# Irrigation Uniformity

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Increasing production efficiency is becoming a major theme for producers in order to maintain or increase their economic return in an increasingly competitive global market. In the case of irrigated agriculture, producers must also address increasing public concern about water conservation, water quality, and environmental protection.

Two irrigation management issues require attention in order to maximize production efficiency. These are irrigation scheduling and irrigation uniformity. Irrigation scheduling involves determining the proper amount and timing of water applications throughout the growing season. Proper irrigation scheduling results in irrigation applications that supply the water needs of the crop without the development of deficit or excess soil moisture conditions.

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Both over- and under-irrigation reduce crop yield and/or quality. For example, Figure 1 shows the impact of over- and under-irrigation on potato yield. The data shown in Figure 1 were collected from an irrigation management study of 45 commercial fields under sprinkler irrigation in southeastern Idaho during 1995. A mere 10 percent departure of seasonal water application from seasonal evapotranspiration (ET) can begin to decrease tuber yield and impact quality. Yield reduction due to over-irrigation can be attributed to poor soil aeration, increased incidence of disease, and leaching of mobile nutrients below the crop root zone. In general, over- and under-irrigation adversely impact the yield and quality of all crops.

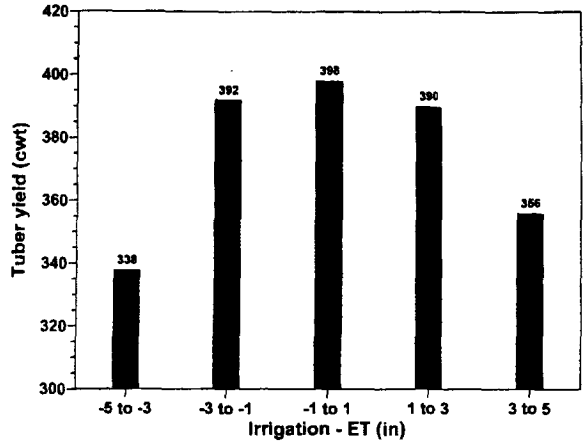


Figure 1. Total potato yield as influenced by the difference between irrigation and seasonal evapotranspiration (ET) on 45 commercial potato fields in southeastern Idaho in 1995.

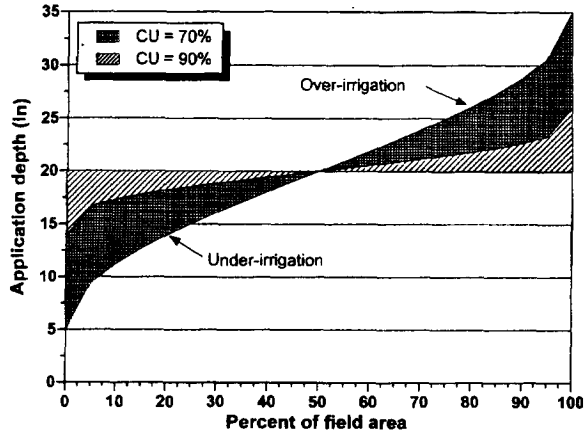


Figure 2. Seasonal water application depth versus field area for two levels of irrigation uniformity and an average application depth of 20 inches.

While the results shown in Figure 1 emphasize the importance of proper irrigation scheduling in attaining maximum yield and quality, irrigation uniformity is just as important. Irrigation uniformity describes how evenly an irrigation system distributes water over the field area. The most common quantitative measure of irrigation uniformity is the Christiansen uniformity coefficient (CU). The CU provides a quantitative measure of the average deviation from the mean application depth relative to the mean application depth. When water application is perfectly uniform, which is impossible on a field scale, the CU is 100 percent. Field evaluation of irrigation uniformity requires considerable effort. Details on sampling requirements, procedures, and calculation of the CU can be found in the American Society of Agricultural Engineers Standards (ASAE, 1999).

The numerical significance of the CU is illustrated in Figure 2 using a cumulative frequency distribution of seasonal water application depth versus field area. The cumulative frequency distributions shown in Figure 2 are applicable to sprinkler and microirrigation systems. Figure 2 graphically shows cumulative water application distributions for CU values of 70 and 90 percent with a seasonal average water application of 20 inches. By definition, half of the field area receives less than the average application depth and half of the field area receives more than the average application depth. Lower CU values result in greater deviations from the average application depth as illustrated by the greater extremes in water application depth for a 70 percent CU versus a 90 percent CU.

The usefulness of the relationships shown in Figure 2 stems from the graphical representation of cumulative seasonal water application. For example, 20 percent of the field area receives 13.9 inches of water or less when the irrigation system has a CU of 70 percent compared to 0 percent of the field area when the irrigation system has a CU of 90 percent. Assuming seasonal ET for the potato yield data shown in Figure 1 is 20 inches, a seasonal water application of 17 inches or less would be expected to result in a tuber yield reduction of 60 cwt/ac (from 398 to 338 cwt/ac) or more. Based on the graphs in Figure 2, 34 percent of the field area would receive less than 17 inches with an irrigation

system having a CU of 70 percent, but only 9 percent of the field would receive less than 17 inches with a CU of 90 percent. Maximum yield is expected to occur on 34 percent of the field when the irrigation system has a CU of 90 percent but only on 10 percent of the field when the irrigation system has a CU of 70 percent. Thus, total yield would be lower with the lower uniformity since a much larger portion of the field would receive over- or under-irrigation. This is summarized in Figure 3 which shows the expected yield distribution at both CU levels resulting from combining the data of Figures 1 and 2. Overall, total yield increases 6 percent, from 362 cwt/ac to 385 cwt/ac, by increasing the CU from 70 percent to 90 percent. The estimated irrigation uniformity effects on yield, quality, and gross receipts are summerized in Table 1. Tuber quality data is based on the 1995 irrigation study depicted in Figure 1. The estimated increase in gross receipts firm increasing CU from 70 to 90 percent is $144/acre. Smaller increases in CU would generate smaller increases in gross receipts. Tuber quality will likely be more variable when the irrigation system has a low CU. The percentage of field area receiving deficit water application can be reduced by additional irrigation, but overall production will not increase because the additional irrigation causes over-irrigation on other portions of the field, which reduces yield there.

Application system type, design, physical condition, and the operating environment largely determine irrigation uniformity. A high degree of control is required to achieve high irrigation uniformity. Only irrigation systems which precisely control the amount and location of water application are capable of high irrigation uniformity.

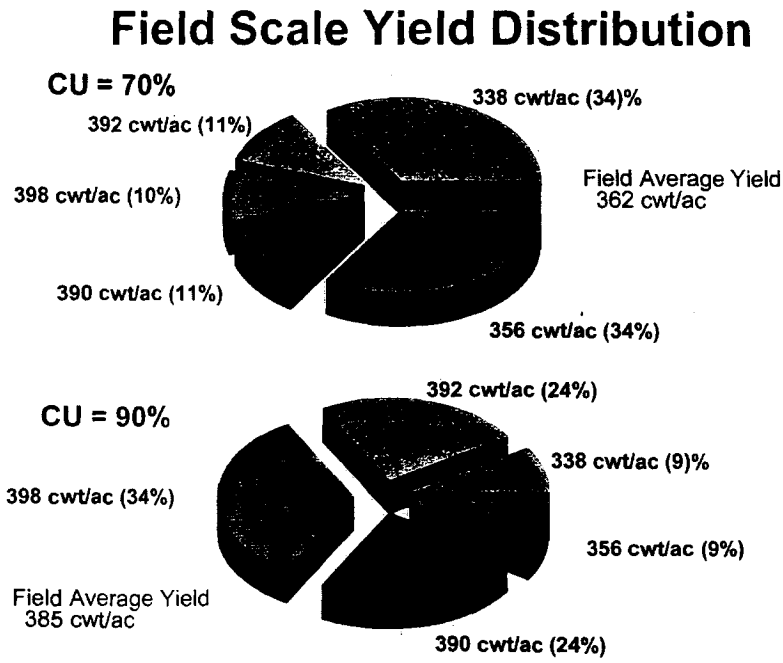


Figure 3. Comparison of estimated field scale potato yield for two levels of irrigation uniformity.

Table 1. Estimated irrigation uniformity effects on yield, grade and gross receipts for Russet Burbank.

| Irrigation Uniformity | Yield | | | Incentive | |
|---|---|---|---|---|---|
| | Total cwt/acre | U.S. No. 1's cwt/acre | 7 to 14 oz cwt/acre | Adjusted Price $/cwt | Gross Receipts $/acre |
| 70% | 362 | 277 | 138 | 4.74 | 1716 |
| 90% | 385 | 310 | 148 | 4.83 | 1860 |
| Difference | 23 | 33 | 10 | 0.09 | 144 |

## MANAGING IRRIGATION SYSTEMS FOR HIGH CU

The various types of irrigation application systems require varying levels of management and attention to different operational details to achieve high irrigation uniformity. Following installation of an irrigation system, it becomes the irrigation manager's responsibility to maintain the level of irrigation uniformity. The key items requiring attention that can be manipulated to achieve high irrigation uniformity are described below by irrigation application system type.

### Center pivot and linear-move systems

Center pivot and linear-move irrigation systems equipped with new pressure-regulated, low-pressure sprinkler packages are capable of attaining CU values of 90 to 95 percent. A CU value of 85 percent is generally considered to be the minimum value below which a system needs updating or maintenance. Center pivot sprinkler nozzle sizes are selected by computer to attain a high degree of irrigation uniformity for a given sprinkler model and available spacing. Nozzle sizes must be installed in the correct locations along the center pivot lateral for optimum system performance. In general, sprinklers on center pivot and linear-move systems have an overlap factor of two to four which results in very uniform water application. Computer simulations of water application depth with wind-affected sprinkler patterns indicate that winds below 10-12 mph have little effect on application uniformity. Wind tends to shift the application pattern downwind while largely maintaining the irrigation uniformity under no-wind conditions.

In the case of center pivot and linear-move systems, factors that influence irrigation uniformity can produce a random effect or cumulative effect. Random effects are less important as they tend to even out over the course of the irrigation season. Wind is the most common factor which produces a random effect on irrigation uniformity. Cumulative effects are more important as they result in differences in water application that increase throughout the irrigation season. Worn or malfunctioning equipment and improper design and installation are the most common factors that produce cumulative effects on irrigation uniformity.

The primary objective in the maintenance of a center pivot or linear-move irrigation system is to maintain the design flow rate from each sprinkler. This requires that the design pressure and nozzle size at each sprinkler be maintained. Common problems are worn or plugged sprinkler nozzles, plugged or malfunctioning pressure regulators, and improper installation of the sprinkler package nozzle sizes on center pivots. Of these common problems, only a plugged sprinkler nozzle or regulator is easy to spot when the system is operating. The other common problems are not readily discernable by visual observation of the system in operation. Malfunctioning pressure regulators are nearly impossible to visually identify, however, some emit water through the sides of the regulator when they fail structurally. A malfunctioning regulator will result in a sprinkler pressure that will be too high. A sprinkler emitting a fine spray relative to adjacent sprinklers may indicate a malfunctioning pressure regulator. For situations where the sprinkler is readily accessible, flow rate measurements from 10 to 20 randomly selected sprinklers can be used to judge the condition of the sprinkler package. Flow rate measurements can be made using a large graduated container such as a 12 qt pail and a stopwatch. The container can be positioned to encompass the sprinkler and capture flow from the sprinkler for a specific time measured with the stopwatch. Sprinkler flow rate can then be calculated from these two measurements and compared to the nominal flow rate value for the nozzle size and pressure. Nominal sprinkler flow rates for common center pivot sprinkler pressures and nozzle sizes are provided in Table 2. Differences greater than ±10 percent indicate a problem. A repeated measurement should be used to confirm flow rate measurements greater than ±10 percent of the nominal flow rate.

**Example:** 8.5 quarts caught in 36 seconds from a sprinkler with a #22 nozzle and 20 psi pressure regulator

Measured flow rate

$$\left(\frac{8.5\text{qts}}{4\text{qts/gal}}\right) \times \left(\frac{60\text{ sec/min}}{36\text{ sec}}\right) = 3.54\text{ gpm}$$

Nominal flow rate
From Table 1 3.78 gpm

$$\text{Difference} = \left(\frac{3.54 - 3.78}{3.78}\right) \times 100 = -5.1\% < 10\% \text{ okay}$$

**Table 2.** Nominal sprinkler nozzle flow rates in gpm for center pivot and linear-move systems. Nozzle sizes are given in 128th inch increments e.g. #22 is $^{22}/_{128}$ inches in diameter.

| Pressure psi | Nozzle Size #9 | #10 | #11 | #12 | #13 | #14 | #15 | #16 | #17 |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.47 | 0.57 | 0.69 | 0.82 | 0.96 | 1.11 | 1.27 | 1.44 | 1.63 |
| 15 | 0.57 | 0.70 | 0.84 | 1.00 | 1.17 | 1.35 | 1.55 | 1.76 | 1.98 |
| 20 | 0.66 | 0.81 | 0.97 | 1.15 | 1.35 | 1.56 | 1.79 | 2.03 | 2.28 |
| 25 | 0.73 | 0.90 | 1.08 | 1.29 | 1.50 | 1.74 | 1.99 | 2.26 | 2.55 |
| 30 | 0.80 | 0.98 | 1.19 | 1.41 | 1.65 | 1.90 | 2.18 | 2.47 | 2.78 |

| Pressure psi | Nozzle Size #18 | #19 | #20 | #21 | #22 | #23 | #24 | #25 | #26 |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 1.82 | 2.02 | 2.23 | 2.46 | 2.69 | 2.94 | 3.19 | 3.46 | 3.74 |
| 15 | 2.22 | 2.47 | 2.73 | 3.00 | 3.29 | 3.58 | 3.90 | 4.22 | 4.56 |
| 20 | 2.55 | 2.84 | 3.14 | 3.45 | 3.78 | 4.13 | 4.49 | 4.86 | 5.25 |
| 25 | 2.85 | 3.17 | 3.50 | 3.85 | 4.22 | 4.60 | 5.01 | 5.42 | 5.86 |
| 30 | 3.11 | 3.46 | 3.83 | 4.21 | 4.61 | 5.03 | 5.47 | 5.93 | 6.40 |

| Pressure psi | Nozzle Size #27 | #28 | #29 | #30 | #31 | #32 | #33 | #34 | #35 |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 4.02 | 4.32 | 4.63 | 4.95 | 5.28 | 5.61 | 5.96 | 6.32 | 6.69 |
| 15 | 4.91 | 5.27 | 5.65 | 6.03 | 6.44 | 6.85 | 7.27 | 7.71 | 8.16 |
| 20 | 5.65 | 6.07 | 6.50 | 6.95 | 7.41 | 7.88 | 8.38 | 8.88 | 9.40 |
| 25 | 6.30 | 6.77 | 7.25 | 7.75 | 8.27 | 8.80 | 9.34 | 9.91 | 10.48 |
| 30 | 6.89 | 7.40 | 7.93 | 8.48 | 9.04 | 9.62 | 10.22 | 10.83 | 11.46 |

| Pressure psi | Nozzle Size #36 | #37 | #38 | #40 | #42 | #44 | #46 | #48 | #50 |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 7.07 | 7.46 | 7.86 | 8.69 | 9.57 | 10.48 | 11.43 | 12.43 | 13.46 |
| 15 | 8.63 | 9.10 | 9.59 | 10.61 | 11.67 | 12.78 | 13.95 | 15.16 | 16.42 |
| 20 | 9.93 | 10.48 | 11.04 | 12.21 | 13.44 | 14.72 | 16.06 | 17.46 | 18.91 |
| 25 | 11.08 | 11.69 | 12.32 | 13.62 | 14.99 | 16.42 | 17.91 | 19.47 | 21.09 |
| 30 | 12.12 | 12.78 | 13.47 | 14.89 | 16.39 | 17.95 | 19.59 | 21.59 | 23.07 |

When one or more sprinklers are found to have flow rates greater than ±10 percent of the nominal flow rate, a second set of 10 to 20 randomly selected sprinklers need to be tested. If more sprinklers are found to have flow rates greater than ±10 percent of the nominal flow rate, the cause needs to be identified and corrected. Measured flow rates below the nominal flow rate indicate that the actual pressure is below the assumed or pressure regulator rated pressure. This can be due to plugging or system operating pressure below the design pressure. Measured flows above the nominal flow rate indicate a malfunctioning pressure regulator. A good strategy against worn nozzles and malfunctioning pressure regulators is to replace the sprinkler package every five to seven years. This will ensure that the highest possible irrigation uniformity is maintained throughout the life of the irrigation system.

Pressure measurements are necessary to correctly diagnose measured flow rate anomalies and verify pressure regulator operation. A Pitot tube attached to a pressure gauge, Figure 4, is used to field check pressure regulator operation. Both are available from most irrigation equipment suppliers. The Pitot tube should be small to minimize flow interference. Pressure measurements are taken by placing the Pitot tube directly into the flow jet exiting the nozzle such that the open end of the tube is perpendicular to the flow jet. If the Pitot tube is inserted into the nozzle, the flow will be reduced, but a properly functioning pressure regulator will readjust to maintain the pressure within ±2 psi of the regulator pressure rating. Pressure measurements greater than 2 psi above the regulator pressure rating indicates a malfunctioning pressure regulator. Pressure measurements more than 2 psi below the regulator pressure rating indicates plugging or low system operating pressure.

The Pitot tube shown in Figure 4 may physically be too large to allow pressure measurements on some models of center pivot sprinklers. A modified version with a smaller diameter tube and longer length may need to be constructed to allow insertion into the water jet exiting the sprinkler nozzle. The only critical issue when constructing a Pitot tube is to make sure that the bend does not close off the tube leading to the pressure gauge.

**Figure 4.** Pitot tube attached to pressure gage that is used to measure operating pressure of a sprinkler nozzle.

The height of the sprinkler above the crop canopy can significantly affect irrigation uniformity. In general, sprinkler height should be approximately 3 feet above the plant canopy to ensure good irrigation uniformity. Sprinkler heights greater than 6 feet above the plant canopy increase wind drift and evaporation losses. More details on sprinkler type, height, and spacing are available in Bulletin 797, "Optimal Performance from Center Pivot Sprinkler Systems."

With center pivot and linear-move irrigation systems, uniform travel speed is important in attaining optimum irrigation uniformity for the total field area. Excessive slippage of the outer or end tower(s) through wet areas and up steep slopes will tend to slow the speed of the system and increase application depths relative to other areas of the field. Booms can be used to offset sprinklers behind the lateral near the towers to reduce water application ahead of the tower wheels, thereby–reducing slippage potential and rutting. The continuous motion of hydraulic drive versus the start-stop motion of electric drive systems often leads to questions concerning the impact of continuous movement on irrigation uniformity. There is no discernable difference in irrigation uniformity at the individual plant scale between hydraulic and electric drive systems for the sprinkler packages used in Idaho where individual sprinkler patterns are typically 45 feet in diameter or greater and sprinkler overlap is typically a factor of two or greater.

With center-pivot and linear-move irrigation systems, the timing of successive irrigations at a given field location is critical in optimizing irrigation uniformity for the total field area. Water loss due to evaporation and wind drift differs by 3 to 8 percent between day and nighttime hours. The diurnal difference in net water application must be spread over the total field area throughout the irrigation season in order to maintain high irrigation uniformity. The system needs to be operated such that successive irrigations at a given field location occur at different times during the day. This can be achieved with center pivot systems by setting the system rotation time to be something other than a multiple of 24 hours. Suitable rotation times are 18, 30, 36, 42, 54, 60 hrs and so on.

### Wheel line and hand line systems

Irrigation uniformity of set-move sprinkler systems such as wheel lines and hand lines is dependent upon several factors. These include sprinkler spacing, operating pressure and orientation, wind speed and direction, and pressure distribution in the sprinkler lateral. A set-move system can achieve CU values of 80-90 percent with proper design and maintenance under moderate to low wind conditions, i.e. less than 10 mph. Values as low as 60 percent can occur with systems on undulating topography, with worn or plugged nozzles, and/or under windy conditions.

As with center pivot and linear-move systems, the primary objective of system maintenance is to maintain the design flow rate and application pattern from each sprinkler along the lateral. Common problems are worn or plugged nozzles, pressures that are too high or too low, irregular rotation of the sprinkler head, a sprinkler axis of rotation that is not vertical, and system leaks. If high irrigation uniformity is to be achieved, each of these items needs to be monitored and corrected if necessary.

Set-move sprinkler systems require a daily commitment to detail to achieve optimum irrigation uniformity throughout the season. Symmetrical application of water around the sprinkler is necessary for optimum uniformity. This means that the sprinkler riser must be set vertical. For wheel line systems the self-levelers must be maintained to provide free movement for proper functioning. System leaks resulting from damaged gaskets or malfunctioning automatic drains need to be repaired regularly. Replacement of gaskets and seals every five years is a good practice. The bearings on the standard impact sprinkler need to be checked yearly to ensure that rotation of the sprinkler is free and smooth for uniform rotation speed. Any of the above items can significantly reduce irrigation uniformity if not corrected.

Sprinkler operating pressure has a significant impact on irrigation uniformity. The optimum operating pressure for an impact sprinkler with a standard straight bore nozzle is 45 to 60 psi. The water jet leaving the nozzle will not break up sufficiently at low pressures (<40 psi) resulting in concentrated water application where the jet lands. The water jet leaving the nozzle will have excessive breakup at high pressures (>70 psi) resulting in concentrated water application near the sprinkler. Sprinkler operating pressure can be readily checked with a Pitot tube attached to a pressure gauge, Figure 4. Pressure variation along a lateral should be less than 20 percent to achieve acceptable irrigation uniformity. Excessive pressure variation can be a problem on undulating or sloping topography. Pressure compensating nozzles or pressure regulators can be used in these situations to limit the pressure variation along the lateral.

The water jet from a standard straight bore nozzle should exit as a solid stream. A diffuse stream indicates a problem. A diffuse stream can result from foreign material lodged in the nozzle, mineral deposits or corrosion, and worn nozzles. Visual inspection of the nozzle will reveal mineral deposits or corrosion. However, wear is not readily discernable by visual inspection. Nozzle wear can be tested using a new drill bit of the same size as the nozzle diameter. The shank of the drill bit is inserted into the nozzle while operating, and the distance water sprays out is a good measure of nozzle wear. If the nozzle is new or has no wear, inserting the drill bit shank into the nozzle will yield a nearly watertight fit with just a few drops exiting. If the wear is slight, a fine spray extending less than 10 feet will exit. If the nozzle is moderately worn, a large spray extending 10 to 15 feet will exit. When a nozzle is extremely worn, a coarse spray extending greater than 15 feet will exit. Under the latter two situations, sprinkler discharge is 7 to 20 percent greater than the design discharge.

When pressure–compensating or controlled-droplet type nozzles are used, the procedures for evaluating sprinkler flow rates with center pivot irrigation systems can be used. A large diameter hose can be used to direct water from the nozzle into the graduated containers. The measured flow rates can be compared to the manufacture's published values to judge condition of the sprinkler system.

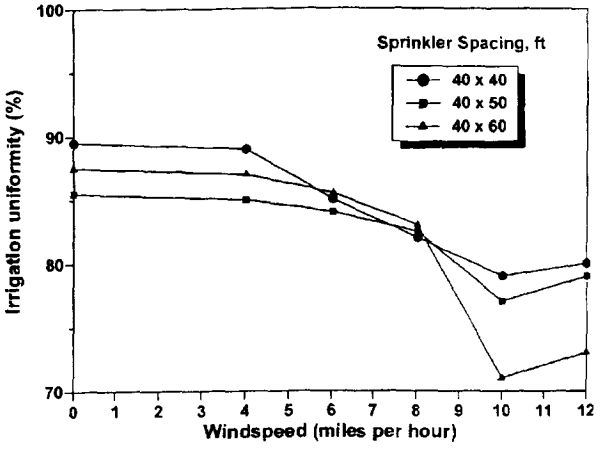


Figure 5. General decrease in irrigation uniformity with increasing wind speed for lateral spacings of 40, 50 and 60 feet. Adapted from Kincaid (1984).

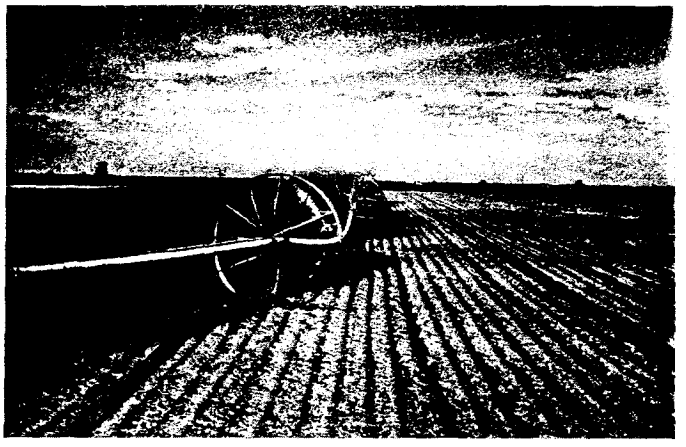

Figure 6. Wind greatly affects the water application pattern from set-move sprinkler system. Here the dark colored soil is wetted and the light colored soil is dry. Wind direction is from right to left.

Wind speed in conjunction with sprinkler spacing has a large impact on irrigation uniformity with set-move sprinkler systems. In general, irrigation uniformity at any sprinkler spacing will decrease as wind speed increases above approximately 5 mph as indicated in Figure 5. Set-move sprinkler systems are especially susceptible to "wind skips". Wind skips occur when there is a large difference in wind speed and/or direction between adjacent irrigation sets. This problem is depicted in Figure 6. For the irrigation event shown in Figure 6, a temporary dry zone will likely develop adjacent to the sprinkler lateral on the upwind side because the following adjacent irrigation set will probably not occur under the same wind speed and direction. Under extreme wind conditions, as that depicted in Figure 6, wind skips will occur with any reasonable sprinkler spacing, however, reducing the sprinkler spacing will reduce the extent of the wind skip. Fortunately, wind skips are usually not cumulative and cumulative irrigation uniformity increases with successive irrigations as shown in Figure 7.

Application rate patterns from a single impact sprinkler equipped with a 9/64 inch straight bore nozzle in a 1 mph wind and a 3/16 inch nozzle in a 14 mph wind are shown in Figure 8. The effect of wind is to elongate the application pattern in the down wind direction and to cause water application to be concentrated near the sprinkler. The simulated effect of wind on the combined application rate pattern from nine sprinklers having a 40 by 60 ft spacing with a 14 mph wind oriented perpendicular to the lateral is shown in Figure 9. The average application rate is 0.28 in/hr, but with a range of 0.07 to 0.48 in/hr resulting in a CU of 66 percent. A 14 mph wind is a common daytime occurrence during spring and early summer in southern Idaho.

In practice, wind speed and direction vary throughout an irrigation event. This tends to average out application rate variations and increases the CU for an actual irrigation event compared to that depicted in the simulation of Figure 9. However, when chemicals are applied through the irrigation

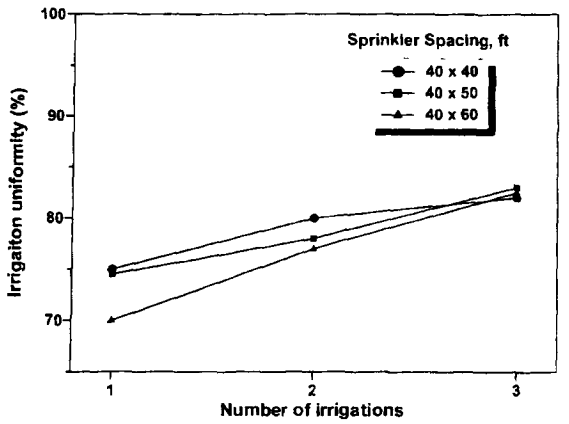


Figure 7. General increase in cumulative irrigation uniformity with successive irrigations for set-move systems. Adapted from Kincaid (1984).

system over a short time period, the application pattern shown in Figure 9 is representative of actual conditions. For windy conditions such as those shown in Figure 9, reducing the distance between laterals may have little effect on irrigation uniformity.

Changes in wind speed and direction tend to increase the cumulative irrigation uniformity calculated over multiple irrigations. A management strategy that can further increase seasonal irrigation uniformity is the practice of offsetting the placement of sprinkler laterals over successive irrigations. This management practice increases irrigation unformity by averaging out spatial differences in water application. This management practice effectively reduces the lateral spacing averaged over multiple irrigations by one-half to one-third.

The effect of offsets on improving the application pattern for the conditions of Figure 9 is shown in Figure 10. The simulated combined application pattern shown in Figure 10 was for a two-hour duration with one hour in each lateral location. The average depth of application is 0.56 inches with a range of 0.29 to 0.82 inches resulting in a CU of 76 percent. The CU increased by 10 percent which will likely have a positive impact on crop yield and quality. While offsets are an effective way to increase seasonal irrigation uniformity, wind skips will remain a problem with individual irrigations for shallow-rooted, water-sensitive crops such as potatoes. Offsets of one -half the lateral spacing are usually only possible with hand line systems. For wheel line systems, the offset spacing must be a complete roll of the lateral when moved. This limitation commonly results in offsets of one-third and two-third the lateral spacing.

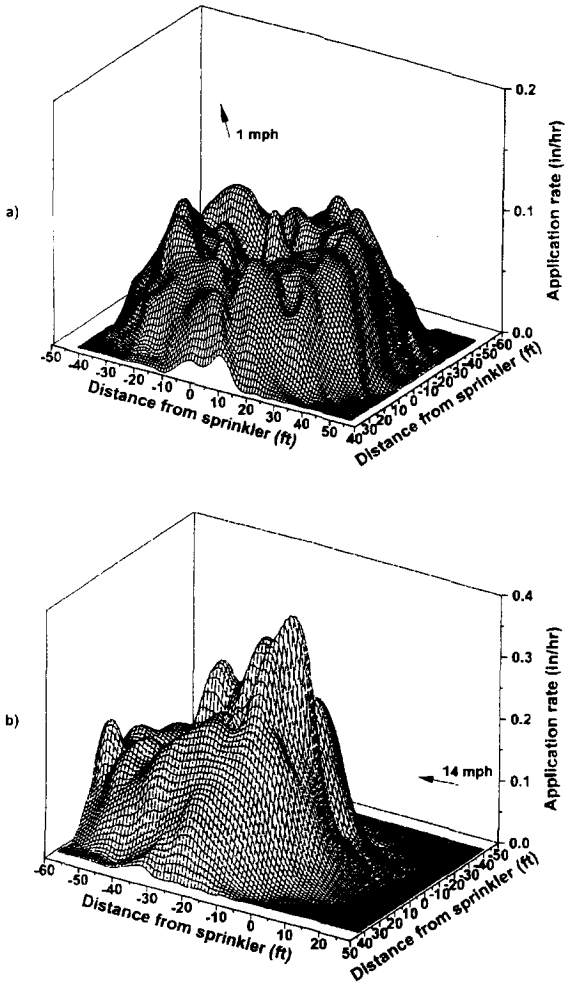


Figure 8. Affect of wind on application rate pattern of impact sprinkler equipped with straight bore nozzle; a) 9/64 inch nozzle and b) 3/16 inch nozzle.

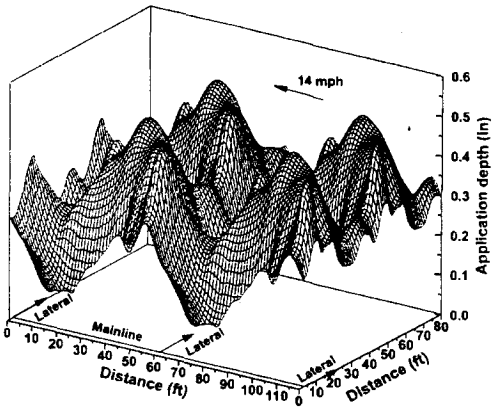


Figure 9. Combined application pattern from nine sprinklers with a 40 ft sprinkler spacing and 60 ft lateral spacing in a 14 mph wind oriented perpendicular to the laterals.

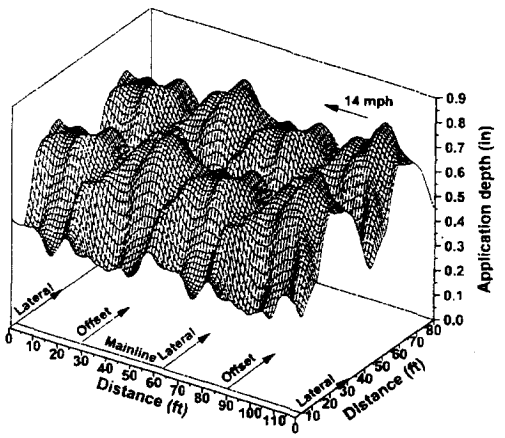


Figure 10. Combined application pattern over two irrigation events when using 30 ft lateral offsets with a 40 ft sprinkler spacing and 60 ft lateral spacing in a 14 mph wind oriented perpendicular to the laterals.

### Microirrigation systems

Microirrigation systems employ low-pressure emission devices for the frequent, slow application of water either directly onto the land surface or into the root zone of the crop. Microirrigation encompasses both surface and subsurface drip, micro-sprinkler, and bubbler irrigation systems. In all cases, water is precisely metered to a specific location allowing high irrigation uniformity. Irrigation uniformity of a microirrigation system is usually based on measurement of emitter discharge. A microirrigation system on uniform topography should be designed for a minimum CU of 85 percent for annual row crops and 90 percent for permanent crops.

The primary objective in the maintenance of a microirrigation system is to maintain the design flow rate from each emission device in the system. This requires that the design pressures are maintained throughout the system and that plugging of emission devices does not occur. Maintaining the design pressures throughout the system involves monitoring operating pressure at key locations and regular maintenance of pressure regulating devices to ensure their proper operation.

Physical, chemical, and biological agents can cause plugging of emission devices. Every microirrigation system should be designed with filtration equipment to remove contaminants over 100 micron (0.1 mm or 1/250 of an inch) in size. However, development of chemical and biological agents within the system must be monitored and periodically treated. Chlorine and acid injection are the most common treatments for biological and chemical agents. Physical agents smaller than 100 micron which enter the system through the water source can coalesce and settle at the end of supply lines and/or cause plugging. All supply lines must be periodically flushed to prevent this from occurring. Lastly, daily monitoring and maintenance of the primary and secondary filtration equipment is required. Overall, the degree of management and routine maintenance required to keep a microirrigation system in top condition is greater than for any other type of irrigation application system.

An indication of system condition can be obtained by occasional measurement of emitter discharge and comparing it to the rated discharge of the emitter. A graduated container such as a household measuring container and stop watch can be used to measure emitter flow rate. Thirty to forty emitters should be measured at random field locations. The mean and range in measured flow rate can be used to judge system condition. The measured mean flow rate should be nearly equal to the manufacture's rated design flow rate. No more than 20 percent of the measured flow rates should be greater than ±10 percent of the mean in order to have an irrigation uniformity of 85 percent. The CU value can also be computed directly using the measured emitter flow rates

### Surface irrigation systems

Irrigation uniformities as high as 95 percent can be achieved with surface irrigation systems under extremely ideal conditions and management. In contrast to microirrigation and sprinkler irrigation systems where water distribution is primarily dependent upon the physical attributes of the system hardware, water distribution in surface irrigation systems is highly dependent upon water infiltration rate into the soil. Infiltration rate is largely unmanageable and varies both in time and in space. Water application to individual plants can vary from one-half to twice the field average due to spatial variability in infiltration rate, resulting in irrigation uniformities below 50 percent. Changes in slope along the furrow length adversely impact irrigation uniformity.

Besides infiltration rate, other factors that affect irrigation uniformity are flow rate, furrow roughness, compaction, length, and slope. Flow rate and furrow length are the factors that can be adjusted to improve irrigation uniformity. With surface irrigation, water is required to traverse the field by overland flow. The time required for water to reach the end of the field leads to a greater infiltration opportunity time at the inflow compared to the out flow end, resulting in differences in infiltration. To achieve maximum uniformity, the differences in infiltration opportunity time must be minimized. This can be accomplished by increasing inflow rate, furrow or corrugate smoothing and/or compaction, and shortening furrow length.

The effect of shortening furrow length on irrigation uniformity is depicted in Figure 11. The situation shown in Figure 11 is for uniform soil conditions with infiltration characteristics representative of a Portneuf silt loam soil. Case A is for a field length of 1300 ft with 1 percent uniform slope and desired irrigation depth of 2.3 inches. An irrigation time of 36 hours is required to advance the water to the end of the field and infiltrate the desired depth at the end of the field when the furrow flow rate is 3.8 gpm. The resulting irrigation uniformity is 85 percent. Case B is for the same field conditions except that the field length is reduced by one-half to 650 ft. An irrigation time of 12 hours is now required to advance the water to the end of the field and infiltrate the desired depth at the end of the field when the furrow flow rate is 3.5 gpm. The resulting irrigation uniformity is 96 percent. Irrigation unifor-

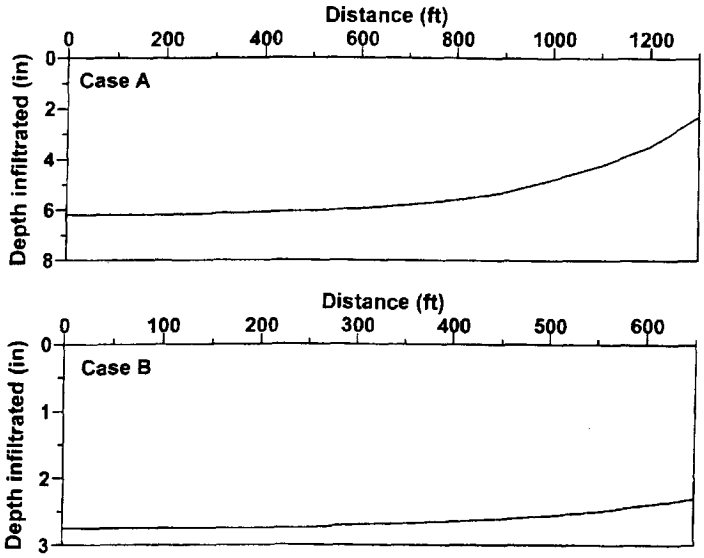


Figure 11. Effect of reducing field length on irrigation uniformity for a furrow irrigation system. Case A - 3.8 gpm for 36 hours and Case B - 3.5 gpm for 12 hours.

mity is increased by 11 percent while water use is decreased by 50 percent. However, labor costs are doubled and runoff is increased 7 fold. The increase in irrigation uniformity results in a large decrease in deep percolation which is the reason for 50 percent less water use. The environmental impact of the increased runoff could be effectively handled by employing a tailwater reuse system or effectively reduced by employing cutback, cablegation, or surge irrigation.

Due to the nature of surface irrigation, direct comparison of Christiansen uniformity coefficient values with other types of irrigation systems is not meaningful. An additional uniformity measure termed the Low-Quarter Distribution Uniformity (DU) is often used to quantify irrigation uniformity of surface irrigation systems. The low-quarter distribution uniformity is the ratio of the average of the lowest one-fourth of the infiltrated depths to the mean infiltrated depth, expressed as a percentage. For the situation shown in Figure 11, the DU for Case A is 72 percent and for Case B is 92 percent. For surface irrigation systems, DU provides a better measure of the nonuniformity occurring near the end of the field. Surface irrigation systems can be managed to provide good irrigation uniformity. However, the amount of labor required to accomplish this is often far greater for surface irrigation systems than other irrigation system types.

## CONCLUSIONS

Irrigation uniformity is an important consideration when striving to increase production efficiency in irrigated agriculture. Irrigation uniformity often receives little attention compared to irrigation scheduling, yet it is just as important. Problems arising from poor irrigation scheduling are often much more noticeable because they occur on a larger scale over a short period of time. Problems arising from poor irrigation uniformity occur at diverse locations in the field and often gradually appear over the growing season. Any type of irrigation system can be designed to provide good irrigation uniformity, but it is management's responsibility to sustain the irrigation uniformity over the life of the irrigation system through proper maintenance.

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