Miao and Shi, Irrigat Drainage Sys Eng 2017, 6:3
DOI: 10.4172/2168-9768.1000193

Irrigation & Drainage Systems Engineering

Research Article Open Access

Field Assessment of Basin Irrigation Performance in Hetao, Inner Mongolia

Miao Q* and Shi H

College of Water Conservancy and Civil Engineering, Inner Mongolia Agricultural University, Hohhot, P.R. China

Abstract

Hetao irrigation district (Hetao) is located in the upper reaches of Yellow River basin. Surface irrigation is used because there is a high charge of sediments in the irrigation water and is appropriate to leach salts. Basin irrigation is the most used irrigation method. Traditional practices are inadequate for saving water and surface irrigation modernization is needed. A better knowledge of the performance of irrigation systems is required to base that modernization. An experimental research work was developed at Dengkou Experimental Station to assess the irrigation performance in laser land leveled fields. It is located on an irrigation sector supplied in agreement with a rotational delivery scheme managed by the Water Users Association (WUA), which usually practices a total of 7 events and the autumn irrigation. The typical field length is 50 m, with a width between 10 and 50 m, with a silt loamy soil. The irrigation performance was assess from field measurements carried out in several fields, cropped with the main irrigated crops, wheat, maize and sunflower. The irrigation field evaluation was based on observations of advance and recession times, soil moisture, inflow discharges, application time, topographic survey and crop development data. In addition, infiltration curves for typical and seasonal irrigation events were developed, and the Kostiakov infiltration parameters were estimated from field observations using the inverse method with the SIRMOD model. The irrigation operative parameters and the performance indicators were obtained, concluding that the distribution uniformity is very high, between 90 and 96%, and that the cutoff time has a very sensitive effect on beneficial water use fraction. Finally, the results of this study allowed the appropriate knowledge, including the crop irrigation scheduling data, for the irrigation design models aimed at developing irrigation alternatives.

Keywords: Surface irrigation; Distribution uniformity; Beneficial water use; Infiltration curves

Introduction

The Hetao irrigation district (Hetao), located in the upper reaches of the Yellow River, is one of the largest irrigation districts of China, with 0,570 Mha of irrigated land. The average annual rainfall is near 200 mm, so only irrigated agriculture is feasible. The canal network is supplied directly from the Yellow river. Due to increased demand for non-agricultural sectors, the Yellow River Commission aims to reduce the Hetao demand for water, which is a very great challenge that implies the adoption of modern technologies that should enable water saving, optimizing water productivity and improving farmers' incomes.

Surface irrigation systems, mainly basin irrigation, are the most representative of Hetao. Commonly, the performance of traditional irrigation methods is considered to be low but appropriate field assessments are lacking. On the one, farmers are aging and adopt traditional irrigation practices. On the other hand, the water fee is defined according to the field size and not depending upon the water use, so not motivating water saving. In addition, the water management by the Water Users Association s (WUA) is considered to be poor, with the distributor ditches often non-lined and gates of poor quality. However new lined distributors and new gates are presently in operation. Fields are usually non precisely levelled. Irrigation in field is also disorder. The water delivery calendars to the fields lack rationality and the rotation delivery is causing the need for irrigation by night, which is less efficient. The conditions observed in Hetao are quite similar to those previously identified for Huinong [1-3].

Aiming at water saving and modernization of surface irrigation, a better knowledge of the performance of irrigation systems is required. General conditions of Hetao are appropriate for surface irrigation due to the high charge of sediments on irrigation water, flat land, and farmer's knowledge, high compatibility with the canal conveyance and distribution network, and appropriateness to leach salts. To control salinity, farmers often over-irrigate as a guarantee to leach soil salts. However, generally, the autumn irrigation appropriately helps to control salinity and application depths should be selected according to soil salinity [4].

An experimental research work has been developed at Dengkou area in 2012 to assess the irrigation performance focusing laser land levelled fields. The study was located in an irrigation sector where a rotational delivery scheme managed by the WUA was practiced. A parallel study on irrigation scheduling has demonstrated that the farmers practice in Dengkou is quite acceptable [5]. The delivery schedule accepts up to 7 events and the autumn irrigation. The typical field length is 50 m and widths vary between 10 and 50 m. The soil is a silt loamy soil. The irrigation performance was assessed through field measurements [6,7] carried out in several fields, cropped with the main irrigated crops: wheat, maize and sunflower. Impacts of land levelling are under scrutiny [8].

To provide field information for irrigation modernization, an infiltration evaluation was also performed because infiltration is a crucial factor affecting surface irrigation. This process controls the amount of water entering the soil and the advance rate of the overland flow. Infiltration is a complex process, so it is difficult to predict with reliability and accuracy if appropriate field observations are not practiced [6]. The modified Kostiakov equation was applied to compute

***Corresponding author:** Miao Q, Assistant Professor, College of Water Conservancy and Civil Engineering, Inner Mongolia Agricultural University, Hohhot, P.R. China, Tel: 15049121836; E-mail: imaumqf@imau.edu.cn

Received November 22, 2017; **Accepted** December 01, 2017; **Published** December 08, 2017

Citation: Miao Q, Shi H (2017) Field Assessment of Basin Irrigation Performance in Hetao, Inner Mongolia. Irrigat Drainage Sys Eng 6: 193. doi: 10.4172/2168-9768.1000193

Citation: Miao Q, Shi H (2017) Field Assessment of Basin Irrigation Performance in Hetao, Inner Mongolia. Irrigat Drainage Sys Eng 6: 193. doi: 10.4172/2168-9768.1000193

soil infiltration and to characterize field infiltration. A set of infiltration data concerning families of infiltration curves and seasonal irrigation events is then required [9]. Thus, the objectives of this study were to characterize infiltration and advance and recession of water within the basins, as well as to determine main performance indicators aiming at further application of improved design [10,11] focusing water saving and higher farmers' incomes.

Material and Methods

The experimental work was developed at six laser leveled fields of Dengkou, cultivated with maize, sunflower and wheat. The irrigation field evaluations focused on observations of advance and recession times, soil moisture, inflow discharges, application time, as well as a topographic survey and observation of crop development data, using the methodology proposed by Walker and Skogerboe et al. [6]. Data are described in Table 1.

An infiltration study was performed to characterize standard infiltration curves for Hetao, representative of soil infiltration under surface irrigation conditions, which can be used for modelling purposes aiming at field assessment and improving surface irrigation at field scale. The Kostiakov equation was applied to describe soil infiltration [6]:

$$Z = K \cdot \tau^{a} + f_0 \cdot \tau \qquad (1)$$

Where Z is cumulative infiltration (m^3 m^{-1}); τ is infiltration time (min), K (m^3 m^{-1} min^{-a}) and a (dimensionless) are empirically adjusted parameters; and f_0 is basic infiltration rate (m^3 min^{-1} m^{-1}). In this study, f_0 was considered null, following the results of a previous study in Hetao by Zheng et al. [9]. To characterize field infiltration, it is required a set of infiltration data concerning families of infiltration curves, typical of seasonal irrigation events (first, second, and later irrigations) under flat soil infiltration conditions, like basin or border irrigation. For furrowed basins, the parameters were adjusted based on the average wetted perimeter according to Walker and Skogerboe [6]. The infiltration parameters were estimated from field observations using the inverse method in which observed advance and recession curves were compared with those computed with the simulation model SIRMOD [7,12]. The Manning's hydraulic roughness coefficients n used for the simulation was selected on the basis of former studies by Zheng et al. [9]. The optimal parameter values were obtained after several iterations aiming at minimizing the sum of the squares of the deviations between observed and simulated advance and recession times (SQRT), defined as:

$$SQRT = \sqrt{\frac{\sum_{i=1}^{N}(O_{ai} - S_{ai})^2}{N}} + \sqrt{\frac{\sum_{i=1}^{N}(O_{ri} - S_{ri})^2}{N}} \qquad (2)$$

Where O_{ai}, S_{ai}, O_{ri}, and S_{ri} (i=1,2,……,N) are respectively the times (min) observed and simulated for advance and for recession, and N is the number of observations.

The field experimental data to carry out this study were of two sources: a set of field trials developed in Dengkou that provided infiltration data observed on basin irrigation for silt loamy soils, and past observation data [9] from Linhe area, typical for silty soils. These two sources of data are complementary to represent major Hetao soil types.

Results

Advance and recession curves, inflow rates and infiltration parameters

The infiltration parameters (Table 2) were determined in several fields from observation of advance and recession. The SIRMOD model was applied using the inverse method to optimize the infiltration parameters using the observed inflow rates referred in Table 1. Results for observed and simulated advance and recession are presented in Figure 1. A good match of both advance and recession curves was obtained..

The infiltration curves obtained in Dengkou area were grouped by irrigation event. The average curves for the first (SC-I), second (SC-II) and later events (SC-III and SC-IV) were therefore identified (Figure 2a). These results show a significant variability of infiltration from the first to the fourth events in the silt loamy soil. To characterize this soil behaviour, three standard curves (dashed lines in Figure 2a) were considered for later simulating irrigation: high infiltration, which is very close with SC-II curve; the medium infiltration, near the SC-III curve, and low infiltration, close to the SC-IV.

Data of Zheng et al. [9] for the silt soils of Linhe area were considered to complete the set of standard curves (Figure 2b). The SC-

Crop	Field size	Slope	Land Leveling Sd	Irrigation Events	Irrigation date	Applied time T_{app}	Applied depth D_{app}	Inflow rates	Roughness n (s $m^{-1/3}$)	Field Identification
	(m)	(‰)	(cm)			min	(mm)	(l $s^{-1}m^{-1}$)		
Maize	50 × 15	0.5	4.1	1	06-13	40	134	2.8 ± 0.5	0.16	M1-1
				2	07-18	35	105	2.5 ± 0.2	0.14	M1-2
				3	08-28	30	94	2.6 ± 0.3	0.14	M1-3
Maize	50 × 20	0.8	3.8	1	06-13	50	132	2.2 ± 0.4	0.16	M2-1
				2	07-18	52	112	1.8 ± 0.4	0.14	M2-2
				3	08-28	49	90	1.5 ± 0.4	0.14	M2-3
Maize	50 × 30	0.2	2.9	1	06-13	52	131	2.1 ± 0.4	0.16	M3-1
				2	07-18	47	108	1.8 ± 0.4	0.14	M3-2
				3	08-28	62	104	1.4 ± 0.2	0.14	M3-3
Maize	50 × 48	0.1	2.8	1	06-13	62	119	1.6 ± 0.3	0.16	M4-1
				2	07-18	63	106	1.4 ± 0.2	0.14	M4-2
				3	08-28	60	101	1.4 ± 0.3	0.14	M4-3
Wheat	50 × 10	0.5	2.7	1	05-13	29	132	3.8 ± 0.4	0.20	W1-1
				2	05-25	25	108	3.6 ± 0.4	0.16	W1-2
				3	06-13	30	119	3.3 ± 0.1	0.16	W1-3
Sunflower	50 × 15	0.1	2.9	1	07-18	36	104	2.4 ± 0.1	0.14	S1-1
				2	08-28	40	101	2.1 ± 0.6	0.14	S1-2

Table 1: Irrigation experimental field trials at Dengkou area.

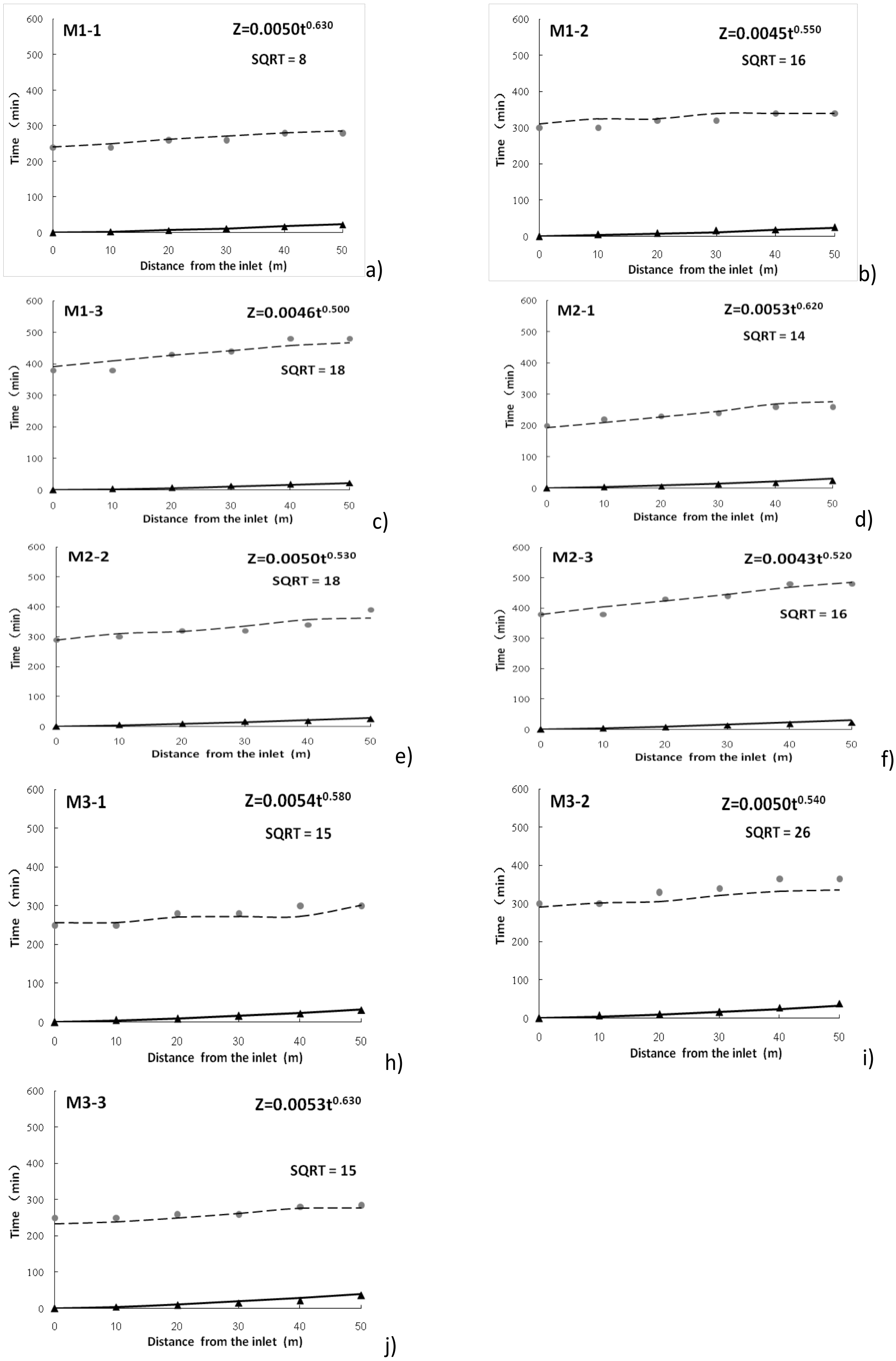

Figure 1: Observed (▲) and simulated(━━)advance, and observed (●) and simulated(– –) recession, including SQRT and best fit infiltration equations for maize fields M1, M2, M3, for first, second and third irrigation events.

Citation: Miao Q, Shi H (2017) Field Assessment of Basin Irrigation Performance in Hetao, Inner Mongolia. Irrigat Drainage Sys Eng 6: 193. doi: 10.4172/2168-9768.1000193

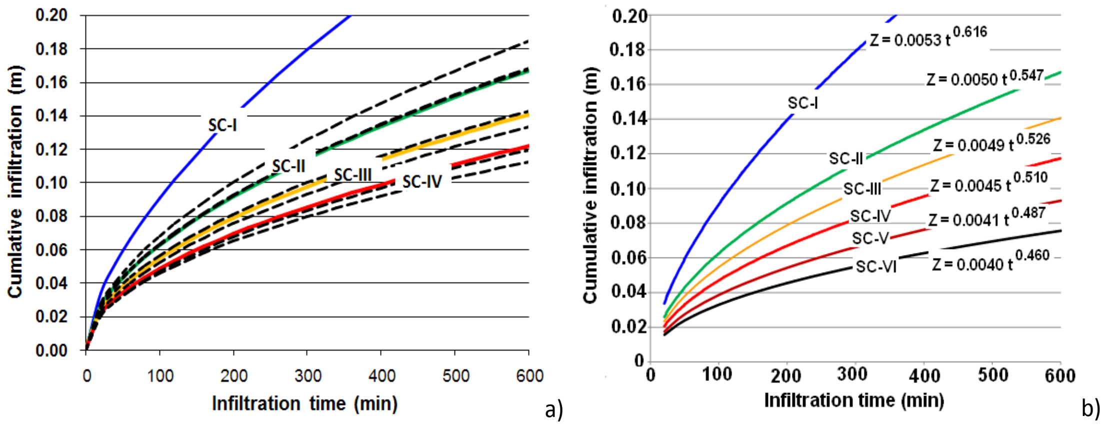

Figure 2: Infiltration curves for a) Dengkou grouped from the first to the fourth events, and b) the six Hetao standard infiltration curves (including Linhe area data)

Treatment	k (m.min^{-a})	a (-)	SQRT (min)
M1-1	0.0050	0.630	8
M1-2	0.0045	0.550	16
M1-3	0.0046	0.500	18
M2-1	0.0053	0.620	14
M2-2	0.0050	0.530	18
M2-3	0.0043	0.520	16
M3-1	0.0054	0.580	15
M3-2	0.0050	0.540	26
M3-3	0.0053	0.540	15
M4-1	0.0055	0.570	20
M4-2	0.0055	0.540	14
M4-3	0.0050	0.550	19
W1-1	0.0058	0.655	17
W1-2	0.0053	0.570	11
W1-3	0.0053	0.555	12
S1-1	0.0053	0.515	13
S1-2	0.0048	0.520	18

Table 2: Infiltration parameters from Dengkou observations.

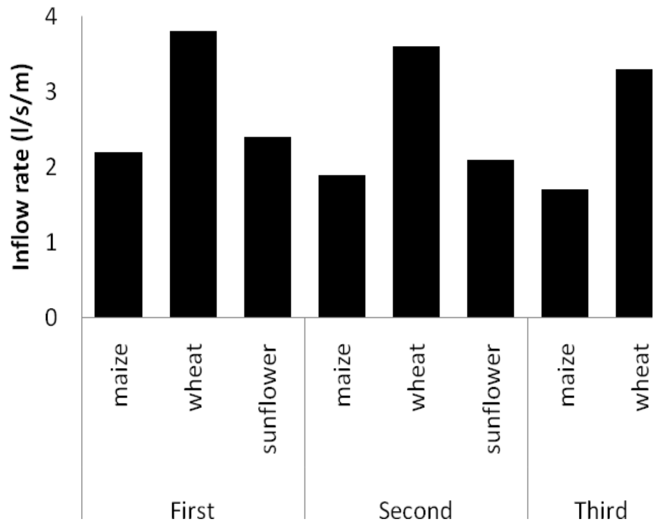

Figure 3: Observed inflow rates curves.

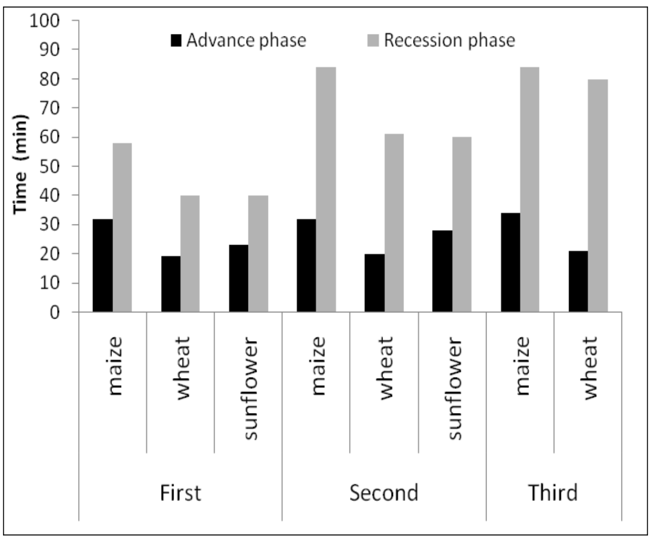

Figure 4: Observed time duration of advance and recession phases.

II represents well the infiltration conditions for the first irrigation event but additional curves SC-V and SC-VI were required. The six standard curves obtained for silt soils are shown in Figure 2b.

Cut-off time analysis

Actual irrigation performance was analyzed using field evaluation data. Inflow rates are given in Figure 3; related data shows that inflow rates decrease from the first to the third irrigation events and are larger for wheat. The observed advance and recession duration, Figure 4 show that advance is shorter for wheat and larger for maize, thus varying in an inverse way of inflow rates. The advance and recession curves in Figure 5 show that the infiltration opportunity time is not very different comparing up- and downstream sections of the fields. Irrigation depths Z_{app} (mm) were observed in the field and compare well with the required infiltration Z_{req} (mm), computed with the ISAREG model [5]. However, the applied irrigation depth Z_{app} are generally larger than Z_{req} (Figure 5), but the resulting over-irrigation is not excessive and may be adequate to leach salts.

Over-irrigation could be controlled by adjusting the cut-off time. The recession and infiltrated curves observed and computed after adjusting the cut-off time are also presented in Figure 3. They show

Citation: Miao Q, Shi H (2017) Field Assessment of Basin Irrigation Performance in Hetao, Inner Mongolia. Irrigat Drainage Sys Eng 6: 193. doi: 10.4172/2168-9768.1000193

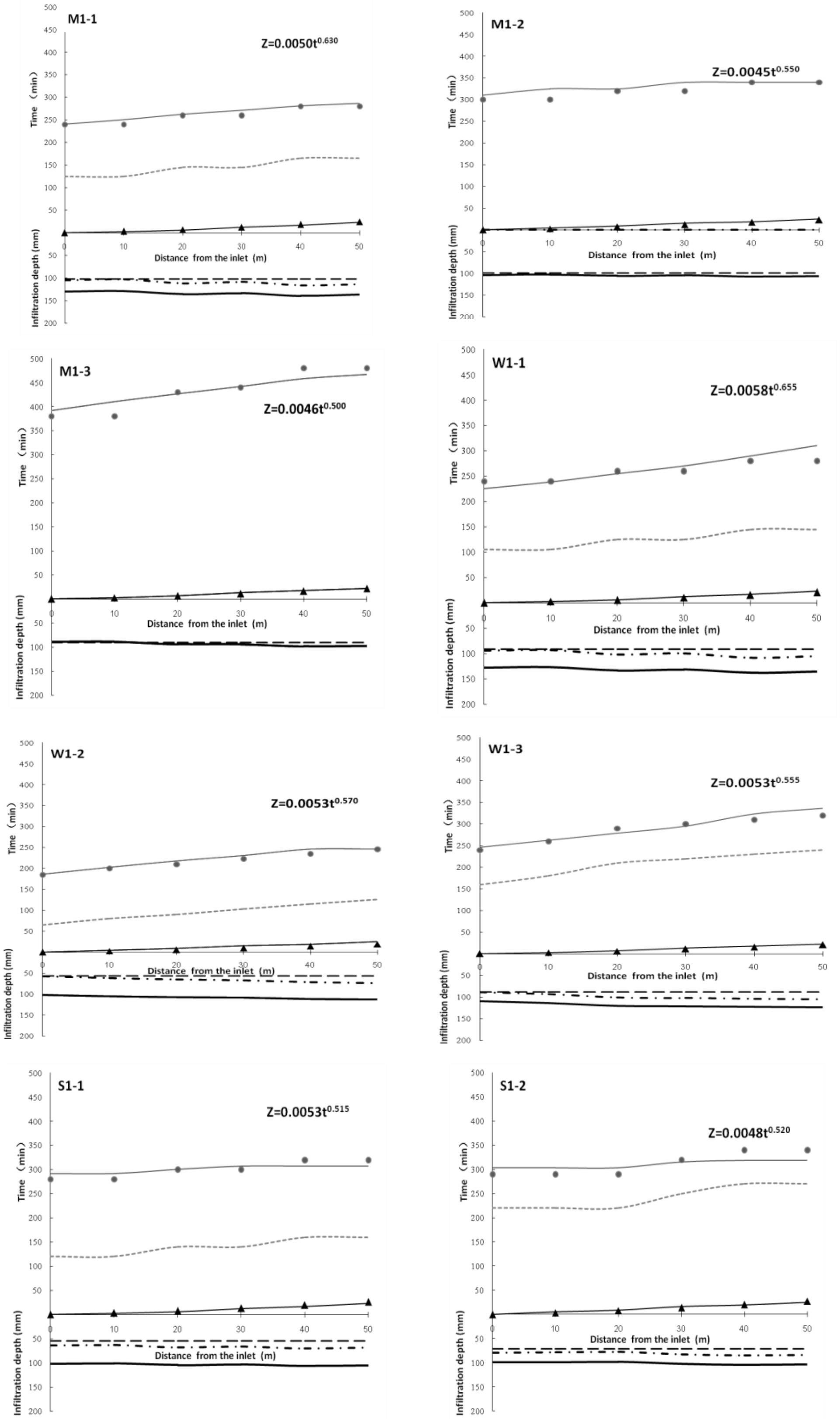

Figure 5: Observed and simulated advance and recession, observed infiltration; cut-off adjusted simulated recession (----) and infiltration curves for M1, W1 and S1 for first, second and third irrigation events, respectively.

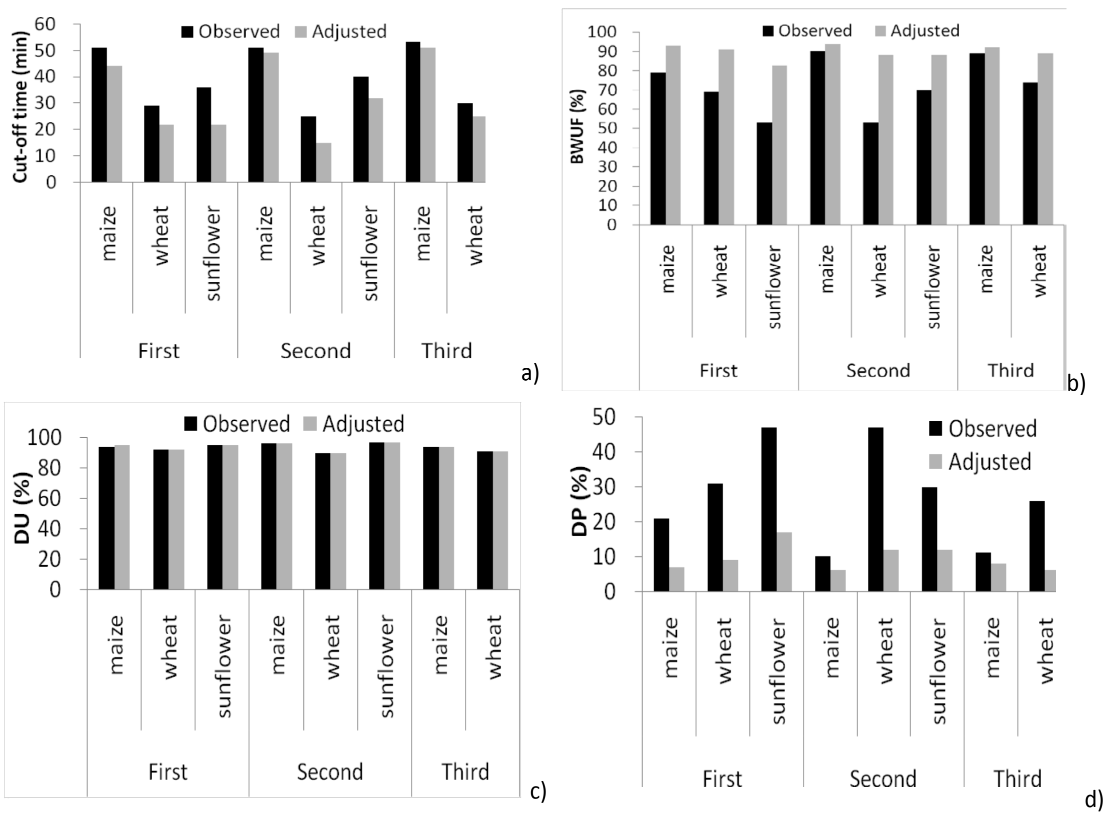

Figure 6: Comparison of a) cutoff time, b) BWUF, c) DU and d) DP curves, for several crops and events, between the observed and the adjusted

that, after adjusting the cut-off time the applied irrigation depths Z_{app}, particularly for wheat and sunflower, are close to Zreq but allowing a slight percolation necessary for leaching, thus indicating that adjusted irrigation is appropriate.

Irrigation performance

The irrigation performance analysis was developed for the actual field conditions and current field slopes. Results are shown in Figure 6 including the distribution uniformity DU (%), the beneficial water use fraction BWUF (%) and deep percolation DP (%). Indicators are defined by Pereira et al. [13]. DU values are generally high because precise land levelling was applied and the length of the basins are small. However, the BWUF are lower than expected for laser land levelled basins due to over-irrigation.

Adjusting the cut-off time's better irrigation performance is obtained. The procedure of adjusting the cut-off time considers the observed advance curve, a simulated recession curve and the recalculation of the infiltration depths according the updated infiltration opportunity times. The adjusted cut-off times are shown in Figure 6a compared with the observed cut-off times. Figure 6b shows how BWUF values increase after cut-off time adjustment, then improving to values larger than 90%. This relates mainly with the control of deep percolation as shown in Figure 6d. Figure 6c shows that DU is generally high because land levelling highly improves uniformity of water distribution within a basin. Overall, results show that irrigation performance could be very good when all factors are well set. More favourable results may be achieved when basin surface are precise levelled, irrigation scheduling is improved and cut-off time is well controlled.

Conclusions

The basin irrigation performance was assessed using field evaluation data and computer simulation after parameterizing infiltration by exploring the model SIRMOD in the inverse way. Typical infiltration curves were obtained. These curves are required for irrigation evaluation and design modelling. It was observed that the present farmers practice is characterized by a small over irrigation due to excessive application time. Precise land levelling leaded to a good uniformity of distribution, DU. However, the BWUF is small if the cut-off times are not adjusted. When adjusted, BWUF are high and deep percolation is reduced.

It was concluded that to achieve water saving and salinity control it is required to adopt precise land levelling and manage crops adopting an adequate irrigation scheduling [5] and performing an appropriate inflow rate control by adopting an accurate cut-off time. Improving the cut-off time for fields with 50 m length through reducing the application time by 5 to 15 minutes, may lead to increase BWUF by 5 to 40%. Further improvements are expected when a modern design will be applied.

Acknowledgements

This study was funded by the project of Inner Mongolia Agricultural University, No NDYB2016-23; the Key project of National Natural Science Foundation, No. 51539005; National Natural Science Foundation, No. 51769024; Project of National thirteenth Five-year Scientific and Technical Support Plan, No 2016YFC0400205., contracted with the Ministry of Science and Technology, China.

References

1. Gonçalves JM, Pereira LS, Fang SX, Dong B (2007) Modelling and multicriteria

analysis of water saving scenarios for an irrigation district in the Upper Yellow River Basin. Agric Water Manage 94: 93-108.

2. Pereira LS, Gonçalves JM, Dong B, Mao Z, Fang SX (2007) Assessing basin irrigation and scheduling strategies for saving irrigation water and controlling salinity in the Upper Yellow River Basin. China Agric Water Manage 93: 109-122.
3. Zheng HX, Shi HB, Guo KZ, Hao WL (2011) Study on influence of field surface slope on irrigation efficiency in combination with different irrigation parameters. Agric Research in the Arid Areas.
4. Li RP, Shi HB, Takeo A, Zhang YQ, Zhang XH (2010) Scheme of water saving irrigation in autumn based on SHAW model in Inner Mongolia Hetao irrigation district. Trans CSAE 26: 31-36.
5. Miao QF, Zhu L, Paredes P, Shi HB, Gonçalves JM (2014) Irrigation scheduling modelling applied to main crops and the intercrop wheat-maize in Hetao. In: CIGR Congress, Beijing.
6. Walker WR, Skogerboe GV (1987) Surface Irrigation. Theory and Practice. Prentice-Hall.
7. Horst MG, Shamutalov SS, Pereira LS, Gonçalves JM (2005) Field assessment of the water saving potential with furrow irrigation in Fergana, Aral Sea Basin. Agric Water Manage 7: 210-231.
8. Xu RZ, Wei ZM, Xia YH, Zhang WL (2012) Effects of laser precision land levelling on border irrigation and its water saving performance. J Irrig Drain 31: 6-9.
9. Zheng H, Shi H, Zhu M, Liu H, Gonçalves JM (2009) Estimation of infiltration parameters for border irrigation based on SIRMOD method and modelling of border irrigation. Trans CSAE 25: 29-34.
10. Gonçalves JM, Pereira LS (2009) A decision support system for surface irrigation design. J Irrig Drain Eng 135: 343-356.
11. Gonçalves JM, Horst MG, Pereira LS, Muga AP (2011) Furrow Irrigation Design with Multicriteria Analysis. Bio Systems Engineering 109: 266-275.
12. Katopodes ND, Tang JH, Clemmens AJ (1990) Estimation of surface irrigation parameters. J Irrig Drain Eng 116: 676-696.
13. Pereira LS, Cordery I, Iacovides I (2012) Improved indicators of water use performance and productivity for sustainable water conservation and saving. Agric Water Manage 108: 39-51.