53 C**	29.08	28.54	28.33	31.65	31.49	**29.82 C**
Mean	**31.56 B**	**29.76 D**	**30.94 C**	**32.83 A**	**32.91 A**		**32.07 B**	**30.07 D**	**30.79 C**	**33.37 A**	**33.44 A**	

determine tolerance to water stress. The interaction significance may be due to the different responses of each maize genotype to the different irrigation regimes as reported by [27] [29] [39].

Table 7. Maize productivity and WUE as affected by surface irrigation systems and maize hybrids during 2013 and 2014 seasons.

Hybrids irrigation systems	**2013**						**2014**					
	SC 10	**SC 130**	**SC 131**	**SC 2031**	**TWC 321**	**Mean**	**SC 10**	**SC 130**	**SC 131**	**SC 2031**	**TWC 321**	**Mean**
Plant grain yield (g.)												
Traditional	158.03 gh	164.56 fg	171.85 def	209.09 a	169.97 ef	**174.70 B**	170.64 f	172.64 f	181.18 def	206.90 b	179.17 def	**182.11 B**
GP1	172.70 def	175.45 de	188.51 c	213.01 a	179.74 d	**185.88 A**	177.48 ef	179.30 def	193.86 c	218.54 a	186.23 cde	**191.08 A**
GP2	129.58 j	140.09 i	151.69 h	200.38 b	152.40 h	**154.83 C**	135.60 i	148.96 gh	159.18 f	190.04 cd	153.07 gh	**157.37 C**
GP3	110.38 l	118.87 k	133.83 ij	165.50 fg	128.86 j	**131.49 D**	105.93 k	122.34 j	146.59 h	158.85 g	123.57 j	**131.46 D**
Mean	**142.67 D**	**149.74 C**	**161.47 B**	**197.00 A**	**157.74 B**		**147.41 D**	**155.81 C**	**170.20 B**	**193.58 A**	**160.51 C**	
Grain yield (kg·ha^{-1})												
Traditional	8188.6 gh	8816.4 f	9149.3 e	10523.0 b	9254.9 de	**9186.4 B**	8524.6 fg	9236.4 de	9744.7 c	10394.9 b	8647.4 f	**9309.6 B**
GP1	8806.6 f	9305.8 de	9808.8 c	11062.6 a	9493.4 d	**9695.4 A**	8992.3 e	9451.9 cd	10167.6 b	10911.8 a	9773.5 c	**9859.4 A**
GP2	6698.6 j	7255.4 i	8439.4 g	9851.5 c	7947.4 h	**8038.5 C**	7358.2 j	7969.2 hi	8535.6 fg	9728.4 c	8186.9 gh	**8355.6 C**
GP3	5811.1 l	6262.6 k	7258.6 i	8785.2 f	6810.7 j	**6985.6 D**	5834.4 l	7035.8 jk	7709.3 i	8260.1 gh	6714.2 k	**7110.8 D**
Mean	**7376.2 E**	**7910.0 D**	**8664.0 B**	**10055.6 A**	**8376.6 C**		**7677.4 D**	**8423.3 C**	**9039.3 B**	**9823.8 A**	**8330.5 C**	
Stover yield (kg·ha^{-1})												
Traditional	9653.8 ghi	11515.9 e	12827.0 bc	13445.3 a	11870.4 e	**11862.5 B**	10380.2 f	11538.0 de	11601.1 e	13247.5 b	11468.2 e	**11647.0 B**
GP1	10116.5 fg	11980.6 de	13330.6 ab	13639.0 a	12013.2 de	**12216.0 A**	10434.2 f	11701.4 de	12501.1 c	13902.2 a	11928.0 d	**12093.4 A**
GP2	7585.2 j	9090.0 i	10472.6 f	12535.7 cd	9690.5 gh	**9874.8 C**	8103.1 i	9692.9 g	9665.8 g	11771.8 de	9463.4 g	**9739.4 C**
GP3	6841.2 k	7338.7 jk	9311.0 hi	9955.7 fg	7651.0 J	**8219.5 D**	7193.8 j	7405.7 j	8543.8 h	9541.7 g	7130.6 j	**7963.1 D**
Mean	**8549.2 E**	**9981.3 D**	**11485.3 B**	**12393.9 A**	**10306.3 C**		**9027.8 D**	**10084.5 C**	**10577.9 B**	**12115.8 A**	**9997.6 C**	
Water use efficiency (kg grains m^{-3})												
Traditional	1.27 l	1.37 jk	1.42 ij	1.64 de	1.44 hi	**1.43 D**	1.33 i	1.44 h	1.52 g	1.62 ef	1.35 i	**1.45 D**
GP1	1.60 ef	1.69 cd	1.78 b	2.01 a	1.72 bc	**1.76 A**	1.63 ef	1.72 cd	1.84 b	1.98 a	1.77 c	**1.79 A**
GP2	1.38 ijk	1.49 gh	1.74 bc	2.02 a	1.64 de	**1.65 B**	1.51 g	1.64 ef	1.75 c	2.00 a	1.68 de	**1.72 B**
GP3	1.32 kl	1.42 ij	1.64 de	1.99 a	1.54 fg	**1.58 C**	1.32 i	1.59 f	1.75 c	1.87 b	1.52 g	**1.61 C**
Mean	**1.39 E**	**1.49 D**	**1.65 B**	**1.92 A**	**1.59 C**		**1.45 D**	**1.60 C**	**1.71 B**	**1.87 A**	**1.58 C**	

3.5. Irrigation Water Use Efficiency

The combined effects of irrigation systems and varieties on irrigation water use efficiency were significant in both seasons (Table 7). GP1 had WUE values that were 5.34%, 11.29% and 23.26% greater than those of GP2, GP3 and traditional methods, respectively. The use of GP1 technique increased WUE from 1.44 kg·m^{-3} for the farmer's usual water management practice to 1.78 kg·m^{-3} as average of both seasons. Increasing irrigation water led to decrease water use efficiency. Low WUE can occur when soil evaporation is high relative to crop evapotranspiration, early growth rates are low, water application does not correspond to crop demand, or shallow roots are unable to utilize deep water in the soil profile [12]. In this concern, [40] found that using gated pipes to irrigate long furrow (100 m long) resulted in saving water by 20% and 38% as well as increasing the water use efficiency by 58% and 26% for beans and corn, respectively compared with conventional surface irrigation method used short furrows (6 - 10 m long) in sandy soil. Meanwhile, [26] stated that use gated pipe system in sugarcane fields can reduce the irrigation quota by 48 - 156 $m^3 \cdot ha^{-1}$ for each irrigation cycle in comparing with open field head ditch.

The differences among the five maize varieties in their WUE were significant in both seasons. It is clear that S.C 2031 variety recorded the highest values followed by S.C 131. On the contrary, the lowest one was obtained by S.C 10. This means that S.C 2031 variety is more able to extract water from soil zones, and convert it into plant biomass than other varieties. [41] reported that maize plants are especially sensitive to water stress because their root system is relatively sparse.WUE of maize cultivars has been studied by several workers including [42] and [43]. These studies are important for identifying maize cultivars that are efficient in the use of limited soil water for biomass and grain yield production.

The response of maize plants to irrigation systems has been shown to change with hybrids (**Table 7**). It is interesting to note that the irrigated S.C 2031 variety with GP1 and GP2 system had highest WUE values similar to those obtained by the same variety under GP3 in the first season. The lower WUE was recorded with traditional irrigation especially under planting S.C 10 variety. Better management of the water balance with gated pipes technique can make significant improvements in water use efficiency under maize genotypes. [31] stated that maize genotypes with early adventitious rooting, increase root NAD^+-alcohol dehydrogenase activity and high starch accumulation in stem tissues showed good tolerance to excess soil moisture stress.

3.6. Nitrogen Accumulation

Plant tissue analysis has been used to reveal the status of nitrogen element in a soil-plant system. The grains and stover nitrogen percentage and accumulations were significantly different with various irrigation regimes and varieties (**Table 8**). Nitrogen % and accumulation were significantly increased by 1.30% and 7.05% in grains and 2.92% and 6.33% in stover, respectively when GP1 was applied in comparing to traditional irrigation. Nitrogen uptake was more dependent on water supply. N uptake decrease with greater water applied [30]. Since the oxygen is limited, microorganisms may turn to pathways of metabolism that can affect the availability and uptake of certain plant nutrients [29]. Adequate moisture improve uptake of nutrients by diffusion and root interaction, and will increase organic matter decomposition, which releases N, P and S. Low moisture can result in the formation of insoluble nutrient-containing. However, flooded or very wet soils increase the solubility of minerals and promote nitrogen leaching and the contamination of ground water by nitrates. [13] stated that maize leaf nutrients concentrations were reduced with increasing applied water quantity, indicating that leaf N concentration with the 0.80 ET_c treatment were generally equal to or higher than the concentrations with 1.00 ET_c.

By comparing the average values of varieties, the highest nitrogen percent and accumulations were attained by S.C 2031 more than other varieties. Meanwhile, S.C 130, T.W.C 321 and S.C 10 had the lowest values of grain N, stover N and accumulations, respectively. The canopy nutritional state can be evaluated through pigment concentration, as chlorophyll concentration in leaves is usually correlated to its nitrogen content. Indices that are good indicators of Chl are usually also good indicators of N-content [33]. Selection of genotypes with a more efficient mechanism of N uptake and metabolism is strategy aimed to increasing maize crop. From these results, it can be concluded that S.C 2031 had the ability to transport enough absorbed nitrogen to grains and stover more than that of other varieties.

Maize varieties differently responded to irrigation systems for grain N and accumulations (**Table 8**). It attributed to the differences of root distribution of genotypes under irrigation regimes. The hybrids response, especially S.C 2031, was increased with using GP1. Under this combination, N accumulations represent the capacity of plants to absorb more N from soil and fertilization applied. These findings are in line with the results of [1].

4. Conclusion

Irrigation management decisions should be made based on the amount of water applied and how this relates to the consumptive use demands of the plants and the soil water holding capacity. Adopting proper irrigation man-

Table 8. Nitrogen percentage and accumulation as affected by surface irrigation systems and maize hybrids during 2013 and 2014 seasons.

Hybrids irrigation systems	2013						2014					
	SC 10	SC 130	SC 131	SC 2031	TWC 321	Mean	SC 10	SC 130	SC 131	SC 2031	TWC 321	Mean
						Grain nitrogen (%)						
Traditional	1.541 cd	1.519 fgh	1.533 def	1.592 a	1.470 k	**1.531 B**	1.520 efg	1.536 e	1.581 ab	1.589 a	1.517 fg	**1.549 B**
GP1	1.563 b	1.537 de	1.555 bc	1.601 a	1.492 j	**1.550 A**	1.571 bc	1.556 cd	1.593 a	1.596 a	1.534 e	**1.570 A**
GP2	1.524 efg	1.492 j	1.512 gh	1.547 cd	1.451 l	**1.505 C**	1.505 gh	1.514 g	1.569 bcd	1.554 d	1.472 i	**1.523 C**
GP3	1.509 hi	1.483 jk	1.496 ij	1.525 efg	1.436 m	**1.490 C**	1.492 h	1.455 j	1.456 j	1.532 ef	1.441 j	**1.475 D**
Mean	**1.534 B**	**1.508 D**	**1.524 C**	**1.566 A**	**1.462 E**		**1.522 C**	**1.515 C**	**1.550 B**	**1.568 A**	**1.491 D**	
						Nitrogen accumulation in grain (kg·ha^{-1})						
Traditional	126.2 h	133.9 g	140.3 def	167.5 b	136.0 fg	**140.8 B**	129.6 gh	141.9 ef	154.1 c	165.2 b	131.2 gh	**144.4 B**
GP1	137.7 efg	143.0 d	152.5 c	177.1 a	141.6 de	**150.4 A**	141.2 f	147.1 de	162.0 b	174.1 a	149.9 cd	**154.9 A**
GP2	102.1 k	108.3 j	127.6 h	152.4 c	115.3 i	**121.1 C**	110.8 j	120.6 i	133.9 g	151.2 cd	120.5 i	**127.4 C**
GP3	87.7 m	92.9 l	108.6 j	134.0 g	97.8 k	**104.2 D**	87.0 m	102.4 k	112.2 j	126.5 h	96.8 l	**105.0 D**
Mean	**113.4 E**	**119.5 D**	**132.2 B**	**157.8 A**	**122.7 C**		**117.2 E**	**128.0 C**	**140.5 B**	**154.2 A**	**124.6 D**	
						Stover nitrogen (%)						
Traditional	0.759	0.723	0.758	0.771	0.685	**0.739 A**	0.733	0.734	0.764	0.773	0.663	**0.733 B**
GP1	0.767	0.763	0.769	0.775	0.699	**0.755 A**	0.773	0.751	0.780	0.798	0.699	**0.760 A**
GP2	0.761	0.698	0.754	0.765	0.676	**0.731 A**	0.742	0.678	0.734	0.768	0.682	**0.721 B**
GP3	0.728	0.677	0.652	0.743	0.645	**0.689 B**	0.717	0.654	0.691	0.735	0.678	**0.695 C**
Mean	**0.754 A**	**0.715 B**	**0.733 AB**	**0.764 A**	**0.676 C**		**0.741 AB**	**0.704 BC**	**0.742 AB**	**0.769 A**	**0.681 C**	
						Nitrogen accumulation in stover (kg·ha^{-1})						
Traditional	73.3 f	83.3 e	97.2 bcd	103.7 ab	81.3 e	**87.8 B**	76.1 ef	84.7 cd	88.6 c	102.4 b	76.0 ef	**85.6 B**
GP1	77.6 ef	91.4 d	102.5 abc	105.7 a	84.0 e	**92.2 A**	80.7 de	87.9 cd	97.5 b	110.9 a	83.4 cde	**92.1 A**
GP2	57.7 h	63.5 gh	79.0 ef	95.9 cd	65.5 g	**72.3 C**	60.0 h	66.0 gh	70.9 fg	90.5 c	64.5 gh	**70.4 C**
GP3	49.8 i	49.7 i	60.7 gh	74.2 f	49.4 i	**56.7 D**	51.6 i	48.4 i	59.0 h	70.1 fg	48.3 i	**55.5 D**
Mean	**64.6 D**	**72.0 C**	**84.9 B**	**94.8 A**	**70.0 C**		**67.1 C**	**71.7 C**	**79.0 B**	**93.5 A**	**68.1 C**	

agement strategies can limit negative impacts. Using a higher efficiency gated pipes irrigation system is recommended for irrigating maize, especially under deficit irrigation in case of water scarcity from a water-saving viewpoint. Selection of maize genotypes that have more efficient water use this will affect positively on agricultural production in general and in particular maize crop. From this study, we can conclude that substantial amounts of water can be saved by applying GP1 (5500 m^3·ha^{-1}) with significant increases in yield especially with sowing the new variety (S.C 2031) where it found that their impacts were positive on water use efficiency and productivity under old lands conditions.

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