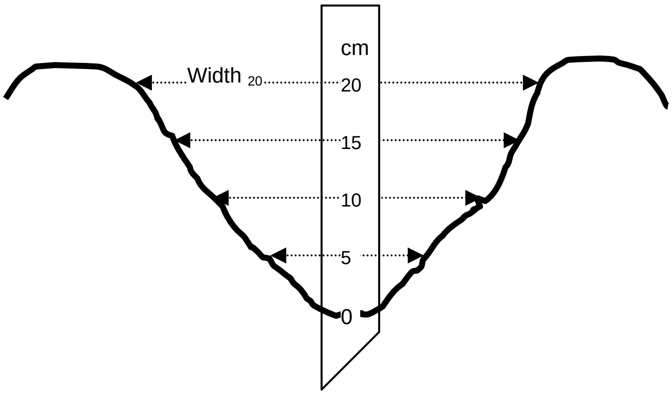
1 FURROW SHAPE

1.1 Methodology

Topwidth of the cross section was measured at 5cm intervals above the furrow bottom as shown in Figure 1, on different dates and on some farms, at sample points down the length of adjacent furrows.

Figure 1 Measurement of Furrow Shape



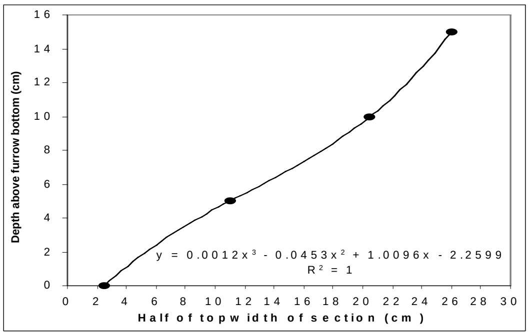
The program illustrated in Figure 2 was used to plot the cross sectional profile and fit a polynomial regression to the average half-width of the furrow at different depths.

Figure 1 Program to estimate values of furrow shape coefficients p1 and p2 (Third order polynomial)

File: Program for p1 and p2 coefficients (3rd order)

To use: Enter furrow width data in cells marked

Depth (cm) (x)	x^2	x^3	Topwidth (cm)	Halved (y)
0	0	0	5.0	2.5
5	25	125	22.0	11.0
10	100	1000	41.0	20.5
15	225	3375	52.0	26.0



Furrow shape coefficients

p_1	0.537
p_2	1.346

Note: if the 3rd order polynomial is not a good fit to the data then try a different equation

Calculated	x=0-5cm	x=0-10cm
X-sectional area of flow (m^2)	0.0060	0.0220

Calculated	x=0-5cm	x=0-10cm
Wetting perimeter (m)	0.247	0.462

The cross sectional area (A) and wetting perimeter (P) are estimated from the fitted curve and the two shape parameters, p1 and p2, calculated as follows (from Irrigation and Drainage Manual 45, FAO):

$$p_1 = a_1^{(1.667-p2)} / b_1^{0.667} \quad \text{.......................(1)}$$

$$p_2 = 1.667 - (0.667 \times b_2 / a_2) \quad \text{................(2)}$$

where

$$a_1 = A_{10} / 10^{a2} \quad \text{.................................(3)}$$

$$a_2 = \log(A_{10} / A_5) / \log(10 / 5) \quad \text{................(4)}$$

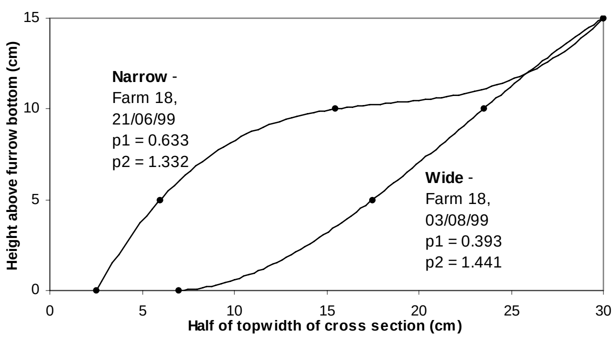
$$b_1 = P_{10} / 10^{b2} \quad \text{.................................(5)}$$

$$b2 = \log(P_{10} / P_5) / \log(10 / 5) \quad \ldots\ldots\ldots\ldots\ldots..(6)$$

and A_5 and A_{10} are cross sectional areas at 5 and 10cm above furrow bottom (m^2), P_5 and P_{10} are wetting perimeters at 5 and 10cm above furrow bottom (m).

Since the depth of water in the furrow would rarely exceed 100mm, the parameters are calculated from the shape of the furrow to this depth. In the majority of cases, a third order polynomial regression was the best fit to half-widths at 0, 5, 10 and 15cm depth. In a few cases, a second order regression was used to 10cm. The type of machine nearly always used for reridging is a spring-tine cultivator with 3 to 5 tines set in a polynomial form. No formal parabolic, trapezoidal or triangular shapes were encountered, perhaps because a ridger with rigid shares is rarely used. The program described above would be satisfactory for all furrow shapes except parabolic. Figure 2 illustrates the extreme effects of furrow shape on the parameters using data from the same field at farm 18 measured on different dates. Furrows had been interrow cultivated before measurement on 21-06-99, irrigated immediately afterwards and not cultivated again before irrigation on 03-08-99. The wider is the furrow, the smaller is p_1 and the larger is p_2.

Figure 2 Effect of Furrow Shape on Parameters p1 and p2



1.2 Analysis of data

The most comprehensive data was provided by the Turkmenistan team for farm Murgap (no 18). This field is not ideal in that it is almost horizontal and slopes down to the centre from the ends. Topwidths were measured at 16 or 19 points along the length of three adjacent furrows on four occasions. Summary of the statistical analysis is given in Table 1.

Table 1 Summary Statistics of Furrow Shape Parameters Measured on Farm 18

Date	Mean	Maximum	Minimum	SE_{mean}	Coeff. of Variation (%)	Variance Ratio (F) between means of furrows	points	Least Signif. Diff. (P=5%) between means of furrows	points
				Shape parameter p_1					
01-Jun-99	0.531	0.634	0.377	0.053	10.1	0.6 ns	0.8 ns	0.089	0.120
21-Jun-99	0.589	0.696	0.456	0.047	6.7	6.7 **	1.9 *	0.078	0.105
12-Jul-99	0.579	0.683	0.417	0.050	7.3	8.9 **	3.0 **	0.083	0.112
03-Aug-99	0.459	0.536	0.383	0.028	5.2	0.07 ns	2.4 *	0.047	0.064
				Shape parameter p_2					
01-Jun-99	1.367	1.470	1.305	0.034	2.5	1.1 ns	0.8 ns	0.057	0.076
21-Jun-99	1.333	1.397	1.286	0.023	1.5	5.2 *	2.0 *	0.038	0.052
12-Jul-99	1.336	1.430	1.283	0.027	1.7	4.8 *	2.8 **	0.045	0.061
03-Aug-99	1.392	1.447	1.336	0.022	1.3	0.01 ns	2.9 **	0.037	0.050

	Mean	Mean	Range of mean	
Overall	p_1=0.539	p_2=1.357	p_1 =59%	p_2=14%

Linear regression (y=ax+b): p_1 against p_2

Date	A	b	R^2
01-Jun-99	-0.6267	1.7002	0.96
21-Jun-99	-0.4824	1.6168	0.96
12-Jul-99	-0.4986	1.6242	0.95
03-Aug-99	-0.7818	1.7503	0.89

The field was interrow cultivated on 22 and 27 May, 9 and 16 June and 2, 11 and 26 July. Clearly these operations before irrigations in June and July rebuilt the ridges and increased the value of p_1. Parameter p_1 varied from 0.377 to 0.696 and p_2 from 1.283 to 1.470, these absolute ranges being 59 and 14 percent of the respective means, reflecting in the SE_{means}. In the middle furrow, there was a significant reduction in p_1 and increase in p_2 in the centre of the field, which was not reflected in the adjacent furrows, probably the consequence of the uneven land surface.

Although parameter p_1 is clearly more variable than p_2, there was a close relationship between them as shown for different dates in June in Figures 2 and 3, and in Table 1. The negative slope coefficient of the linear relationship became less steep and the intercept smaller for the second and third irrigations, while the R squared value remained the same. The reduction in coefficient of variation with time increased the variance ratios and forced six extra furrow sample points outside the fiducial limits at P = 5 percent, as shown in the Figures.

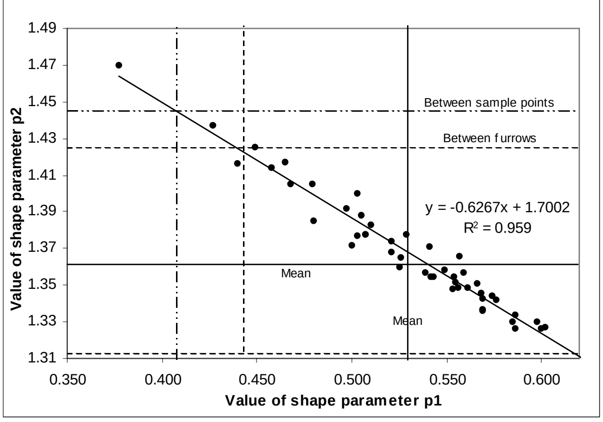


Figure 3 Furrow Shape Parameters: Farm 18 on 01/06/99

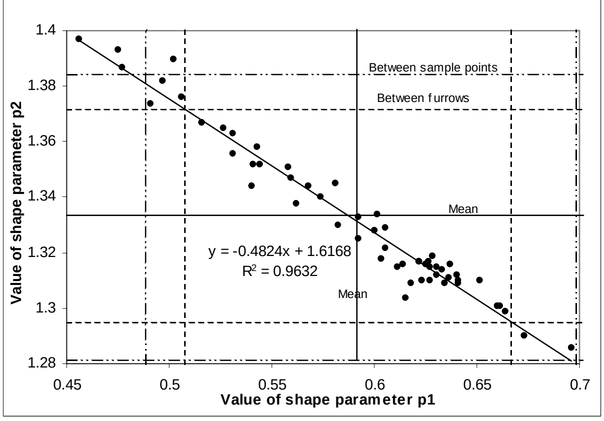


Figure 4 Furrow Shape Parameters: Farm 18 on 21/06/99

There is less variation in shape parameters between farms than was expected, as shown by the mean values in Table 2. The reasons may be that the same kind of machinery was used on all farms and there is not much variation between farms in soil texture. Highest values of p_1 at farm 18 after later cultivations were 29 percent above the overall mean and lowest values after irrigation on the same farm were 14 percent below it.

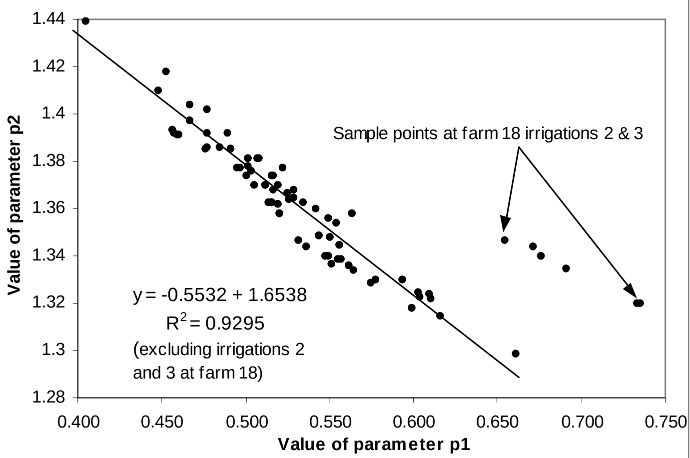
Table 2 Mean p_1 and p_2 Shape Parameters by Farm

Farm no.	Field no. *	No. of tests	Mean p_1	Mean p_2	Comment
3	1D	6	0.569	1.338	
9	2D	2	0.556	1.357	
14	3C+5D	5	0.492	1.390	
18	9D	48	0.531	1.367	first irrig.
18	9D	114	0.693	1.334	irrig. 2 & 3
18	9D	57	0.459	1.392	irrig. 4
22	10D	9	0.556	1.338	
24	9D	21	0.493	1.385	
34	1D+5C	14	0.560	1.344	
35	10D	9	0.514	1.366	before irrig.
35	10D	2	0.477	1.386	after irrig.
Overall total/mean		**287**	**0.536**	**1.362**	

* D = demonstration field, C = control field

The plot of all values of p_1 against p_2 is shown in Figure 5. Due to the same furrow form at most farms, the values of p_1 and p_2 are closely related overall, with the exception of the mid-season measurements at farm 18. The heavy interrow cultivations before the second and third irrigation created much narrower furrows and markedly changed the relationship between p_1 and p_2. However, the operation was not repeated before the fourth irrigation and the striking fall in the value of p_1 between measurements in July and August indicates the considerable slumping of the furrow walls that had occurred during the third irrigation.

Figure 5 Plot of Shape Factors p1 Against p2



1.3 Sensitivity of Water Management Criteria to Shape Parameters

Figures 6 and 7 demonstrate the effect of widening an average furrow by about 15cm on farm 3 on optimal water management criteria. In the examples, the value of p_1 falls by 31 percent and the effect is that the wider furrow can take a 17 percent greater furrow flow rate, with a 29 percent reduction in duration of irrigation. Resulting from these changes, the application efficiency increases from 30 to 36 percent. The marked widening of the furrow between the third and fourth irrigations of the field in farm 18 by about 15cm reduced the value of p_1 by an average 33 percent. The result was a 15 percent increase in optimum furrow flow-rate, 30 percent fall in irrigation duration while application efficiency increased from 30 to 39 percent. The irrigation at farm 35 reduced p_1 by 7 percent on average but this increased optimum furrow flow-rate by only 3 percent reducing duration by the same margin while Ea remained at 58 percent.

Clearly, the sensitivity of the water management criteria to furrow shape depends on the particular circumstances of the field.

1.4 Recommended Values of p_1 and p_2

Excepting at farm 35 and the last irrigation at farm 18, the furrow data were measured after interrow cultivation and before irrigation. Slumping and settling of furrow sides during irrigation clearly changes the shape parameters by broadening the furrow. At farm 35, the reduction in p_1 was 7 percent and the increase in p_2 was 1.5 percent but the effect was much greater at farm 18. This process occurs from the time water arrives at a point in the furrow to its recession, and is likely to be greatest when the water level is greatest. Based on this rather scanty data, it is suggested that the mean value of p_1 for each farm should be reduced by 5 percent and p_2 increased by 1 percent as shown in Table 3.

Table 3 Adjusted Values of p_1 and p_2

Farm no.	Mean p1	Mean p2
3	0.541	1.351
9	0.528	1.371
14	0.467	1.404
18	0.582	1.365
22	0.528	1.351
24	0.468	1.398
34	0.532	1.357
35	0.488	1.379
Overall	**0.509**	**1.376**

It is recommended that in future tests the furrow shape should be measured both before and after irrigation.

Figure 6 Optimum Furrow Flow Rate, Irrigation Time to Cut-off and Application Efficiency - Narrow Furrows

File: PUMA Program						
Enter the following field data:	File:	Figure 6		Date:	15-Sep-	
Oblast:	S Kazakhstan					
Rayon:	Makhtaral					
Name of farm:	Farm 03 - Djambul					
Brigade:						
Field identification:	3					
Parameter: enter required values	Symbol	Units	Value			
Soil type		USBR	ZL			
Furrow length	L	m	250			
Av slope	So		0.0005			
Field width	W	m	100			
Furrow spacing	w	m	0.9			
Discharge to field	Qt'	l/sec	50			
Net irrigation requirement	Zreq'	mm	50			
Furrow velocity	V	m/min	8.0			
Parameter: change values when necessary				first irrig	later irrig's	v. weedy
Furrow shape	p1		0.633			
	p2		1.332			
Manning resistance coeff	n		0.04	0.04	0.02	0.15
Kostiakov-Lewis parameters for soil type	k		0.0027			
	a		0.473			
	fo		0.00029			
Solver Section						Eqn. No.
Application efficiency	E_a	%	**30**			69
Automatically calculated: don't change!!!						
Net irrigation requirement as	*w*Zreq'/1000*					
	Zreq	m^3/m	0.045	Continuous irrigation:		
No. furrows in field	W/w	no.	111	Block width (m)	31	
Simultaneous irrigation - no. furrows	Qt/Q_o	no.	35	No. blocks	3.2	48
Discharge to field from canal	Qt	m^3/min	3	No. days to end	1.0	
Maximum furrow flow rate as	*((Vmax^p2*n)/(60*p1*So^0.5))^(1/(p2-1))*					67
	Qmax	l/sec	7.05	m^3/min	0.423	
Optimum flow rate	Q_o	l/sec	1.44	m^3/min	0.086	
Time to cut-off	t_{co}	h	7.3	min	437	68

Note: To avoid erosion, maximum recommended furrow flow velocity for silty soil - 8 m/min, for clay soil - 13m/min.

Figure 7 Optimum Furrow Flow Rate, Irrigation Time to Cut-off and Application Efficiency - Wide Furrows

File: PUMA Program						
Enter the following field data:	File:	Figure 7		Date:	15-Sep-99	
Oblast:	S Kazakhstan					
Rayon:	Makhtaral					
Name of farm:	Farm 03 - Djambul					
Brigade:						
Field identification:	3					
Parameter: enter required values	Symbol	Units	Value			
Soil type		USBR	ZL			
Furrow length	L	m	250			
Av slope	So		0.0005			
Field width	W	m	100			
Furrow spacing	w	m	0.9			
Discharge to field	Qt'	l/sec	50			
Net irrigation requirement	Zreq'	mm	50			
Furrow velocity	V	m/min	8.0			
Parameter: change values when necessary				first irrig	later irrig's	v. weedy
Furrow shape	p1		0.464			
	p2		1.393			
Manning resistance coeff	n		0.04	0.04	0.02	0.15
Kostiakov-Lewis parameters for soil type	k		0.0027			
	a		0.473			
	fo		0.00029			
Solver Section						Eqn. No.
Application efficiency	E_a	%	**36**			69
Automatically calculated: don't change!!!						
Net irrigation requirement as	*w*Zreq'/1000*					
	Zreq	m^3/m	0.045	Continuous irrigation:		
No. furrows in field	W/w	no.	111	Block width (m)	27	
Simultaneous irrigation - no. furrows	Qt/Q_o	no.	30	No. blocks	3.7	48
Discharge to field from canal	Qt	m^3/min	3	No. days to end	0.9	
Maximum furrow flow rate as	*((Vmax^p2*n)/(60*p1*So^0.5))^(1/(p2-1))*					67
	Qmax	l/sec	24.52	m^3/min	1.471	
Optimum flow rate	Q_o	l/sec	1.69	m^3/min	0.101	
Time to cut-off	t_{co}	h	5.2	min	311	68
Note: To avoid erosion, maximum recommended furrow flow velocity for silty soil - 8 m/min, for clay soil - 13m/min.						