Performance and Design of Border Checks on a Sandy Soil

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LEVEL and low-gradient border checks for irrigating field crops are used where irrigation water is limited, where periodic leaching of salts is required, and where maximum use of rainfall is desired. Level basin irrigation has been used for centuries, especially for rice irrigation. In northern Italy where rice is one crop in the rotation, level basins are used for irrigation of other farm crops. These systems briefly described by Mead (5)* are still in use today. Petrov (7) described similar systems on natural slopes in the Golodnaya Steppe where land slopes range from 0.05 to 0.25 percent.

This paper presents the results of a field study of the operational characteristics of low-gradient border checks used for normal irrigations. The objectives of this study were to provide data on water application efficiencies, limitations of border checks, and to develop guides or design criteria for use in other areas. A portion of the operational characteristics was summarized in an earlier publication (4)†.

Characteristics of Border Checks

A border check as used in this discussion is a nearly level strip of land with a low dike on all four sides. A graded border strip is similar, except it has a well-defined grade in the longitudinal direction and usually is not diked at the lower end. The lower end of a graded border strip commonly has less intake opportunity time than the upper end. A border check allows no runoff and the water is held on the land until it infiltrates. Intake opportunity time at the lower end of a border check can be modified by changing the surface slope or total drop from the upper to the lower end. On soils with relatively low intake rates, border checks, uniformly graded and nearly level, have the following desirable characteristics: (**a**) high water-application efficiency and uniform distribution, (**b**) reduced labor costs, (**c**) increased infiltration of rainfall, (**d**) reduced erosion from irrigation and rainfall, and (**e**) more uniform leaching for salt control, according to Ross and Swanson (10).

When intake rates are low, level border checks can give uniform and high water-application efficiencies consistently. On sandy soils with high intake rates, the gradient necessary to secure uniform irrigation and high water-application efficiencies with light irrigations becomes critical.

Design Problems

Numerous field studies and analytical analyses have been conducted on graded border systems. The major problem involved is predicting the advance of the water down the border strip. Philip and Farrell (9) using the Laplace transformation presented a detailed derivation of a general solution of the Lewis-Milne infiltration-advance equation. Particular solutions were presented by Philip and Farrell for the following forms of the cumulative intake function: $I = at + b(1 - e^{-rt})$, $I = b(1 - e^{-rt})$, and $I = at + ct^{1/2}$. Fukuda (1) presented a solution using $I = ct^{1/2}$. These solutions when used to predict the rate of advance in graded border strips requires the assumption that the average depth of water is constant during the advance of water or that the depth at the upper end, D_o, is constant. Hall (2) presented a finite-difference approach to predicting the advance of water in border strips and later presented refinements in the application of this procedure to the actual design of border strips, Hall (3). Hall's approach also considers the depth constant at the upper end.

The infiltration-advance problem also exists in the design of nearly level border checks. In practice very little actual theory has been involved in the design of border checks.

The main practical problem that arises with border-check design is whether or not to construct the checks absolutely level or to build in a small gradient. For long runs, Ross and Swanson (10) recommended a maximum drop of 0.2 ft. Another recommendation is for the total drop not to exceed one-half the depth of irrigation water applied. In more humid areas a small gradient with facilities for removal of excess water from rainfall runoff is considered to be an essential element of bench-leveled systems, Phelan (8).

The assumption of constant depth at the upper end of the border strip for a given set of conditions is reasonable when the border strips are not level or nearly level. Under level or nearly level conditions, D_o varies continuously during the advance of the water in the border strip further complicating the infiltration-advance problem.

Prediction of the variation in D_o with zero or very low gradients is also needed in designing border checks. Studies are currently under way on the terminal shape of a shallow liquid front. Results to date have provided equations for terminal shape of laminar and turbulent flows with zero intake and with artificial roughnesses, Tinney and Bassett (11). However, both equations presented involve normal depth which would not occur with zero slope.

Detailed analyses of zero and low-gradient basin irrigation have not been conducted. Petrov (7) analytically and experimentally evaluated the total water required to fill basins formed on natural land slopes as a function of their size. This evaluation consisted of merely filling the basin until the depth of water reached a prescribed value at the upper end. Thus, the required depth of application increased with slope and length and decreased with stream size.

A simplified approach to this problem is to express the advance of the water, A, as follows (Dimensions of either length L or time T are indicated):

$$A = \frac{q\ t_o}{C_1 D_o + C_2 I_o} \quad \ldots\ldots\ [1]$$

where

- A = distance to the streams leading edge, L
- D_o = depth of water at the upper end, L (normal depth for graded borders)
- C_1 = coefficient varying from about ⅔ to < 1.0
- C_2 = coefficient varying from 0.5 to < 1.0
- I_o = cumulative intake at the upper end, L
- t_o = time water has been on the upper end, T

The water surface during the advance of the stream has a parabolic shape with respect to the land surface. $C_1 D_o$ represents the average depth of water on the surface. $C_2 I_o$ represents the average depth of infiltration over

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* Numbers in parentheses refer to the appended references.

† A field measurements were made by O. W. Howe formerly located at Scottsbluff, Nebr.

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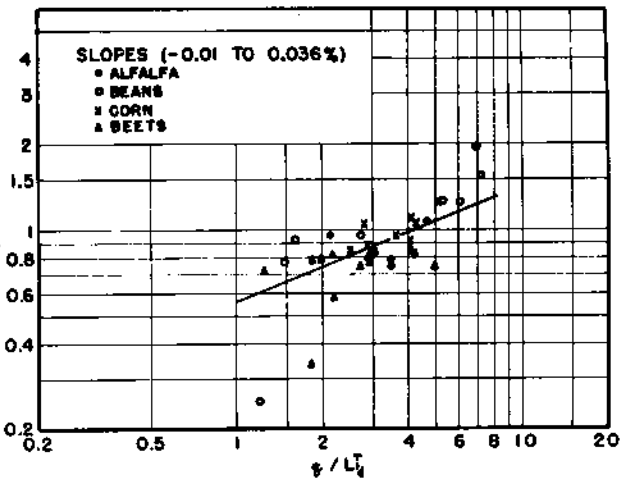

FIG. 1 Observed relationship between irrigation uniformity (T_l/T_u) and ratio of application rate to mean intake rate (q/Li_d).

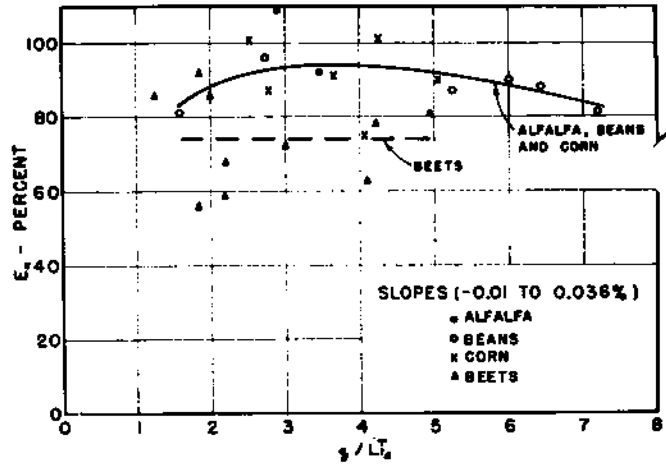

FIG. 2 Water-application efficiency (E_a) is greatest when the ratio of application rate to mean intake rate (q/Li_d) is between 3 and 5.

the advance distance A, where I_o is the cumulative intake at the upper end. Ostromecki (6) evaluated coefficients for this equation using $I_o = at^b_o$ and indicated that C_2 is a function of A, t, and b, and therefore is not a constant. He obtained mean values of C_2 from experimental data ranging from 0.72 to 0.95 as b decreased from 1.0 to 0.25. These values of C_2 appear to be too large for low-gradient checks with slow advance rates as will be shown later.

Values of C_1 and C_2 observed under field conditions assuming the cumulative intake can be adequately represented by the equation $I = at^b$ are presented in this paper along with observed variations in D_o.

Site Conditions

The irrigated fields on the experiment station at Scottsbluff, Nebr., have natural slopes of 1.5 to 3 percent. Irrigation on these slopes often results in low irrigation application efficiencies using downslope irrigation methods. In 1956 some of the fields on the station were converted to a contour-bench level irrigation system using limited prevailing design criteria. This system has been operated satisfactorily for 7 years, essentially eliminating erosion. Some problems of maintaining dike escarpments and operation of tillage equipment to maintain level conditions on the benches have been encountered.

The soil on the experimental area is Tripp fine sandy loam. The soil is about 7 ft deep underlain with sand to a water table never less than 30 ft below the surface. The available water-holding capacity ranges from 1.5 to 1.75 in. per foot of depth.

Special smoothing of the border checks was not done because an evaluation of the system under normal farming conditions was desired. Consequently, precision of hydraulic data is limited. Slopes ranged from near zero to about 0.1 percent and lengths from 380 to 733 ft.

Procedure

Flow and Depth Measurements

The water applied to a border check was measured with a Parshall flume. The water-surface profiles were determined by using stakes at 50-ft intervals as bench marks. A detailed topographic survey was made of each border check with five elevation readings taken at 25 ft stations.

Water Application Efficiency

Soil samples were taken one day before and two to three days after each irrigation to measure the increase in soil moisture resulting from irrigation. Three soil cores were taken by 1-ft increments at the 50-ft stations to a depth of 6 ft. Irrigation-application efficiencies were calculated as follows:

$$\text{Irrigation application efficiency} = \frac{(\text{Gain in soil water} + E_t)\ 100}{\text{Water delivered to the border check}}$$

where E_t is the estimated evapotranspiration during the sampling period. The depth of water applied at each irrigation was the estimated amount required to bring the soil profile to field capacity. A slightly greater amount was used with crops having high retardance to assure uniform water distribution.

Irrigations

All crops were irrigated in a normal manner in 1960 using a single stream size. In 1961 several stream sizes were used.

Intake Rates

Intake opportunity time was determined for each 50-ft station by observing the time water reached and receded from each station. Cylinder infiltration rates determined on several checks in 1960 indicated that the cumulative intake could be represented adequately by an equation of the form $I = at^b$. Values of b averaged 0.67 on alfalfa, 0.69 on beans, 0.65 on corn and 0.63 on sugar beets. Since intake opportunity time was available for each 50-ft station, values of a were obtained for each of 40 irrigations in the following manner. First, it was assumed that $b = 0.67$ for all irrigations. Then, using the value of a as determined from the cylinder infiltration data and the intake opportunity time for each station, the estimated total intake volume per unit width was computed as follows:

$$V_s = a_c \sum_{1}^{n} (T_i^{0.67}\ \Delta x_i) \quad . \ . \ . \ . \quad [2]$$

where

V_s = computed volume of intake per unit width of the check, L^2

n = number of stations

T_i = observed total intake opportunity time at each station, T

Δx_i = length of border check represented by an individual station, L

a_c = value of a from the cylinder infiltrometer data, $L/T^{0.67}$

The value of a for each individual irrigation was determined by comparing the inflow volume V_i to the border check with the computed intake volume V_s as follows:

$$a = ka_c \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad [3]$$

$$\text{where k} = \frac{V_i}{V_s} = \frac{qt}{a_c \sum_{1}^{n} (T_i^{0.67}\ \Delta x_i)}$$

Other Data

The average slope of a border check was determined by the least squares technique after eliminating the elevation of the end stations. These two stations often were much higher than the mean grade line. The depth of water, D_o, was measured at the 50-ft station using either the mean grade line or the average elevation from

25 to 75 ft as the datum. Additional measurements of surface roughness, initial storage in cracks and voids, and crop density, height and stem thickness were made but are not included in this paper.

Values of C_1 and C_2 were obtained by plotting measured water surface and computed intake profiles at 20, 30, 40, 50, 60, and 80 min. Total surface storage and intake were determined by graphically integrating the area between the water surface profile and the ground elevation and the area under the cumulative intake profile.

Results and Discussion

Performance

The performance of border checks can be related to the major variables involved during each irrigation. Thus performance parameters can be expressed as a function of the major variables as follows:

$$\text{Performance parameter} = f\,(d,\, q,\, \bar{i}_d\, I_o,\, L,\, \Delta z,\, \lambda\, R,\, \ldots) \qquad [4]$$

where

- d = mean depth of irrigation, L
- q = unit stream size, L^2/T
- $\bar{i}_d$ = mean intake rate for a given depth of irrigation $\bar{i}_d = d/\bar{T}$, L/T
- L = total length of the border check
- Δz = total fall of the border check, L
- λ = mean deviation of the land surface at a station from the mean grade line, L
- R = retardance or roughness of the soil and crop, not dimensionally defined here
- $\bar{T}$ = mean intake opportunity time, T

Two performance parameters were used to evaluate the border checks: (a) uniformity of irrigation as indicated by the average intake opportunity time for the lower one-third divided by the average intake opportunity time for the upper one-third of the border check, T_l/T_u, and (b) water-application efficiency, E_a. A summary of data from all irrigations is presented in Table 1.

Once the border checks have been installed and planted to a given crop, the operator can essentially vary only the rate of water application, q, and the depth of the irrigation, d. Effective retardance, R, also may be modified to a limited degree by changing the furrow shapes with row crops. The dimensionless ratio $q/L\bar{i}_d$ expresses the rate of water application compared to the mean rate of intake for a given depth of irrigation over length L. This ratio can be referred to as an "operations parameter" expressing how the system was operated. The total length of the border check L is fixed and the mean intake rate will usually decrease as the depth of water applied increases.

The observed effects of stream size on uniformity are summarized in Fig. 1. These values are from border checks whose slopes ranged from −0.01 to 0.036 percent. The trend line indicates that uniform application occurred when water was applied approximately 3 to 5 times faster than the average intake rate ($T_l/T_u \cong 1.0$). Thus a reasonably uniform irrigation can be expected when all of the water is applied in one-fifth to one-third of the average total intake opportunity time. The two very low values shown were the result of insufficient amounts of water applied. The two high values occurred on beans where small amounts of water remained standing at the lower end several hours longer than the average intake opportunity time.

High water-application efficiency requires uniform water distribution when the soil profile is to be filled to field capacity. Therefore, maximum water-application efficiencies can also be expected when $q/L\bar{i}_d$ ranges from 3 to 5. High water-application efficiency occurred over a wide range in the dimensionless application rate parameter as shown in Fig. 2. This indicates that for border checks stream size was not critical as long as adequate stream was available ($q/L\bar{i}_d > 1.5$). Several values of application efficiencies over 100 are

TABLE 1. SUMMARY OF IRRIGATION DATA WITH A BORDER CHECK SYSTEM

Year	Crop	Border No.	Border length, L	Mean slope, S	Date of irrig.	Crop height	Depth of irrig., d	Mean intake rate, $d/\bar{T}$	Intake coeff., a*	Stream size, q	Appln. time, T_a	Advance time, T_L†	Mean intake oppor. time, $\bar{T}$	Uniformity, T_l/T_u	Water appln. eff., E_a
			ft	%		ft	ft	ft/hr		ft²/min	min	min	min		%
1960	alfalfa	11(a)s	450	0.031	6/10	1.5	0.81	0.078	0.0111	2.70	135	80	626	1.08	....
1960	alfalfa	11(a)s	450	.031	7/10	1.5	.56	.171	.0164	2.73	92	102	196	.96	....
1960	alfalfa	12(a)s	400	.002	8/12	....‡	.64	.140	.0153	2.70	98	84	275	.79	109
1960	alfalfa	12(b)s	380	.001	7/10	1.5	.61	.124	.0139	2.73	85	59	294	.79	....
1960	alfalfa	12(b)s	380	.001	8/12	....‡	.61	.123	.0141	2.70	86	67	298	.75	92
1960	alfalfa	11(b)s	415	.078	6/10	1.5	.50	.099	.0111	2.73	74	61	304	1.29	....
1960	alfalfa	11(b)s	415	.078	7/10	1.5	.50	.148	.0148	2.78	75	66	203	1.17	....
1960	alfalfa	11(b)s	415	.078	8/12	....‡	.65	.126	.0145	2.70	100	86	310	1.17	82
1960	beans	5n	677	0.013	8/23	1.25	0.50	0.212	0.0178	2.86	118	135	142	0.25	....
1960	beans	5s	570	.011	8/23	1.25	.50	.205	.0190	2.86	101	96	147	.77	....
1960	beans	6s	525	.036	7/30	1.00	.36	.352	.0240	2.73	69	71	61	.67	63
1960	beans	6s	525	.036	8/23	1.25	.42	.259	.0205	2.86	77	95	97	.66	89
1960	beans	3s	550	.024	8/10	.80	.50	.189	.0146	2.82	87	58	163	.93	81
1960	beans	3s	550	.024	8/30	.80	.43	.113	.0115	2.74	84	80	227	.96	96
1960	beans	4n	693	.035	8/10	.80	.41	.056	.0071	4.40	68	55	438	1.97	88
1960	beans	4n	693	.035	8/30	1.25	.40	.053	.0059	4.17	55	59	469	1.56	81
1960	beans	4s	550	.034	8/10	.80	.41	.077	.0098	3.72	61	45	320	1.27	87
1960	beans	4s	550	.034	8/30	1.25	.37	.068	.0087	3.75	54	64	323	1.26	90
1960	corn§	3n	684	0.016	7/20	3.3	0.58	0.092	0.0096	2.93	133	64	386	1.06	....
1960	corn	3n	684	.016	8/10	8.0	.57	.066	.0076	3.08	126	43	517	1.11	....
1960	corn	4n	693	.025	7/20	3.3	.58	.071	.0079	3.00	133	73	485	.96	91
1960	corn	4n	693	.025	8/10	8.0	.28	.110	.0088	3.18	61	57	152	.85	101
1960	corn	4n	693	.025	9/2	8.0	.28	.096	.0081	3.08	64	68	175	.89	87
1960	corn	4s	550	.024	7/20	3.3	.49	.077	.0083	3.00	90	56	381	1.07	101
1960	corn	4s	550	.024	8/10	8.0	.34	.066	.0067	2.93	60	51	305	1.26	90
1960	corn	4s	·550	.024	9/2	8.0	.28	.083	.0074	3.08	46	46	178	.92	75
1960	sugar beets	7n	460	0.015	7/7	1.25	0.49	0.182	0.0171	2.80	81	57	162	0.79	86
1960	sugar beets	7n	460	.015	7/30	1.5	.61	.118	.0133	2.73	103	76	310	.84	....
1960	sugar beets	7n	460	.015	8/25	2.5	.53	.122	.0121	2.73	84	87	263	.77	....
1960	sugar beets	7s	540	.020	7/7	1.0	.51	.248	.0201	2.80	95	82	126	.72	86
1960	sugar beets	7s	540	.020	8/25	2.5	.41	.166	.0151	2.73	81	125	148	.34	56
1960	sugar beets	8n	506	−.010	7/9	1.0	.51	.168	.0157	2.90	89	68	184	.79	92
1960	sugar beets	8n	506	−.010	8/25	2.5	.49	.107	.0114	2.70	92	120	277	.75	....
1960	sugar beets	8s	500	.045	8/25	2.5	.47	.138	.0133	2.73	86	76	204	.96	....
1961	sugar beets	5s	570	−0.007	7/28	1.5	0.46	0.087	0.0109	3.47	75	92	315	0.83	78
1961	sugar beets	5s	570	−.007	8/23	2.5	.60	.081	.0111	3.80	97	104	445	.75	81
1961	sugar beets	6n	733	−.006	7/28	1.5	.70	.120	.0141	4.51	115	128	353	.84	72
1961	sugar beets	6n	733	−.006	8/23	2.5	.91	.085	.0114	4.25	149	160	646	.85	63
1961	sugar beets	6s	525	.027	7/29	1.5	.37	.141	.0129	2.71	76	102	167	.58	68
1961	sugar beets	6s	525	.027	8/23	2.5	.80	.142	.0167	....	....	....	339	.83	59

* From the equation $I = at^{0.67} = ft$; t = minutes after water is applied.
† From a smoothed curve at L.
‡ Two weeks after cutting.
§ All water applied was assumed held between outer rows.

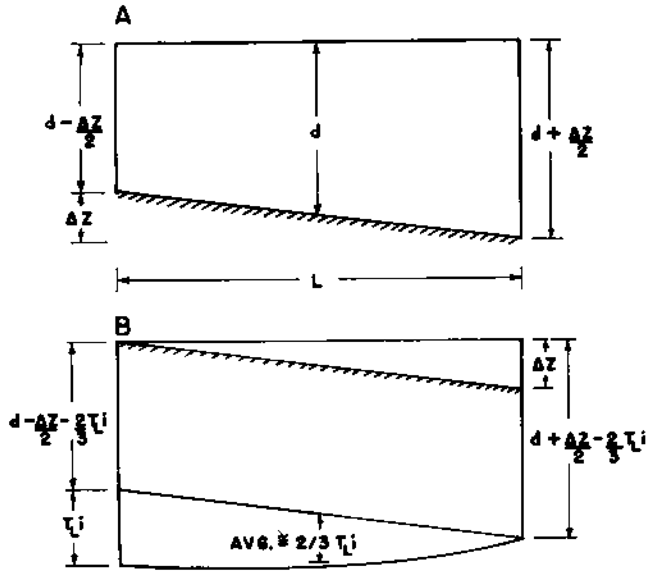

FIG. 3 Distribution of water placed in a border check instantaneously (A) and the effect of advance time, T_L, on water distribution.

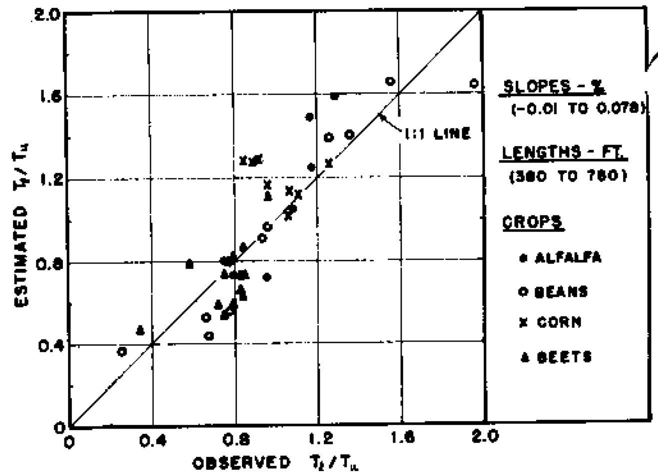

FIG. 4 Predicted uniformity compared with observed uniformity.

believed to have been due to the slight "transverse concaveness" of some of the checks resulting in more water retained in the sampling area than the mean depth applied. The lower values obtained on sugar beets were caused by the application of excess water on sugar beets to assure adequate irrigation at the lower end. As the sugar beet crop develops, the leaves create severe retardance to the flow of water. However, if this crop is grown in only one year out of four to six in a rotation, then excess applications for one or two irrigations would be more practical than increasing the slope. Increasing the slope to increase application efficiency with beets would probably reduce the water-application efficiency on all other crops in the rotation. Maintaining an open furrow along both sides of the check will improve water distribution in crops with high retardance.

Mean deviation from the mean grade line at a station, λ, also affects the intake opportunity time. A comparison of the ratio of intake opportunity time at a station to the average, $T/\bar{T}$ *vs* λ/d, in the upper one-third of the border check and in the lower one-third indicated that more uniform land leveling is required in the lower part of the check than the upper part to assure uniform irrigation. $\bar{T}$ is the average intake opportunity time for the entire border check and T is the intake opportunity time at a station.

Design Criteria

Prior to constructing a border-check irrigation system, the designer can select, within limits, various combinations of slope or total drop, length, width, depth of irrigation and stream size to maximize uniformity and efficiency of water application. Most of these factors have inherent limits in variation as with depth of irrigation which is determined by the soil-moisture holding capacity and the rooting depth, and allowable soil-moisture depletion levels for the crops grown. Similarly, the length of the border check is limited to the existing field length or some fraction thereof such as one-half, one-third, or one-fourth. The variable that the designer can adjust most freely is the total drop within the border-check length.

An equation predicting the desired drop can be derived by first assuming that all of the water is placed in the basin instantaneously as shown in the upper part of Fig. 3. The border check has a drop of Δz in length L. In this case, the depth of water available is $(d - \Delta z/2)$ at the upper end and $(d + \Delta z/2)$ at the lower end.

Under field conditions water is not applied instantaneously but advances nonuniformly to the end. The difference in intake opportunity time during advance of the water along a level basin will follow a parabolic-shaped curve of the form $\Delta T = C_3 - C_4 x^m$ whose average value will be approximately ⅔ T_L, where T_L is the total time for water to reach the end and $C_3 = T_L$. For the border checks used in this study, m was approximately equal to 1.5 and the average value of $\Delta T \cong 0.6\, T_L$. The average depth of water that has infiltrated on the upper end of the border check, and thus is not available for infiltration at the lower end, as in the instantaneous case, is approximately ⅔ $T_L i$ where i is the intake rate towards the end of the infiltration period (Fig. 3). In place of the intake rate near the end of the infiltration period the average intake rate, $\bar{i}_d$ is used herein though it is somewhat too large. The depth of water infiltrating at the upper end is then approximately $d - \Delta z/2 + \tfrac{1}{3} T_L \bar{i}_d$ and at the lower end $d + \Delta z/2 - \tfrac{2}{3} T_L \bar{i}_d$. The ratio of intake opportunity time at the lower end to that at the upper end is:

$$\frac{T_l}{T_u} = \frac{(d + \Delta z/2 - \tfrac{2}{3} T_L \bar{i}_d)/\bar{i}_d}{(d - \Delta z/2 + \tfrac{1}{3} T_L \bar{i}_d)/\bar{i}_d} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [5]$$

which reduces to

$$\frac{T_l}{T_u} = \frac{3d + 1.5\Delta z - 2T_L \bar{i}_d}{3d - 1.5\Delta z + T_L \bar{i}_d} \quad \ldots \quad [6]$$

This equation is based on the assumption that the water surface will become level soon after shutting off the water to the check and before disappearing at the upper end. It indicates that the uniformity is influenced by d, Δz, T_L and $\bar{i}_d$. This equation also indicates that the operator can improve uniformity of irrigation by increasing the depth of irrigation, d. Excessive irrigation would, however, reduce the water-application efficiency. An increase in d would also result in a lower average intake rate, $\bar{i}_d$. Increasing the stream size would reduce the time of advance, T_L.

A comparison of computations made using equation [6] and observed uniformity is illustrated in Fig. 4 using the mean intake opportunity time from the upper and lower one-third of the check instead of at the end points. Reasonable agreement was obtained with experimental data; equation [6], therefore, can be solved for Δz or slope by setting $T_l/T_u = 1.0$, or by equating the depth infiltrating at the upper and lower ends,

$$\Delta z = T_L \bar{i}_d \quad \ldots\ldots\ldots\ldots \quad [7]$$

$$\text{and } S = \frac{\Delta z}{L} = \frac{T_L \bar{i}_d}{L} \quad \ldots\ldots \quad [8]$$

The average intake rate for the depth of irrigation and the total time for the advancing front to reach the end of the border check is needed to select the desired drop or gradient. The intake rate function is usually known for the soil in question but the total advance time is more difficult to predict without field trials. Slopes of 0 to 0.05 percent have little influence on rate of advance because dense vegetation greatly retards the flow of water. Crops such as alfalfa and sugar beets severely retard the rate of advance. Increasing stream size with these crops increases rate of advance only slightly because of the greater volume of storage on the surface. Large furrows not blocked by vegetation increase the rate of advance on row crops like corn.

This study did not permit evaluating the separate effects of stream size, slope, and crop retardance for all crops. However, sufficient data were obtained with one stream size on alfalfa to illustrate the type of data needed to predict the rate of advance in low gradient checks. When using equation [1] with a unit stream of about 0.045 $ft^3/sec/ft$ of border width or 2.70 ft^2/min and the magnitudes of the other variables obtained from experimental data values for C_1 and C_2 were obtained. The value of C_2 remained essentially constant at 0.68 for all irrigations on all crops. The value of C_1 increased slightly with ground-surface slope from the average elevation at the upper end to the leading edge of the advancing stream. The computed coefficient C_1 could be represented by the following equation:

for $0 < S_o < 0.001$

$$C_1 = 0.7 + 200\, S_o \quad \ldots\ldots\ [9]$$

where S_o = ground slope from the average elevation near the upper end to the mean grade line at the advancing front, L/L.

C_1 varied from 0.70 to 0.90 in the slope range indicated. The larger value of C_1 illustrates that a more uniform depth occurs behind the leading edge as S_o increases.

The depth of water at the upper end, D_o, increased continuously as water was applied within the above slope range for advance distances up to 400 ft. The depth D_o was less as expected with steeper slopes. The experimental data can be represented by the following equation:

$$D_o = 0.175\, A^{0.19} - C_s \quad \ldots\ [10]$$

where A = the distance to the advancing front, feet

D_o = the depth of water at the upper end, feet

C_s = correction for slope, feet ($C_s = 300\, S_o - 1500\, S_o^2$ for $0 < S_o < 0.001$ ft/ft)

In this study, slope and stream size data were usually confounded for crops other than alfalfa so that individual effects could not be separated. However, at the same stream size as used for alfalfa, the depth D_o during the second and third irrigation on sugar beets with checks having slopes of about 0.02 percent could be expressed by $D_o = 0.0077\, A^{0.3}$. During the first irrigation on sugar beets on a slope of 0.015 percent $D_o = 0.0032\, A^{0.35}$. The nearly doubled value of D_o during the second and third sugar beet irrigations illustrates the influence of increased vegetation on the rate of advance of the irrigation stream. The depth of water given for sugar beets is the average depth across furrows and ridges. The water normally will overtop the ridges when retardance is high.

When inadequate data are available for predicting the rate of advance, then field trials may be necessary. Field trials to evaluate the advance of the irrigation stream combine the effects of slope, crop, intake rate, and stream size. The advance of irrigation water for all irrigations in this study could be expressed as a function of time as $A = ct^n$. On this soil, the value of n was always about 0.67 for the crops and stream sizes used. If one could assume that the value of n remains fairly constant for a given soil, the operator or designer can predict the time for water to reach various distances, A, by noting the time required for the leading edge to reach, say, 200 ft. Using $200 = ct^n{}_{200}$ and $A = ct^n{}_A$, then

$$t_A = \left[\frac{A}{200}\, t^n{}_{200}\right]^{1/n} \quad \ldots\ [11]$$

Summary

A field evaluation of the performance and operating characteristics of border-check irrigation indicated that water-application efficiencies of 80 to 95 percent are easily attained. The rate of water application for maximum efficiency and uniformity of irrigation should be from three to five times the average intake rate. Irrigating crops having a high retardance to flow such as sugar beets results in lower efficiencies.

Closer tolerances in land leveling may be required for border checks than for some other methods of irrigation. However, deviations from the mean grade line of ± 0.2 the depth of irrigation did not greatly affect the uniformity within the upper one-half of the border check. More refined leveling may be required in the lower half of the border check.

Procedures for estimating the total drop or slope for maximum efficiency and uniformity were developed. Coefficients for a water-balance equation to predict the advance of water in low-gradient border checks were derived from the experimental data. The depth of water at the upper end of low-gradient border checks continuously increased as water was applied and advanced in the check.

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