Furrow Inflow and Infiltration Variability

Thomas J. Trout, Bruce E. Mackey
MEMBER
ASAE

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 31, No. 2, pp. 531-537, 1988)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

ABSTRACT

THE furrow-to-furrow variability of irrigation water inflows is about twice as great with gated pipe and feed ditches as with siphon tubes. The average furrow infiltration coefficient of variation measured on 25 fields in southern Idaho was 25%. As a result of both variabilities, irrigation times and application rates must be increased to insure adequate water application to a desired portion of the field.

INTRODUCTION

Irrigation water is commonly applied to furrows (corrugates, creases) with siphon tubes from earthen or concrete-lined ditches, through adjustable gates in plastic or aluminum surface pipe (gated pipe), or through secondary feed ditches. Feed ditches are small earthen channels between the head ditch and the field with an inlet from the head ditch and small outlet cuts or slots to each furrow.

An irrigator normally attempts to set the furrow inflows as evenly as possible at a rate which will advance the water to the tail of the field rapidly without causing excessive runoff or erosion. The uniformity of water advance and tailwater runoff will depend upon the variability of both the furrow inflow and infiltration rates. Through practical experience with these non-uniformities, the irrigator applies sufficient excess water that his criteria for adequate irrigation are met or exceeded on "most" of the furrows, or equivalently, with a certain probability on each furrow.

Thus, both inflow and infiltration variability contribute to non-uniform water application and excess runoff from fields. The objective of this study is to quatify these variabilities and determine causative factors. A companion paper (Trout and Mackey, 1988c) analyzes the effects of furrow-to-furrow inflow and infiltration variability on irrigation management and performance.

PROCEDURE

Inflow rates at the head and outflow at the tail of all or at least 60 consecutive furrows being irrigated in a set were measured during 29 irrigation events on 25 dry bean or sugar beet fields in South-Central Idaho during 1983, 1984, and 1985. Inflow and outflow measurements were also made on partial sets during 8 irrigations on 5 corn fields in the Grand Valley in western Colorado in 1985 and 1986, and on 13 potato fields in eastern Oregon in 1986 and 1987. Only sets with uniform row lengths were measured.

Furrow inflows were measured volumetrically with a 3.78-L (1-gal) bucket where sufficient free fall was available, or with fiberglass V-notch furrow flumes (Robinson and Chamberlain, 1960; Trout, 1986a). Outflows were measured with furrow flumes. Volumetric measurements were made furrow-by-furrow by one person with the bucket and a second person timing with a stopwatch. For flume measurements, one person installed and levelled each flume, while a second person following 3 to 5 min later checked the flume installation and level and took the reading.

Measurements were made late in the irrigation events so that the rate of change of infiltration rates and the effect of differences in infiltration opportunity times would be minimized. The measurement process on a field involved measuring all the inflows and then the outflows in the same order and normally required 1 to 3 h. Infiltration rate was calculated as the difference between inflow and outflow rates. Fig. 1 shows a bar graph representation of a typical set of inflow and outflow data.

On the Portneuf silt loam soils in southern Idaho and the predominately silt-loam soils in eastern Oregon, flows normally reach the tail of the furrow in two to four hours and outflows reach essentially steady flow conditions within two hours of runoff initiation. The measurements were consequently assumed to represent a final or basic infiltration rate. In the Grand Valley, soil textures varied. On fields with finer-textured soils, infiltration rates continued to decrease to the end of the irrigation event.

Any furrows with no or very little inflow, often due to trash blockage of siphon tubes or gates, were excluded from the analysis. Consequently, the results represent variability in the irrigator's setting of the flows and not that which actually occurs when trash interferes with the system operation. Data sets were visually checked to insure no general inflow or infiltration rate trends across the irrigation set were evident.

Inflow and infiltration rate distributions for each irrigation were tested for normality with the Univariate procedure of SAS (SAS, 1985). Two-thirds of both inflow and infiltration data sets were not significantly different from a normal distribution ($P < 0.10$). In two-thirds of the remaining sets which did not fit a normal distribution well, one or two outliers were the main cause of the poor fit. Logarithmically transformed data did not match

Article was submitted for publication in April, 1987; reviewed and approved for publication by the Soil and Water Division of ASAE in January, 1988. Presented as ASAE Paper No. 84-2588.

The authors are: THOMAS J. TROUT, Agricultural Engineer, USDA-ARS, Soil and Water Management Unit, Kimberly, ID; and BRUCE E. MACKEY, Statistician, USDA-ARS, Western Regional Research Center, Albany, CA.

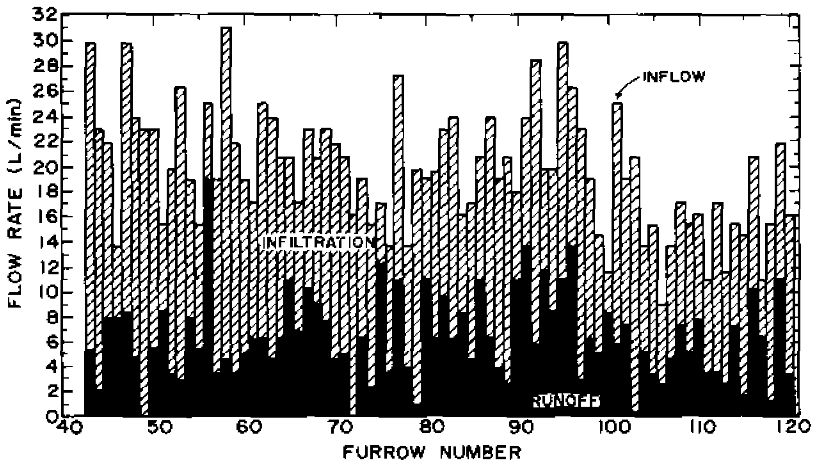

Fig. 1—Graphical depiction of measured furrow inflow and runoff rates for a typical field showing infiltration as the difference. For this field CV_Q = 25%, CV_I = 39%, runoff was 32% of the inflow and two furrows had no runoff.

normal distribution better than the untransformed data. Therefore, normal distribution of the inflow and infiltration data were assumed in all the analyses.

Means and standards deviations were calculated for inflow, outflow and infiltration rates on each irrigation. Standard deviations were found to vary roughly proportionally to the mean, so the more constant coefficient of variation, CV (standard deviation/mean), is used to describe variability. Measured CV's were adjusted downward for the uncertainity in the flow measurement process by subtracting the variance of the measurement process from the measured variance, as explained by Trout and Mackey (1988a-1988b).

Planting, furrowing, and cultivation in the Idaho study area are usually done on three irrigated furrows (six crop rows) per pass, so that means, standard deviations, and CV's were calculated for subsets of each third furrow to isolate any wheel compaction or equipment effects on infiltration. In the Colorado study area alternate furrows are commonly driven on during cultivation, so subsets of alternate furrows were analyzed. In Oregon, although alternate potato furrows are driven on, only alternate furrows are irrigated during a given irrigation, so no subsets were analyzed.

RESULTS

Inflow Vaiability

Table 1 summarizes the Idaho mean measured furrow inflow rate coefficient of variations, CV_Q, for siphon tube, gated pipe, and feed ditch application methods. The "adjusted" values were adjusted for measurement uncertainty (Trout and Mackey, 1988a). The average measurement process CV was 6% and the adjustment in CV_Q averaged about one percentage point.

Siphon tube application method CV_Q for the Idaho data averaged 14%, which was significantly less (at the 1% probability level) than the variability in the other two application methods. Gated pipe and feed ditch application CV's averaged 25% and 29% which are 79% and 107% larger, respectively, than the siphon tube mean value. The measured Colorado and Oregon fields were all siphon tube irrigated and the average adjusted CV_Q values were 15% and 10% respectively.

With normally-distributed data, two-thirds of the data will be within ± 1 standard deviation of the mean. This implies that about one-third of the furrows flowed at least one CV more or less than the mean and that about 5% of the furrows flowed at least 2 CV more or less than the mean. Consequently, on the typical field with gated pipe application to 50 furrows, 16 of the inflows would be more than 25% greater or less than the average and two furrows would flow at least 50% more or less than the average.

The assumption was made that irrigators attempt to set furrow inflow rates evenly and variability thus reflects their inability to do so. However, some irrigators purposely set their flows for perceived infiltration differences. For example, during three measured irrigations in Colorado in which both wheel-compacted and uncompacted furrows were irrigated, the irrigators set the uncompacted furrow inflows 86% higher than the compacted furrow inflows. Some irrigators return to the field late in the furrow stream advance phase and readjust inflows based on observed advance differences so water will reach the ends of all furrows evenly. Both practices result in inflow rates purposely set unevenly to match variable infiltration rates.

Inflow rate was linearly regressed with infiltration rate to determine whether farmers had purposely adjusted

TABLE 1. IDAHO INFLOW VARIABILITY

Application method	No. of fields measured	Ave. no. of furrows/field	Average CV_Q, %	Adjusted CV_Q, % Mean	Median	Range
Siphon tube	23	59	15	14	13	7 to 24
Gated pipe	10	41	26	25	25	13 to 42
Feed ditch	5	47	30	29	27	23 to 38

inflows for known or observed infiltration differences. In 75% of the Idaho data sets, a significant (at the 5% probability level) positive relationship did exist. However, two intercorrelated factors prevent clearly ascribing this relationship to farmers adjusting inflows for infiltration rate. First, infiltration may vary with wetted perimeter and thus flow rate and thus the cause and effect relationship may be the reverse (i.e., higher inflow rates may cause higher infiltration rates). This possibility is analyzed in detail later. Second, since infiltration rate is calculated from the difference between inflow and outflow rates, random inflow measurement errors will bias both inflow and infiltration rates in the same direction, and thus create a measured correlation that may not actually exist.

The measurement error effect was estimated by adding stochastically generated inflow measurement errors to stochastically generated inflow and outflow data sets with normal distributions similar to those measured in the field. The model indicated that when inflow measurement was volumetric, the inflow:infiltration correlation coefficient, r, due to random inflow measurement errors was less than 0.1, while with less accurate inflow flumes, the correlation would range between 0.15 and 0.25.

When this projected measurement process bias is removed, the relationship between inflow and infiltration was still significant on 60% of the Idaho fields and the correlation coefficient was greater than 0.5 on 3 (12%) of the fields. When the correlation is greater than 0.5, more than 25% of the inflow variability is explained by infiltration variability (i.e. $r^2 > 0.25$) and inflow adjustment by irrigators to match infiltration variability is likely. When correlation is significant but lower, the relationship could be due to adjusted inflows, but may result only from a dependence of infiltration on inflow rate.

On the 3 Idaho fields with a high correlation between inflow and infiltration, the average CV_Q was not higher than on the remaining fields. This was also the case for the 9 Oregon fields (2/3 of the total) with high inflow:infiltration correlation. Apparently adjusted inflows were, in general, no more variable than those on fields which were not adjusted, so no corrections need be applied to the averages. The Colorado fields with adjustment for wheel-compaction were not included in the average.

Infiltration Variability

Table 2 summarizes the calculated infiltration variability. The Idaho data is subdivided into preirrigations, second or third irrigations of beans, and September irrigations of sugar beets. The average adjusted infiltration coefficient of variation, CV_I, was 25% with no significant differences between the subsets. The Oregon infiltration data was all collected on potato fields at varying times through the season. The average adjusted CV_I value was 20%. The Colorado measurements were made predominately during preirrigation or first irrigation to corn fields. The average adjusted Colorado CV_I was a much higher 46%.

On an average of 7% of the measured Idaho furrows, 5% of the Colorado furrows, and 1% of the Oregon furrows, the furrow stream advance was not complete at the time measurement was made and there was no runoff. Since the infiltration rate calculation was limited by the inflow rate and was not adjusted for the shorter row length over which the flow infiltrated, rates on those furrows were less than actual rates and generally resulted in a slight underestimate of the variability.

The runoff rate from the Idaho fields averaged 41% of the inflow and averaged less during preirrigation than during later irrigations. Oregon runoff rates averaged 36% of the inflow. Volumetric runoff would average 5 to 10 percentage points less than these assumed steady-state values due to no runoff during advance and lower initial runoff rates. Measured runoff rates in Colorado averaged 43%. Due to rapidly decreasing infiltration rates, a projection of volumetric runoff cannot be made.

On 50% of the measured Idaho fields, farmers had driven on only two of every three furrows with tractor wheels during planting and cultivation. On these fields, the infiltration rate of the third furrow averaged 20% higher than that of the other two. During 1984, when most of these tests were conducted, wheel compaction effects on infiltration were only about half of normal for the area (Kemper et al., 1982; Trout and Kemper, 1983). When the 7 Idaho fields on which wheel compaction effects were greater than 20% are removed from the data set, the adjusted CV_I value of the remaining fields still

TABLE 2. INFILTRATION VARIABILITY

Crop	No. of irrigations measured	Average CV_I, %	Adjusted CV_I, % Mean	Median	Range	Average runoff rate, % of inflow
Idaho beans preirrigation	17	26	23	22	13 to 46	38
Idaho beans mid-season	9	33	29	23	11 to 55	49
Idaho beets late season	3	30	25	24	19 to 33	43
Idaho combined	29	28	25	24	11 to 55	41
Oregon potatoes	14	23	20	18	8 to 38	36
Colorado corn	8	48	46	41	22 to 107	43

average 25%. On 2 of the 3 Colorado fields on which every furrow was irrigated, infiltration rates of alternate wheel-compacted furrows averaged less than 50% those of the uncompacted furrows. When only alternate, evenly compacted furrows are considered, the variability decreased about 30%, and the average CV_I value for all Colorado fields decreases from 46% to 39%. Only alternate, uniformly compacted furrows were irrigated during a given potato irrigation in Oregon.

DISCUSSION

Inflow Variability

An irrigator's only evaluation of the relative size of a feed ditch flow is the cross-sectional flow area in the furrow. Although most irrigators claim, through experience, to be able to judge flows well and set feed ditch water evenly, the most uniformly-set feed ditch inflows were as variable as the least uniformly-set siphon tube flows. Furrow flow depths and widths will generally vary only about three-eights as much as the flow rate (Trout, 1986b), so a 25% flow rate variation would result in only about a 9% flow depth or width variation, which is difficult to detect. Vegetation growth, sediment deposition and erosion change feed ditch capacity and earthen slot sizes and thus flow distribution.

Gated pipe is often considered an improvement over siphon tubes as a water application method, and is sometimes cost-shared with federal funds as a water conservation technique. However, in southern Idaho, gated-pipe applications are significantly less uniform than siphon tube applications. Although gated pipe is commonly used on fields with uneven or steep cross slopes or variable row lengths, which are more difficult to irrigate, such fields were not measured in this study.

Siphon tube inflows are more uniform than gated pipe inflows because siphon tube cross-sectional flow area is fixed by the tube diameter. Also, the head or pressure creating the siphon flow, which is the elevation difference between the ditch water surface and the outflow end of the siphon (or the furrow water level if the end is submerged), is both fairly uniform and easy for the irrigator to see. Siphon tube flow is adjusted by moving the outflow end of the tube up or down. Relative settings are judged either by the relative elevations of the tubes (since the ditch water surface is fairly level), or by the trajectory of the water jet from the fixed-area end. Since siphon flow is proportional to the square root of the head, head, which normally ranges from 100 to 300 mm, would have to vary 50% to cause a 25% flow variation.

A disadvantage of the insensitivity of siphon tube flow to head is its limited flow range. Often, an irrigator's practical means to boost the flow to match higher infiltration rates is to add a second siphon to a furrow, which often results in rates higher than needed.

Head at a gated-pipe outlet is determined by the water pressure in the pipe, which varies both with the relative outlet elevation and the relative location along the pipe. Flow rate is adjusted by changing the gate opening. Gates are usually adjusted by tapping with a shovel. With the small flows and moderate-to-steep pipe slopes in southern Idaho (generally 0.5 to 1.5%), gate opening widths are often in the range of 5 to 20 mm. Consequently, a 25% flow variation would result from only a 1 to 5 mm variation in gate opening, since flow is proportional to opening area. In areas where wider gate openings are used (larger flow and/or lower pipe pressure) less variability would be expected. The irrigator must estimate pipe pressure variations from the outlet jet and adjust opening sizes accordingly. Also, due to the higher pressure and consequent smaller outlet sizes in gated pipe as used in Idaho, outlets are more susceptible to plugging with trash than are siphon tubes.

High gated-pipe application uniformity can be achieved if outlet area and head is uniform. A slotted wedge with an adjustable stop (USDA-ARS, 1986) can be used to uniformaly set gated-pipe outlet openings and reduce much of the random variation caused by gate settings. This device, when used on cablegation systems (Kemper et al., 1981), on which head is carefully controlled through uniform pipe grade, resulted in furrow-to-furrow cumulative inflow CV's of 5%. Barrel spigot-type gated-pipe outlets with setting markings on the handle (USDA-ARS, 1985) and fixed-size outlet holes in pipe have also been used on cablegation systems to achieve CV_0 values of 3 to 5%. In this low CV range, actual flow variability is indistinguishable from measurement uncertainty.

Infiltration Variability

The measured coefficient of variation of furrow-to-furrow infiltration rates averaged 25% in southern Idaho, 20% in eastern Oregon, and 46% in western Colorado. With the normally distributed data these values would produce water application uniformities with Christiansen uniformity coefficients, UC, of 0.80, 0.84, and 0.64 respectively.

Kemper et al. (1982) measured average furrow-to-furrow steady-state infiltration rate CV's of 57% (not adjusted for measurement uncertainty) on six furrow sets on 15 fields in southern Idaho. The average CV's reduced to 38% on subsets of furrows with or without wheel compaction. Trout and Kemper (1983) measured CV's on research plots with uniform tillage and irrigation practices of 20 to 30%.

The measured infiltration is an average value over the furrow length and the calculated variability ignores infiltration variability along a furrow. Bautista and Wallender (1985) measured 180-min infiltrated volume and "quasi-steady" infiltration rate with a recirculating infiltrometer on 30 1-m long subsections of a furrow. Their calculated coefficients of variation were 53% and 21% for cumulative and steady infiltration. Viera et al. (1981) calculated the variability (CV_I) of 1280 ring infiltrometer steady-state measurements taken on a grid in a field as 40%.

An identified cause of furrow-to-furrow infiltration variability is uneven tractor and implement wheel compaction of furrows. Fig. 2 shows the measured and calculated effect of uneven furrow compaction on infiltration variability for Idaho conditions. The infiltration reduction is the average percent infiltration rate reduction due to wheel compaction. The variance ratio is the ratio of the furrow-to-furrow variance (standard deviation, squared) of all furrows relative to the variance of subsets of only compacted or uncompacted furrows. The variance ratio expresses the contribution to the variability of the uneven compaction.

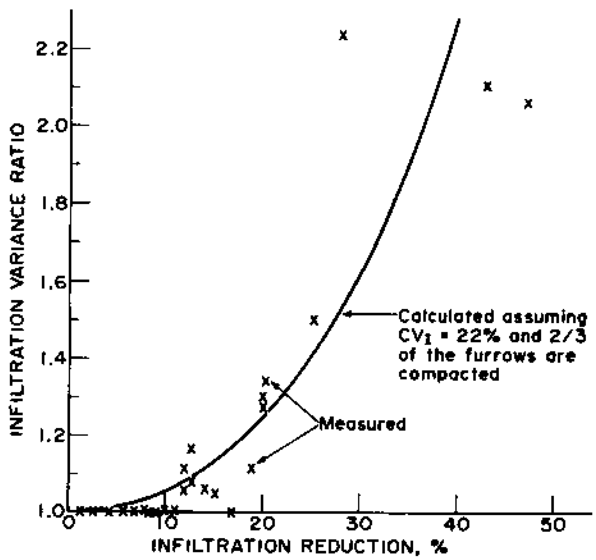

Fig. 2—Calculated and measured effect of uneven furrow compaction on infiltration variability.

The calculated curve assumes two-thirds of the furrows are compacted and the CV_I without uneven compaction is 22%. (The choice of 22% is evident from the next paragraph.) Compacting only half the furrows would change the projected results only slightly. The calculated curve describes the Idaho measured data relatively well.

Fig. 2 shows that when wheel compaction reduces the infiltration rate of two-thirds of the furrows by less than 20%, the contribution to the total variability is small. However, at often-cited infiltration reduction values above 35% (Kemper et al., 1982; Fornstrom et al., 1985; Musick et al., 1985) over half of the total variability is due to uneven wheel compaction (variance ratio >2) and removing uneven wheel compaction would reduce CV_I values by over 30% ($1 - \sqrt{1/2}$). Eliminating uneven wheel compaction effects from all of the Idaho infiltration data sets results in an average CV_I valve if 22%.

As previously discussed, inflow rate and infiltration rate are related on some fields. Increased inflows would increase wetted perimeter which has been linearly related to furrow infiltration (Fangmeier and Ramsey, 1978; Samani, 1983). This relationship can be estimated by assuming that the wetted perimeter varies with the three-eights power of the flow rate (Trout, 1986b), and that infiltration is linearly related to average furrow wetted perimeter at the furrow mid-length. Under these conditions, The CV_I which would result only from inflow variability would be 6% at $CV_Q = 14\%$ (siphon tubes), 10% at $CV_Q = 25\%$ (gated pipe) and 13% at $CV_Q = 29\%$ (feed ditch). When the effect (variances) of these values are subtracted from 25% CV_I, the resulting CV_I values are 24%, 23%, and 21%, respectively. Consequently, although the interaction could contribute significantly to the previously discussed relationship between measured infiltration variability, it would contribute only slightly to the total measured infiltration variability.

Furrow-to-furrow infiltration variability is substantial. Although some causes of the variation, such as uneven compaction during tillage or cultivation or variations in flow rate, are known at least qualitatively, most of the variation is left unexplained. Greater uncertainty in the measurement process than that estimated is possible, but unlikely. Even a 50% higher measurement process CV would reduce the adjusted CV_I for Idaho only an additional 4 percentage points to 21%.

Cumulative and Seasonal Infiltration Variability

This infiltration variability analysis is of infiltration rate measured several hours after the start of irrigation. However, cumulative infiltration determines the water distribution. As explained, the infiltration process in southern Idaho is dominated by the basic or steady-state rate. In fact, correlation between cumulative infiltration and base infiltration rate on experimental plots is generally above 0.9. Thus, variability in the basic rate should be representative of cumulative infiltration variability. The infiltration relationship of the silt loam soils common in eastern Oregon is similarly dominated by the steady-state rate. However, on the finer-textured soils of the Grand Valley in Colorado, final infiltration rates tend to be small relative to initial infiltration, and thus, influence cumulative infiltration much less.

Furrow cumulative infiltration was measured on three experimental plots in Idaho and eight farmer fields in the Grand Valley by recording furrow inflows and outflows on individual furrows regularly over time using the same devices described previously. Cumulative infiltration variability was then compared with the variability of a single randomly chosen set of rate measurements. The average infiltration rate and cumulative infiltration CV of the three Idaho plots was 15% and 10%, respectively. However, much of the difference in these measured values is the result of the measurement since the uncertainty of a single measurement is larger than that of multiple measurements and the relative measurement effect is large when the variability is small. In Colorado, the average final rate CV was 46% compared to a CV of 22% for the cumulative infiltration data, a reduction of half. Thus, a relationship between final infiltration rate variability and cumulative infiltration variability cannot be generalized but will depend on the soil conditions and infiltration relationship. Bautista and Wallender (1985), in fact, found cumulative infiltration more variable than final rate in short sections (1 m) of furrows in a cracking, swelling clay. They attribute this to the large initial effects of localized cracks, which eventually swell closed.

Relative furrow-to-furrow infiltration might also change through a season as furrow perimeters consolidate, seals form, cracking occurs, roughness changes, and/or additional tillage is applied. This would tend to reduce long-term furrow water application variability as wind direction changes reduce seasonal sprinkler application variability. Table 3 shows the average variability of individual irrigations and consecutive pairs of irrigations, compared to the variability of total seasonal water application to research plots at Kimberly, ID, and Fruita, CO. Application times to all furrows in a set were equal. The results show, as expected, that relative infiltration changes over time do tend to reduce the variability of accumulated water application. The benefit gain in crop production of this evening out over the season will depend on the moisture levels sustained and the crop sensitivity to short-term moisture stress.

TABLE 3. VARIABILITY OF MEASURED SEASONAL APPLICATION AND AVERAGE VARIABILITY OF INDIVIDUAL IRRIGATIONS TO INDIVIDUAL FURROWS ON RESEARCH PLOTS

Location	No. of furrows	No. of irrigations	Coefficient of variation, % Average cumulative infiltration variability of individual irrigations	Average cumulative infiltration variability of consecutive pairs of irrigations	Seasonal infiltration variability
Kimberly, ID	6	5	11	9	9
Fruita, CO	6	6	13	10	7
Fruita, CO	8	4	30	24	20

Available Water Variability

When two or more crop rows are planted between widely-spaced irrigated furrows, such as is the case with beans in southern Idaho, only water application from the adjacent furrow has significant effect on the water available to an individual crop row. However, when a crop row has an irrigated furrow on both sides, the two adjacent furrows have nearly equal affect on the water availability. Also, when furrows are not widely spaced, and especially with broadcast crops, subsurface moisture moves laterally and crop roots preferentially grow in moist soil such that moisture can be gained from other than the nearest furrow. Thus, individual furrow infiltration variability will overstate the effective water application nonunformity.

To determine this effective water application non-uniformity, the infiltration variability of consecutive pairs of furrows was determined by calculating the CV_I of 2-furrow running averages across the fields. The adjusted infiltration rate CV of furrow pairs in southern Idaho was 19% compared to 25% for individual furrows. The adjusted CV_I for furrow pairs in the Grand Valley was 28% compared to 46% for individual furrows. Recall that the average CV_I of individual furrows in the Grand Valley was only 39% on subsets of wheel compacted or uncompacted furrows, so a large portion of this difference is the result of uneven compaction. In eastern Oregon, alternate furrows were irrigated every other irrigation on most fields, and thus only alternate furrows were measured. The 2-point running average CV_I of these alternate furrows was 16% compared to 20% for individual furrows. Thus, individual furrow variability overstates the effective water availability variability by 25 to 50% for crops which absorb moisture from more than one furrow.

Consequences of Inflow and Infiltration Variability

The consequences of furrow-to-furrow inflow and infiltration variability are irrigation water loss and/or high system and labor costs. In order to insure adequate furrow advance times on those furrows with higher infiltration rates and/or lower inflow rates, the irrigator must either return to the field to boost the inflow on furrows with slow advance, or must initially set all inflows higher. The result of higher inflows is higher runoff from the tail end of the furrows. The average runoff rate on the measured fields was 40%.

In order to apply adquate water to furrows with low infiltration rates, the irrigation time must be extended until the required water has infiltrated. In the process, excess water will be applied to all furrows with higher infiltration rates. The greater the infiltration variability, the greater the excess application and, thus, deep percolation loss. The relationship between runoff and deep percolation loss and inflow and infiltration variability is quantified in Trout and Mackey (1988c).

SUMMARY AND CONCLUSIONS

1. Irrigators apply water to furrows much more evenly with siphon tubes than with gated pipe or feed ditches. The measured coefficient of variation in southern Idaho of the three application methods is 14%, 25%, and 29%, respectively. Hydraulic principles can explain these differences.
2. The furrow-to-furrow base infiltration rate coefficient of variation is 25% in southern Idaho, 20% in eastern Oregon, and 46% in western Colorado. When the effect of uneven furrow wheel compaction is removed, the values are 22%, 20%, and 39%, respectively. Most of this large variability in whole-furrow infiltration is unexplained.
3. The variability of cumulative infiltration will generally be less than infiltration rate. The reduction will depend upon the soil infiltration relationship. Relative infiltration changes with time will decrease seasonal infiltration variability below that of individual irrigations.
4. Crops which utilize water from more than one furrow will experience 20 to 30% less water availability variability than those with only one furrow supplying water.
5. Furrow inflow and infiltration variability causes farmers to apply excess water in order to adequately irrigate a major portion of a field.

References

1. Bautista, E., and W. W. Wallender. 1985. Spatial variability of infiltration in furrows. TRANSACTIONS of the ASAE 28(6):1846-1851, 1855.

2. Fangmeier, D. D., and M. K. Ramsey. 1978. Intake characteristics of irrigated furrows. TRANSACTIONS of the ASAE 21(4):696-700, 705.

3. Fornstrom, K. J., J. A. Michel, Jr., J. Borelli, and G. D. Jackson. 1985. Furrow firming for control of irrigation advance rates. TRANSACTIONS of the ASAE 28(2):519 531.

4. Kemper, W. D., W. H. Heinemann, D. C. Kincaid, R. V. Worstell. 1981. Cablegation I: Cable controlled plugs in perforated supply pipe for automatic furrow irrigation. TRANSACTIONS of the ASAE 24(6):1526-1532.

5. Kemper, W. D., B. J. Ruffing, and J. A. Bondurant. 1982. Furrow intake rates and water management. TRANSACTIONS of the ASAE 25(2): 333-339.

6. Musick, J. T., F. B. Pringle, and P. H. Johnson. 1985. Furrow compaction for controlling excessive irrigation water intake. TRANSACTIONS of the ASAE 28(2):502-506.

7. Robinson, A. R., and A. R. Chamberlain. 1960. Trapezoidal flumes for open channel flow measurement. TRANSACTIONS of the ASAE 13(2):120-128.

8. Samani, Z. A. 1983. Infiltration under surge irrigation. Ph.D dissertation, Utah State University.

9. SAS. 1985. SAS Procedures Guide for Personal Computers, Version 6 Edition. SAS Institute, Inc., Box 8000, Cary, NC 27511. pp. 350-351.

10. Trout, Thomas J. 1986a. Installation and use of the Powlus fiberglass V-notch furrow flume. Unpublished report. Powlus Manufacturing, 269½ Addison Avenue West, Twin Falls, ID 83301.

11. Trout, Thomas J. 1986b. Flow velocity and wetted perimeter effect on furrow infiltration. ASAE Paper No. 86-2573, ASAE, St. Joseph, MI 49085.

12. Trout, Thomas J., and W. D. Kemper. 1983. Factors which affect furrow intake rates. In: Advances in Infiltration. Proceedings of National Conference on Advances in Infiltration. ASAE. St. Joseph, MI 49085. pp. 302-312.

13. Trout, Thomas J., and B. E. Mackey. 1988a. Furrow flow measurement accuracy. Journal of Irrigation and Drainage Engineering, ASCE 114(2):244-255.

14. Trout, Thomas J., and B. E. Mackey. 1988b. Inflow-outflow infiltration measurement accuracy. Journal of Irrigation and Drainage Engineering, ASCE 114(2):256-265.

15. Trout, Thomas J., and B. E. Mackey. 1988c. Consequences of furrow inflow and infiltration variability. TRANSACTIONS of the ASAE (in process).

16. USDA-ARS. 1985. 1985. Cablegation Update. USDA-ARS, Route 1, Box 186, Kimberly, ID 83341,

17. USDA-ARS. 1986. 1986 Cablegation Update. USDA-ARS, Route 1, Box 186, Kimberly, ID 83341.

18. Viera, S. R., D. R. Nielsen, and J. W. Biggar. 1981. Spatial variability of field measured infiltration rate. Soil Sci. Soc. Am. J. 45:1040-1048.