FIELD CALIBRATION AND MODIFICATION OF SCS DESIGN EQUATION FOR PREDICTING LENGTH OF BORDER UNDER LOCAL CONDITIONS

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Field tests were conducted to calibrate the existing SCS design equation in determining field border length using field data of different field lengths during 2nd and 3rd irrigations under local conditions. A single ring infiltrometer was used to estimate the water movement into and through the irrigated soil profile and in estimating the coefficients of Kostiakov infiltration function. Measurements of the unit discharge and time of advance were carried out during different irrigations on wheat irrigated fields having clay loam soil. The collected field data were used to calibrate the existing SCS design equation developed by USDA for testing its validity under local field conditions. SCS equation was modified further to improve its applicability. Results from the study revealed that the Kostiakov model over predicted the coefficients, which in turn overestimated the water advance length for boarder in the selected field using existing SCS design equation. However, the calibrated SCS design equation after parametric modification produced more satisfactory results encouraging the scientists to make its use at larger scale.
Keyword: Border irrigation, design, SCS equation, border length

INTRODUCTION

Irrigated agriculture is a challenge to mankind, which is getting more severe with increase in population worldwide. Water is applied to the field in different ways but the most widely used irrigation practice is the flooded surface irrigation. In surface irrigation systems typically two times water is being applied to the fields, as will be utilized by the crops being grown (Strelkoff and Katopodes, 1977). The excess water evaporates, drains off at the end of the field as surface runoff and eventually percolates through the soil, which may join the groundwater reservoir. This relatively low local utilization of water mainly results from improper system design and/or system operation (Choudry *et al.*, 1995). Experience gained over centuries has shown that if irrigated agriculture has to be sustained, it must be designed to consider the irrigated land as a system for efficient utilization of water (Khan, 1982).

Level Boarder or Basin irrigation practice is the most popular and commonly used irrigation method in Pakistan due to its inherent advantages that include; uniformity of water application and subsequent salt balance control, no runoff and reduced labour and energy requirements (Mahmood *et al.*, 2003). Local research on level boarder irrigation is limited, however, research studies conducted at different parts of the world indicates that properly designed and managed level boarder irrigation systems have the potential to perform at higher levels of efficiency than pressurized systems, particularly sprinkler irrigation (Carr, *et al.*, 199; Keller, 1990; Ross and Hedlund, 1991). Many empirical and mathematical models have been used abroad as design tools for surface irrigation systems and one of them is the SCS design equations as developed by United States Department of Agriculture (USDA) for surface irrigation systems (James, 1988; Sakkas and Bellos, 1991). The values derived by SCS method for boarder irrigation are dependent on flow rate, crop and climatic field conditions. The variability of these parameters sometimes poses difficulties in using this method at different parts of the world. More importantly, the SCS equations are suited to larger field lengths, which are not practically feasible in Pakistan as the farmers usually divide their fields according to their convenience resulting in a wide range of field lengths and widths (Raza, 1993). This demands calibration and validation of the empirical formulae derived from SCS methods under local conditions. The present study was an attempt to calibrate and further improve the design predictability of SCS border design equations in terms of field length for meaningful application in local environment.

THEORETICAL CONSIDERATION

SCS Border Model

The soil conservation services (SCS) of United States Department of Agriculture (USDA) developed equations (USDA, 1974; USDA, 1979) for the design of level borders based on continuity and a volume balance approaches using the assumptions as given below.

- The volume of the water delivered to the border strip is adequate to cover the area of the border strip to an average depth that is equal to the gross irrigation application.
- The intake opportunity time at the down stream end of the border strip equals the time required for the net irrigation to enter the soil.
- The longest intake opportunity time at any point on the border strip is such that deep percolation is minimized.

The opportunity time is defined as the time duration at a given location of field between Advance and Recession. The opportunity time can be computed using the following Kostiakov equation (USDA, 1979);

$$F = aT^{b} + c \quad (1)$$

Where: F = Cumulative infiltration, mm; T = Opportunity time, mintues & ‘a’,‘b’,‘c’ are constants.

Based on the above given assumptions, the SCS design presented the following empirical equation for determining the length of level border (USDA, 1979)

$$L_t = \frac{6x10^4 Q_u T_t}{\frac{aT_t^b}{1+b} + 7.0 + 1798 n^{\frac{3}{8}} Q_u^{\frac{9}{16}} T_t^{\frac{3}{16}}} \quad (2)$$

Where: L_t = Length of Advance, m; T_t = Time of Advance, minutes; a, b, c = Kostiakov Intake Constants; Q_u = Unit flow rate, m^2 sec $^{-1}$ & n = Roughness Coefficient.

The flow rate, crop and climatic conditions existing in Pakistan vary significantly as compared to those considered by SCS, which pose further difficulties in using this method. Use of SCS method needs modification to meet the requirements of local condition for precise designing of level border irrigation system.

comparison of model out put of theoretical predictions with the actual observation is necessary for model calibration. The calibration of a model/system can only be approached but never achieved. The calibration of an equation like SCS can be done by evaluating the coefficients or by adjusting the powers of the variables used in the non-linear regression equation, which could be solved by Gauss Newton method, which is a very lengthy procedure and needs much iteration (Raza, 1993). GENSTAT, 1988 uses this procedure to solve such complex problems. Thus, SCS equation parameters of ‘Qu’, ‘Tt’, ‘a’,‘b’,‘c’ was calibrated for the local conditions of fields.

FIELD EXPERIMENTATION

A field of one and a half acre (53.7 m x 108.7 m) was selected at the experimental farm and leveled using Laser Land Leveling technique. The field was divided into border of different lengths i.e., 41 m, 64 m and 105 m, keeping a constant width of 6 m (Fig 1). Each length treatment was replicated thrice and wheat was sown in the experimental plots. The mechanical composition of the soil was determined by using hydrometric method and USDA Soil Triangle technique. Soil composition of the experimental site based on the proportions of sand, silt and clay was found to be 52.4%, 25.4% and 21.8% respectively, which showed soil texture of clay loam.

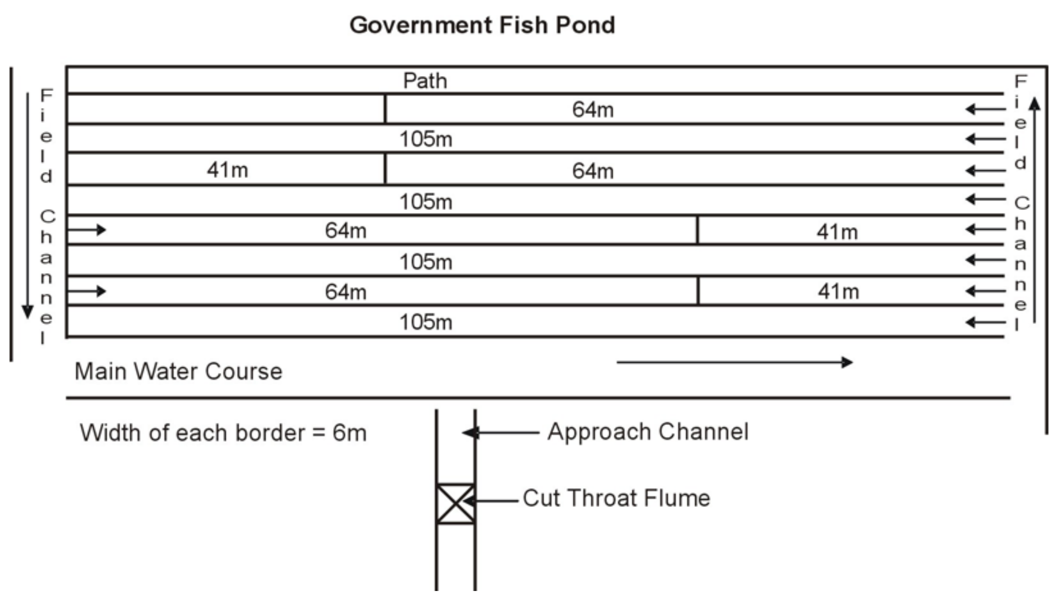

Figure 1. Field layout of experimental plot

Calibration of SCS model

A model is a simplified representation of a system intended to enhance our ability to understand, predict and possibility control the behavior of the system. The model is not an exact representation but a close approximation of the real system. Therefore, the

Irrigation water was applied to the borders in accordance with the irrigation turn, each time allowing the water to reach the end of field during irrigation under local rotational system. A Cutthroat flume (8” x 3” size) was installed at the main watercourse to measure the discharge of water. During irrigation, the infiltration rate was measured using a single ring infiltrometer that was installed in the border. The depth of water in the infiltrometer was noted after frequent intervals until the rate of infiltration became constant. The observed values of the time interval and cumulative infiltration were used to evaluate the coefficients of Kostiakov equation (Eq. 1) during irrigations. The advance rate of water flowing, during each irrigation was observed by placing wooden stakes at 5 m interval along the border length. The total time to irrigate a border and cutoff times were also recorded. Data collected during different irrigations were used to plot the advance curves for different sized borders. The recession in borders could not be noted due to excessive darkness as the irrigation turn was quite late at experimental site. The averaged field data collected during 2nd and 3rd irrigations was used to modify the existing SCS design equation for the given local conditions of soil texture class, inflow rate and topographical slope etc.

RESULTS AND DISCUSSION

The SCS design equation required the measurements of unit discharge 'Qu', time of advance 'Tt', intake constants 'a' 'b','c' and roughness coefficient 'n' during experimentation. These data were collected in the field and the values of 'L', 'Qu', 'Tt', 'a','b','c' and 'n' when used in the SCS design equation for border, predicted the design length of border which was compared with the actual ones in each treatment. The description of procedure and resulting modification in the parameters of SCS existing equation is discussed next.

Soil Infiltration Characteristics

The observed values of cumulative infiltration from the field were compared with those predicted by the Kostiakov equation and those from calibrated Kostiakov equation are given in Table 1 and Table 2 for both 2nd and 3rd irrigations, respectively. The cumulative infiltration observed from the field was very less at the beginning as predicted by Kostiakov equation (Eq.1). Two minutes later, the observed cumulative infiltration increased only to 0.079 inches while the Kostiakov equation predicted 0.3 inches during 2nd irrigation (Table 1). At elapsed time of 180 minutes, the predicted infiltration became equal to the observed infiltration. This shows the Kostiakov model over predicted the cumulative infiltration for most of the period utilized for accomplishing irrigation. It was further noted that the rate of infiltration after 2 minutes was found to be 9 inches/hr as given by the Kostiakov and that observed in the field was only 2.36 inches/hr. The observed and calculated rates of infiltration approached the same value at the end of 180 minutes. This pattern of variation showed depicts that existing Kostiakov infiltration model tended to over predict the cumulative as well as the rate of infiltration. The Kostiakov Model was calibrated using the observed infiltration and time data and GENSTAT software and new values of constants 'a','b' and 'c' were found for each irrigation, as presented Table 3. The calibrated values for the same time intervals indicated a fair matching behavior with the observed field infiltrometer data both for cumulative infiltration and rate of infiltration. Table 2 revealed that the cumulative infiltration for 3rd irrigation was lower than that of 2nd irrigation. This was because of settlement of soil due to irrigations and passage of time. While comparing the cumulative infiltration with the Kostiakov predicted and calibrated infiltration, similar finding were observed i.e., Kostiakov predicted values were higher than the field observed cumulative infiltration. However, the calibrated infiltration values were close to the observed values.

Table 4 presents a summary of statistical analysis of data for 2nd irrigation and 3rd irrigations. The correlation coefficient was found to be R^2 =0.98 which showed

Table 1. Comparison of observed 'obs', Kostiakov model predicted 'Kp', and calibrated model predicted 'Kc' cumulative infiltration and infiltration rates during 2nd irrigation

Time (min)	Cumulative Infiltration (in)			Infiltration Rate (in/hr)		
	Observed (Obs)	Kostiakov predicted (Kp)	Calibrated (Kc)	Observed (Obs)	Kostiakov predicted (Kp)	Calibrated (Kc)
2	0.079	0.3	0.1	2.36	9.0	3.0
5	0.158	0.31	0.15	1.884	3.7	1.81
10	0.226	0.32	0.2	1.42	2.95	1.2
20	0.276	0.36	0.27	0.83	1.1	0.79
35	0.315	0.385	0.32	0.54	0.65	0.56
50	0.354	0.42	0.37	0.424	0.5	0.45
65	0.394	0.46	0.42	0.36	0.4	0.38
90	0.472	0.5	0.47	0.32	0.36	0.31
120	0.532	0.56	0.53	0.27	0.27	0.26
150	0.57	0.6	0.57	0.23	0.22	0.22
180	0.61	0.64	0.61	0.203	0.21	0.20

Table 2. Comparison of observed 'obs', Kostiakov model predicted 'Kp', and calibrated model predicted 'Kc' cumulative infiltration and infiltration rates during 3rd irrigation

Time (min)	Cumulative infiltration (in)			Infiltration Rate (in/hr)		
	Observed (Obs)	Kostiakov predicted (Kp)	Calibrated (Kc)	Observed (Obs)	Kostiakov predicted (Kp)	Calibrated (Kc)
10	0.059	0.28	0.06	0.37	0.5	0.363
15	0.079	0.3	0.08	0.316	0.4	0.3
55	0.177	0.36	0.177	0.193	0.3	0.193
85	0.236	0.38	0.24	0.166	0.2	0.174
125	0.335	0.42	0.33	0.16	0.17	0.16
165	0.443	0.46	0.42	0.157	0.16	0.153
205	0.492	0.48	0.5	0.144	0.14	0.146

that 98.7 % of the total variation among the values of infiltration was due to the time observed and 98% of the predicted values were close to the observed values for 2nd irrigation. Further, it could be observed from the Table 5 that the parameter 'a' was strongly and negatively correlated with 'b' and 'c' and 'c' with parameter 'b' is strongly and positively correlated with 'c' (Table 5). Similar results for the calibrated Kostiakov model for 3rd irrigation were achieved (Table 4 & 5). The results of both 2nd and 3rd irrigations showed that the cumulative infiltration and infiltration rate decreased with the period of time. The parameter 'a','b' and 'c' also changed as the irrigations advanced. The basic infiltration rate or constant 'c' decreased from 0.275 inch/hr at the first irrigation to 0.0251 inch/hr at the third irrigation. Similar results were found by Khan (1993) in a research conducted at Postgraduate Agricultural Research Station (PARS). He found that the value of 'c' decreased from 801 mm/hr to 363 mm/hr during 1st to 4th irrigation.

Table 3. Kostiakov model calibrated constants for 2nd and 3rd irrigations

Irrigation	Kostiakov Model Constants		
	A	B	C
2nd	0.0989	0.375	0.0251
3rd	0.00437	0.8816	0.0272

Advance Time and Distance

Advance time is the time required for the unit flow rate to advance to the far end of the border (FoK and Bishop, 1965). Tables 6 to 8 present the observed, predicted and calibrated advance time for the 41m, 64m and 105m which are shown in Figures 2 to 4 respectively for more clarity .Tables 6 to 8 shows significant deviation between the observed and predicted advance times by SCS equation in all field lengths. The deviation between the observed and predicted advance times on the completion of irrigation was 14 m, 16m and 25m in 41, 64 and in 105m border,

Table 4. Statistical analysis summary of infiltration for 2nd and 3rd irrigations (ANOVA)

Description	Second Irrigation			Third Irrigation		
	Degree of Freedom (d.f.)	Sum of Squares (s.s.)	Mean Square (m.s.)	Degree of Freedom (d.f.)	Sum of Squares (s.s.)	Mean Square (m.s.)
Regression	2	188.144	94.072	2	109.459	54.7298
Residual	8	2.037	2.037	4	0.2547	0.06367
Total	10	190.182	190.182	6	109.7143	18.2857
Coefficient of Determination (R^2)		0.98			0.99	

Table 5. Correlation of calibrated Kostiakov model parameters for 2nd and 3rd irrigations

	Second Irrigation			Third Irrigation		
	a	b	c	a	b	c
A	1.000			1.000		
B	(-) 0.998	1.000		(-) 0.996	1.000	
C	(-) 0.895	0.871	1.000	(-) 0.983	0.966	1.000

Table 6. Comparison of observed 'Lobs', predicted 'Lscs' and calibrated 'Lcscs' length as a function of advance time for 41 m border

Time (min)	Length (m)		
	Observed (Lobs)	Predicted (Lscs)	Calibrated (Lcscs)
0.0	0	0.0	0.0
0.7	5	6.3	3.0
1.8	10	13.0	8.5
3.5	15	22.7	14.7
4.8	20	28.4	19.0
6.3	25	35.6	26.0
7.6	30	41.8	32.0
9.3	35	48.0	36.0
10.8	40	54.5	40.0
11.1	41	55.0	41.5

Table 7. Comparison of observed 'Lobs', predicted 'Lscs' and calibrated 'Lcscs' length as a function of advance time for 64 m border

Time (min)	Length (m)		
	Observed (Lobs)	Predicted (Lscs)	Calibrated (Lcscs)
0.0	0	0.0	0.0
0.7	5	6.3	3.0
1.9	10	13.7	7.5
1.9	15	18.8	12.0
3.8	20	24.0	14.6
5.0	25	29.8	19.0
6.7	30	38.0	27.0
7.8	35	42.8	30.0
9.7	40	50.8	36.0
10.7	45	54.8	39.0
12.5	50	61.6	45.0
14.2	55	68.6	51.0
15.8	60	74.0	56.0
17.7	64	80.0	61.0

respectively. Thus the SCS equation over predicts the length of border. On analyzing the data using the computer software's i.e. (MINITAB, 1991 & GENSTAT, 1988), the calibrated SCS equation is given as follows.

$$L_t = \frac{720 Q_u T}{\frac{aT^b}{1+b} + c + 18.6 n^{0.4562} Q_u^{\;0.1729} T_t^{\;0.0285}} \qquad (3)$$

The calibrated equation gave promising border length and thus in fairly close to actual field data during both 2nd and 3rd irrigations. The results of advance length were comparable between observed and predicted calibrated model as shown for clarity in Fig. 2 to 4. However, in case of 64m border the values did not matches with the observed length. The reasons for such variation remain Table 9 presents a summary of statistical analysis for calibrated SCS equation. The correlation coefficient R=0.95 indicate that 95.7% of the total variation among the values of advance time is due to the length of the border and discharge.

CONCLUSIONS

Despite the inherent losses and other inefficiencies of the irrigation system, proper field design is a powerful tool for the management of water in surface irrigation system. Many mathematical and empirical approaches available at present and their uses is common in different part of the world. But their adoptability is restricted as it is and their modification is paramount important for achieving precise results. Present study was an attempt to modify the existing SCS design equation for making its abundant use under local field conditions. Results from the present study revealed that the Kostiakov model over predicted the infiltration parameter 'a','b' and 'c' for the second and third irrigations but the calibration

Table 8. Comparison of observed 'Lobs', predicted 'Lscs' and calibrated 'Lcscs' length as a function of advance time for 105 m border

Time (min)	Length (m)		
	Observed (Lobs)	Predicted (Lscs)	Calibrated (Lcscs)
0.0	0	0.0	0.0
0.7	5	6.3	3.0
1.9	10	13.7	7.5
2.7	15	17.8	12.0
3.7	20	23.0	14.6
4.8	25	28.8	19.0
5.8	30	34.0	27.0
6.8	35	39.0	30.0
8.2	40	43.8	36.0
10.2	45	52.8	39.0
12.2	50	60.0	45.0
13.7	55	66.0	51.0
15.0	60	71.6	56.0
16.9	65	76.0	61.0
19.0	70	85.0	66.2
21.2	75	92.8	74.0
23.0	80	99.0	79.6
25.0	85	105.0	85.0
27.1	90	112.0	92.0
29.3	95	118.9	98.0
31.0	100	124.0	103.0
33.0	105	130.0	108.0

Table 9. Statistical analysis summary of SCS calibrated model (ANOVA Table)

Description	Degree of Freedom (d.f.)	Sum of Squares (s.s.)	Mean Square (m.s.)
Regression	2	260597.00	130298.50
Residual	33	10965.00	332.30
Total	35	271562.00	7758.90
Coefficient of Determination (R^2)		0.95	

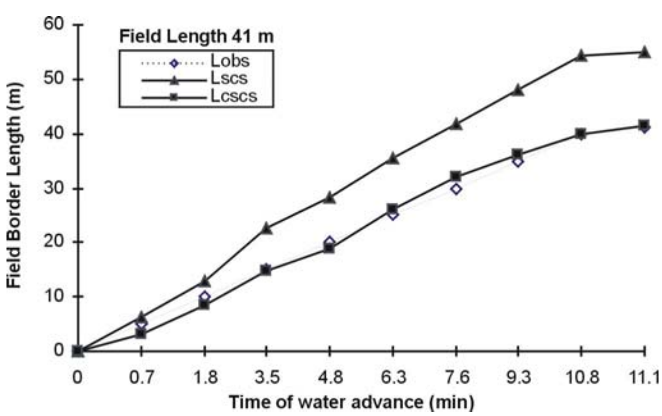

Fig. 2. Comparison of observed 'Lobs' predicted 'Lscs' and calibrated 'Lcscs' lengthas a function of advance time for 41 m border

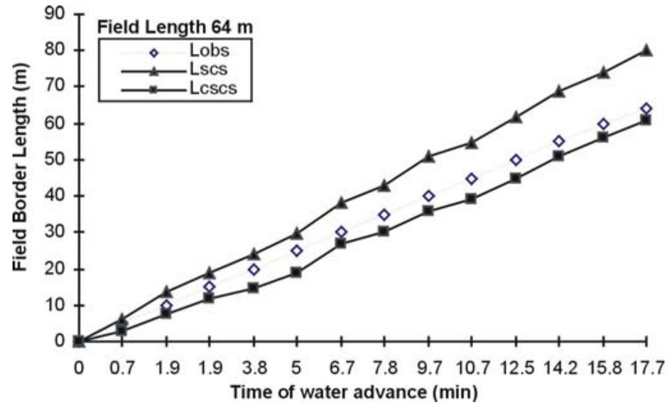

Fig. 3. Comparison of observed 'Lobs' predicted 'Lscs' and calibrated 'Lcscs' length as a function of advance time for 64 m border

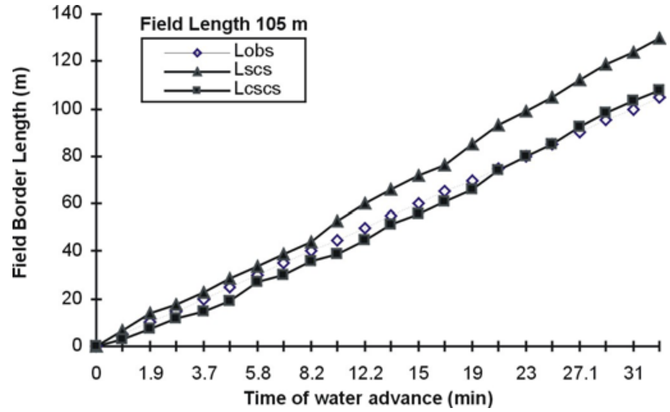

Fig. 4. Comparison of observed 'Lobs' predicted 'Lscs' and calibrated 'Lcscs' length as a function of advance time for 105 m border

parameters predicted model presented satisfactorily results with a high degree of coefficient of determination that ranged from 98% to 99% for second and third irrigations. A similar pattern was observed for the length of level border using SCS equation but however the resulted field lengths obtained from calibrated SCS equation has shown a promising behavior for different field lengths even with a coefficient of determination of 95%.

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